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Developing a Framework for Establishing a Risk-Based Geotechnical Asset Management Program in Illinois

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16. Abstract

Geotechnical asset management (GAM), transportation asset management (TAM), and performance management have progressively become routine terms at many transportation agencies throughout the United States, Canada, and world. Geotechnical assets represent the "foundational" platform for other transportation infrastructure assets. With their extensive presence and critical role in the highway network, evaluating the condition and deterioration mechanics of these assets through a proactive assessment and intervention program helps improve the overall network condition and avoid costly, disruptive, and risky serviceability and ultimate "failures." This study presents a flexible and holistic GAM framework and workflow. To date, many GAM frameworks proposed in practice have focused on creating an asset inventory and inspection procedures. Although data collection and inspection procedures are the core of GAM, a functional and robust GAM program should address other components such as risk management as well as deterioration and performance modeling to be effectively integrated with other TAM programs and achieve agency objectives. This report provides a comprehensive discussion on asset inspection and condition evaluation procedures for four geotechnical asset families: soil slopes and embankments, rock slopes, retaining walls, and mechanically stabilized earth walls. Moreover, the research team developed applications and tools to facilitate asset inspection and condition evaluation, risk management at the asset and asset family levels, and performance deterioration modeling to allow for proactive implementation of the framework. The report summarizes the main findings, gaps, and recommendations from the study.

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EXECUTIVE SUMMARY

This study provides a flexible and holistic geotechnical asset management (GAM) framework and workflow. To date, many GAM frameworks proposed in practice have focused on creating an asset inventory and inspection procedures. Although data collection and inspection procedures are the core of GAM, a functional and robust GAM program should address other components such as risk management as well as deterioration and performance modeling to be effectively integrated with other transportation asset management (TAM) programs and achieve agency objectives.

The framework is divided into seven major steps:

- Step 1: Identify and locate assets
- Step 2: Risk-based data collection
- Step 3: Condition evaluation
- Step 4: Performance modeling and network impacts
- Step 5: Investment strategies
- Step 6: Communication
- Step 7: Updates and program improvements

These steps are organized sequentially. However, progress in different steps may vary in early implementation stages. Due to the extensive number and types of geotechnical assets and the limited available human and funding resources, a tiered data collection approach was developed in this framework. The tiered system defines data collection cycles and inspection procedures depending on asset condition and risk assessment. Detailed yet simplified data-inspection procedures were developed in this study to allow for smoother adoption and implementation. The inspection procedures should be reassessed and updated routinely to address gaps and shortcomings and to incorporate other objective engineering measurements.

To facilitate inspection in the field, an application was developed in Survey123 to allow for interactive inspection and capturing images in the field. The data collected through these procedures feed the performance, risk, and deterioration analyses described in the following chapters.

Risk evaluation and management are integral parts of the entire GAM program and are incorporated in multiple steps. The simplest definition of risk is the impact of uncertainty on objectives. The primary objective is to maintain geotechnical assets and the assets they support in acceptable condition, or in a good state of repair, to serve their intended purpose in the network and maximize agency and user benefits. A risk management procedure was developed in this framework to identify and analyze risk sources and plan strategies to control or minimize their consequences. The risk management procedures can be applied for both asset-level and asset family-level assessment and management and fed into the overall GAM program-level risk assessment and management.

Moreover, the steps can be adapted for qualitative, semi-quantitative, and quantitative or probabilistic approaches. The tools developed in this study, however, use qualitative and semi-quantitative approaches.

Deterioration modeling procedures and tools are discussed and developed in this study to allow for performance modeling during framework implementation. Performance models capture the change in asset condition and performance, which can be presented by performance measures, over time. These models are critical for many reasons:

- Forecasting future improvement strategy needs
- Estimating risks associated with geotechnical assets
- Estimating the impact of deterioration and improved geotechnical assets on the network performance
- Estimating the benefits attained from the GAM program and improvement strategies
- Prioritizing the list of projects planned for detailed evaluation

Implementation recommendations and examples are provided for different components of the framework. The report also discusses current gaps and future needs to implement and improve the framework. Some of the major recommendations are listed as follows:

- Create a data inventory structure even if initially it only contains a few entries. The structure should be implemented within different tools, different transportation asset components and systems, and the primary asset management system, which is currently dTIMS. Implementation of this recommendation will allow the Illinois Department of Transportation to assess the practicality of the different definitions for data structure and recommended procedures as well as to identify challenges to be addressed.
- Establish an early GAM working group including different stakeholders benefiting from GAM. This working group may change over time and will oversee early implementation as well as assess the benefits, improvement needs, and most effective implementation steps. The group will also focus on communicating the program's benefits on Illinois Department of Transportation objectives and strategic goals.
- Conduct an implementation pilot program. The implementation pilot program can focus on high vulnerability and critical corridors with diverse geotechnical assets and conditions. The program should extend over multiple years, starting with focused implementation of the tools and procedures recommended in this study for one cycle, followed by an assessment of that implementation for appropriate revisions and updates to the tools and procedures. This pilot should include development of a core database that can be used to develop performance and deterioration models.

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CHAPTER 1: INTRODUCTION AND BACKGROUND

GEOTECHNICAL ASSET MANAGEMENT SYSTEMS AND PROGRAMS

Geotechnical asset management (GAM), transportation asset management (TAM), and performance management have progressively become routine terms at many transportation agencies throughout the United States, Canada, and world. Geotechnical assets represent the "foundational" platform for other transportation infrastructure assets. Since the term "geotechnical assets" may be interpreted in several ways, our understanding and interpretation of that term as used in this study is as follows: Geotechnical and foundational assets apply to all assets constructed on or of soil and rock. Depending on a specific application, a geotechnical asset may serve as a foundation of another asset, or the asset itself, or both. For example, an earth-retaining structure may serve as both a foundation and an asset if it supports pavement leading to a bridge or an abutment of a bridge. In that sense, geotechnical assets can fall under two major categories: stand-alone assets and support assets.

With their extensive presence and critical role in the highway network, evaluating the condition and deterioration mechanics of these assets through a proactive assessment and intervention program helps improve the overall network condition and avoid costly, disruptive, and risky serviceability and ultimate "failures" (NCHRP, 2023). In addition, almost every transportation project contains one or more geotechnical assets. Currently, these geotechnical assets are sparsely documented, and it can be a challenge to access this information. Establishing a GAM system and program can help identify the location of these assets and help organize such information.

The scope and overall desired outcomes from the GAM programs vary widely between agencies. Some agencies have initiated extensive data collection programs focused on development of inventories (Anderson et al., 2022), others have focused on "worst-first" approaches almost exclusively focused on geohazards (Beckstrand et al., 2017a), and others have focused on high-level frameworks incorporating multiple assets and overall TAM requirements (Beckstrand and Mines, 2017; Mines et al., 2022). The goal of this project is to develop a holistic GAM framework focusing on data collection and building inventory, assessing condition and performance of various geotechnical assets, assessing and managing risks, and integrating the GAM system with Illinois TAM systems and workflow.

TAXONOMY

Transportation Assets

As identified by the Federal Highway Administration (FHWA), a transportation asset is a physical feature including vehicles, facilities, equipment, and fixed infrastructure used in or by a transportation agency (Biton et al., 2019). This understanding of an asset as a physical feature or set of features is shared across state and local transportation agencies, including the American Association of State Highway and Transportation Officials (AASHTO).

These definitions are consistent with the historical intent of TAM systems and focused on the operation, maintenance, and improvement of said assets under MAP-21 requirements (US DOT, FHWA, 2019). As a result of this use-driven data approach, FHWA and other transportation agencies have consistently, albeit unintentionally, limited the consideration of assets to those physical features that are clearly visible, readily inspected, and user-oriented, such as pavements and bridge superstructures (NCHRP, 2019c).

More recently, AASHTO, FHWA, and several state agencies have identified the unintended limitation of asset types as a potential deficiency in operations. These agencies have subsequently developed guidelines and recommendations to further incorporate ancillary assets, such as non-pavement systems, bridge substructures, and other broadly considered geotechnical assets (NCHRP, 2019a, 2019b, 2019c).

Geotechnical Assets

Explicit definition of assets that should be identified as "geotechnical assets" is important to better document which features and information should be recorded. Like the general term of transportation assets, identification of geotechnical assets to be included in GAM systems and programs has varied by agency. The focus for GAM is often on physical features and condition assessments that directly quantify asset performance. A general definition of geotechnical assets can include all assets constructed on, in, or of soil and rock. This definition can be expanded further to include non-physical assets such as geotechnical data and historical records. Although many geotechnical and foundational assets can be included in a GAM program, there are several considerations affecting agencies' decisions when selecting and defining the geotechnical assets to be included. One consideration is ownership of the asset. For example, some agencies include structural foundations and geotechnical assets, such as embankments and earth-retaining systems, adjacent or leading to a bridge as part of their bridge management system. Moreover, the selection of the assets depends on the maturity of the GAM program. Many agencies start with the most widespread assets which have clear inspection, condition, or performance evaluation procedures.

According to NCHRP (2019b) Research Report 903 (Vol. 2), a geotechnical asset can be defined as, "an embankment, slope, retaining wall, or constructed subgrade that contributes to the performance of your transportation system." Moreover, the report states: "These assets also contribute to the performance of the many culverts, pipes, and utilities that penetrate these engineered structures. Geotechnical components, such as ground reinforcements in a wall or embankment, groundwater drainage features, rock bolts, and structure foundations, are the improvements within many geotechnical or other structure assets that help the asset function through routine loading and extreme events" (FHWA, 2013). Several similar definitions are reported in individual research papers and state agency studies addressed in Report 903 (Vol. I) (NCHRP, 2019a).

Based on the various GAM programs and research reviewed, a unique attribute of GAM is the heterogeneity of the geotechnical assets included in the program. The performance, condition rating systems and intended objectives, and serviceability measures of geotechnical assets vary based on the asset type. In summary, agencies decide which geotechnical assets to include in a GAM program based on the asset's criticality, ownership, risks and consequences of not managing the assets, and

maturity of the GAM program. Agencies with more mature GAM programs will be able to accrue greater return on investment by including a larger number of assets and asset families. Agencies just starting their GAM program, however, may elect to initially establish a smaller pilot or test program before including a large number of asset types and families.

ASSET MANAGEMENT SYSTEMS AND PROGRAMS

Transportation Asset Management Systems

Like the restrictive definition of an asset, the understanding of transportation asset management is legally founded in US law under MAP-21, subsequent laws, and agency directives (US DOT, FHWA, 2012). MAP-21 defines asset management as:

> […] a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost. (23 USC. 101(a)(2), MAP-21 § 1103)

While MAP-21 maintains a restrictive definition, the inclusionary understanding of assets and asset management continues to move into practice and is exemplified in ISO 55000, 55001, and 55002 standards. These standards have also been accepted and used as a basis of development in the *International Infrastructure Management Manual*, referenced by the United States Army Corps of Engineers (USACE) Best Practices in Asset Management (Institute for Water Resources, 2013) and Civil Works Strategic Asset Management Plan (US Corps of Engineers Civil Works, 2022).

Geotechnical Asset Management Programs

GAM development and implementation are generally framed like TAM system development, with unique needs and attributes due to the heterogeneity of the geotechnical assets. Unlike pavements, the condition rating systems and intended objectives and serviceability measures of geotechnical assets vary based on asset type. For example, rigid and flexible pavements have different deterioration mechanisms, construction practices, and designs, yet their condition indices can be harmonized by considering ride quality or a pavement condition index. In contrast, an earth-retaining structure and an embankment have totally different condition measurements, performance requirements, deterioration mechanisms, and serviceability impacts on the network. Therefore, at a high level, the performance and serviceability requirements for both pavement families can be compared and prioritized in an asset management system. However, it is more challenging to compare and prioritize the performance requirements and metrics across some geotechnical asset families.

Modeling a GAM program closely aligned to TAM will help agencies develop and implement GAM programs. Agencies can rely on existing technologies and intra-agency experience to identify which assets are best suited for preliminary data collection and to enable rapid inventory development. Agencies may be able to use their existing transportation asset database or a general asset database

as a GAM starting point by selecting already managed assets and reclassifying them as geotechnical assets. The review of existing assets may also be used as a method to identify underlying or supporting assets, features, or structures that may be classified as geotechnical assets but were not previously managed (Beckstrand & Mines, 2017b). A general GAM implementation workflow as presented in NCHRP (2019b) Report 903 is presented in Figure 1.

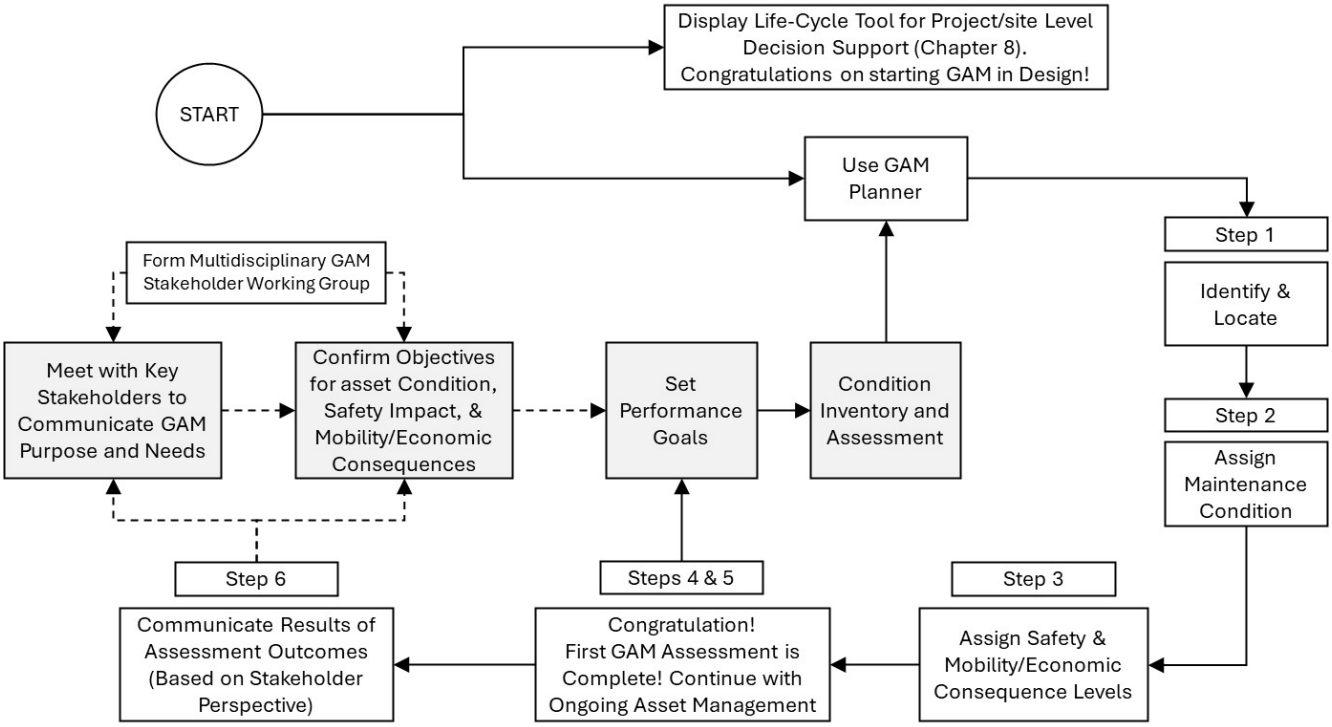


Figure 1. Flowchart. GAM implementation workflow.

Source: Re-created from Figure 2.1 of NCHRP 903 Volume 2

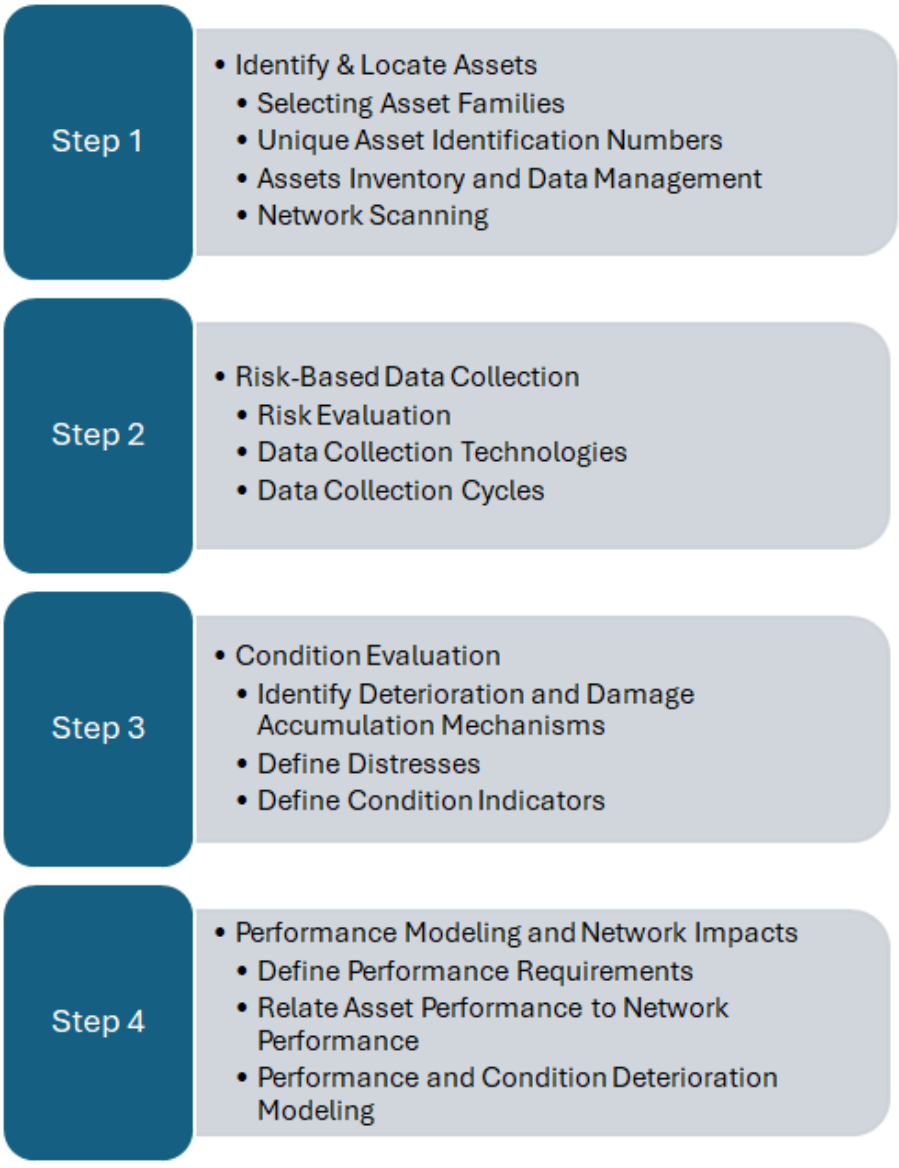
The initial development of a GAM database may be readily followed by expansion of existing TAM programs to include assets of interest or assets identified as areas of concern. In reviewed cases, agencies new to GAM programs tended to defer to NCHRP 903 to identify the physical assets in their GAM as a starting point. In part this is because these assets have well-defined performance metrics, more reliable return on investment (ROI) calculations, and direct impact on public safety and mobility. In many cases these assets are also considered to have higher levels of risk than other geotechnical assets (NCHRP, 2019a). Once the GAM is established, agencies can start exploring other physical assets and non-physical assets such as geotechnical data, user-impression information, and other geotechnical and laboratory information through digitalization of construction records. This staged approach also enables agencies to better evaluate internal review and data usage practices to ensure the highest possible return from implementing GAM. In all cases, a review of NCHRP 903 documents by involved agency staff is recommended to improve GAM acceptance and understanding.

Integration of GAM with Other TAM Systems

The integration of GAM with existing TAM systems is common across reviewed agencies. This integration serves to improve agency readiness to use and expand the GAM through familiarity with collection and access systems and with IT integration. This integration can reduce the cost of GAM expansion. Integration may face limitations depending on the structure and use of existing databases and the methods of collection, with limitations depending on the flexibility of the management system software. Several departments of transportation maintain the use of survey and management software across systems, with ESRI ArcCollector and Survey123 typically used for field collection and ArcGIS or an in-house GIS for data management (Fish et al., 2019; Mines et al., 2022; Waseem et al., 2022; US Department of the Interior, National Park Service, 2018).

CHAPTER 2: ILLINOIS GAM WORKFLOW

The GAM workflow can vary based on an agency's needs and maturity of their GAM system. In this report, we present the proposed GAM workflow shown in Figure 2, which follows the general process outlined in NCHRP Report 903, with minor edits. The steps of the workflow are described in this chapter and following chapters and are tailored to meet the needs of the Illinois Department of Transportation (IDOT). Recognizing that the objective of this project is to develop a framework which IDOT can build upon, expand, and refine, several steps will be discussed in a holistic sense, which might not be fully implemented and executed in this project. The workflow and detailed procedures discussed in this report should be considered a starting point, which can be refined based on feedback from the GAM system implementation beyond this project.



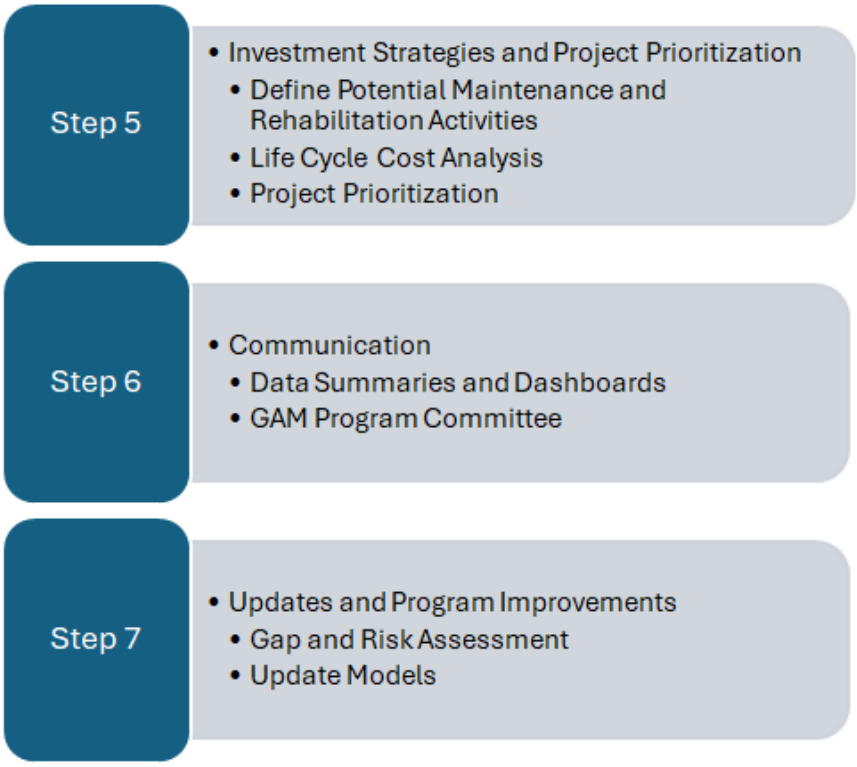


Figure 2. Diagram. IDOT workflow with major components in each step.

STEP 1: IDENTIFY AND LOCATE ASSETS

Selecting Asset Families

As outlined in Figure 2, the first step in the GAM workflow starts with selecting asset families to include in the program. At this early stage, the team performed a qualitative risk evaluation and prioritization during the literature review, a workshop conducted with IDOT in January 2024, and the following meetings and pilot implementation planning. The assessment considered the extent of the geotechnical assets throughout the state, their consequence of failure, and IDOT's needs. As a result, the team focused on the following asset families:

1. Soil slopes and embankments
2. Rock slopes
3. Retaining walls
4. Mechanically stabilized earth (MSE) walls

Unique Asset Identification Numbers

Based on discussions with IDOT, geotechnical assets were defined as a point asset if they do not extend beyond a tenth of a mile. For assets extending more than a tenth of a mile, it is recommended

to subdivide the asset into tenths of a mile segments unless the asset is best handled as a single asset. The asset identification procedure is composed of a field using existing ID procedures in the Illinois Highway Information System (IHIS) combined with the middle mile point, direction, and asset type abbreviation. The key route ID field in IHIS includes six elements:

1. County (three digits with leading zero as needed) with two spaces after it, as shown in Table 3
2. Key route type (one digit, shown in Table 1)
3. Key route number (four digits, with leading zeros as needed)
4. Key route suffix (alpha or a space if not needed)
5. Key route appurtenance type (one digit)
6. Key route appurtenance number (five digits, with leading zeros as needed)

For example:

- 084 10055 000000: Sangamon County, Interstate 55, no appurtenances, therefore mainline
- 084 10055 406680: Sangamon County, Interstate 55, Ramp number 06.680
- 084 10055 507460: Sangamon County, Interstate 55 Frontage Road number 07.460

The next field consists of the following elements:

1. Milepost of the middle point of the asset (five digits with one space after it)
2. Route direction where the asset is closest to (one digit with space after it)
3. Asset type abbreviation (two digits, as shown in Table 2)

For example:

- 00315 E RW

00315: indicates that the middle point of the asset is at 3.15 miles, measured to the nearest 0.01 mile from the beginning of a route. It is recommended to break down the asset into 0.1 mile segments or other lengths depending on the project.

E: indicates the asset is to the eastbound side.

RW: is a retaining wall asset.

Table 2 provides a list of asset type abbreviations.

Table 1. Route Type Code

Code	Description	Code	Description	Code	Description
1	Federal Aid Interstate (FAI)	5	County Highway (CH)	9	Federal Aid Urban (FAU)
2	Federal Aid Primary (FAP)	6	House / Senate Bill (HB / SB)	0	Municipal Street (MUN)
3	Federal Aid Secondary (FAS)	7	Township Road (TR)		
4	State Bond Issue (SBI)	8	Other Road (OR)		

Table 2. Asset Type Abbreviation

Asset	Abbreviation
Retaining Wall	RW
Soil Cut Slope (where soil is the dominant material)	CS
Rock Slope (where rock is the dominant material)	RS
Embankment	EM
Earthen Dam	DM
Ground Improvement	GI
Pavement Foundation	PF
Permanent Erosion Control Feature	EC
Geotechnical Instrumentation and Exploration Data	GD

Table 3. County Codes in Illinois

Code	County	Code	County	Code	County	Code	County
001	Adams	027	Ford	053	Livingston	079	Randolph
002	Alexander	028	Franklin	054	Logan	080	Richland
003	Bond	029	Fulton	055	McDonough	081	Rock Island
004	Boone	030	Gallatin	056	McHenry	082	St. Clair
005	Brown	031	Greene	057	McLean	083	Saline
006	Bureau	032	Grundy	058	Macon	084	Sangamon
007	Calhoun	033	Hamilton	059	Macoupin	085	Schuyler
008	Carroll	034	Hancock	060	Madison	086	Scott
009	Cass	035	Hardin	061	Marion	087	Shelby
010	Champaign	036	Henderson	062	Marshall	088	Stark
011	Christian	037	Henry	063	Mason	089	Stephenson
012	Clark	038	Iroquois	064	Massac	090	Tazewell
013	Clay	039	Jackson	065	Menard	091	Union
014	Clinton	040	Jasper	066	Mercer	092	Vermilion
015	Coles	041	Jefferson	067	Monroe	093	Wabash
016	Cook	042	Jersey	068	Montgomery	094	Warren
017	Crawford	043	Jo Daviess	069	Morgan	095	Washington
018	Cumberland	044	Johnson	070	Moultrie	096	Wayne
019	DeKalb	045	Kane	071	Ogle	097	White
020	DeWitt	046	Kankakee	072	Peoria	098	Whiteside
021	Douglas	047	Kendall	073	Perry	099	Will
022	DuPage	048	Knox	074	Piatt	100	Williamson
023	Edgar	049	Lake	075	Pike	101	Winnebago
024	Edwards	050	LaSalle	076	Pope	102	Woodford
025	Effingham	051	Lawrence	077	Pulaski		
026	Fayette	052	Lee	078	Putnam		

Assets Inventory and Data Management

The data to be acquired and included for each asset is an evolving topic, both as the GAM project progresses and in the future. In this study, the team used ArcGIS Survey123 for field data collection, which will integrate the data in a geodatabase. The geodatabase was developed in three stages:

- **Stage 1**. **Field inspection**: The data collection procedures will be discussed in detail in subsequent sections and chapters. Data collection can be done using different technologies and tools. As a starting point, data can be collected using the developed application in ArcGIS Survey123. It is highly recommended that inspectors use hard copy inspection sheets as a backup in case electronic devices malfunction or lose power or connection to the internet, since the application is not developed for offline data collection. It is crucial that inspectors capture photos of the asset at different locations and angles as well as capture surrounding conditions.

- **Stage 2**. **Quality assurance and data refinement**: Data collected in the field will be reviewed and revised as needed during this stage. Quality assurance is a critical stage in the data collection process and should be performed off-site and within a few days after data collection to guarantee accuracy of the records. This stage can include supplemental information from various sources, including other management programs, project plans, or other maintenance and construction records.

- **Stage 3**. **Data summarization and files export**: After the information for individual assets is collected, checked and refined, and saved in Survey123 and a GIS database, the data can be exported in multiple formats, depending on its use. A major use of the exported data is integrating the condition records in project selection procedures and an asset management system.

In addition to building the database, it is critical to develop data governance and management protocols as well as procedures to help preserve consistent, accessible data and information flow as the GAM program evolves. Data governance and management is an overarching concept and should be considered part of all future implementation activities. Some of the items that should be addressed and documented by a future IDOT GAM committee are presented below and described in Step 6. The list of items are the same as the steps and tasks in the framework, but focus on establishing the protocols, data, and information flow:

- Establish data ownership

- Establish decision rights

- Establish accountability

- Document and update metadata: Proper and sufficient information supporting data collection and modeling procedures to assist others implement the process

- Specify data quality requirements

- Manage change: Examples include procedures for evaluation updates and archiving, adapting for changing data collection technologies, TAM tools, changing goals and requirements

- Troubleshoot procedures: Identify key individuals and points of contact for data collection, storage, analysis, and software tools.

- Training materials and resources: Training materials should be updated and provided regularly to the individuals involved in the GAM program. This is a critical step to manage and transfer knowledge in the long term.

Network Scanning

An initial step to establish the asset inventory is to scan the network and locate assets that will be evaluated and included in the program. To scan the network, the first possible approach is to perform an extensive desk study to locate assets using historical project records or other management systems—namely, bridge and pavement management systems. This is generally not the most effective approach. The second option is to scan the network either by identifying the assets visually using a windshield survey or using remote sensing technologies. For the pilots in this study, the team inspected the images in Google Earth along selected corridors to identify potential assets (Appendix B). Following the desk study to identify potential assets, the inspectors drove along the selected corridors to confirm and refine the asset inventory.

Remote sensing technologies can include terrain analysis of existing LiDAR data, mobile LiDAR, and unmanned aerial vehicles (UAV). These technologies can facilitate and complement the visual inspection procedures at this stage. Exploring available LiDAR data (http://clearinghouse.isgs .illinois.edu/data/elevation/illinois-height-modernization-ilhmp) provides great potential, as additional data become available as the GAM program develops. At present, use of these technologies is not sufficiently mature to extract geotechnical assets and requires further development.

STEP 2: RISK-BASED DATA COLLECTION

Due to the extensive number and types of geotechnical assets and the limited available human and funding resources, a tiered data collection approach is recommended. The tiered system is described below. Recommendations for data collection cycles and inspection procedures will depend on asset condition and risk assessment, as discussed in Chapter 3 (inspection procedures) and Chapter 4 (risk assessment).

- Tier 0. Network Scanning and Inventory (corresponds to network scanning under Step 1)
    - This step is critical to build an inventory of assets.
    - This step is primarily needed in a pilot phase or early implementation and then it can be combined with Tier 1.
    - Collect data for assets with sufficient risk to be considered in the program.

- Remote sensing systems such as LiDAR and UAVs or simple windshield visual inspection can be used for data collection.

- Tier 1. Asset Condition Evaluation
  - This step is critical to assess asset condition, deterioration levels, and performance risks.
  - Collect baseline data for all assets under consideration in the program and then follow a five-year inspection cycle for assets in good or very good condition and a three-year inspection cycle for assets in marginal (fair) condition. The geotechnical asset manager may adjust the inspection cycles based on the risk level of the deteriorated asset, especially based on criticality and consequences of the failure.
  - Use visual inspection and surficial or near-surface engineering measurements.
  - This step yields condition assessments that can be used in deterioration models, performance predictions, and corrective prioritization of projects.

- Tier 2. Repeat Asset Inspection
  - This step is recommended for assets in poor and very poor condition or critical assets with major localized deterioration, leading to hazardous conditions (high risk).
  - High-frequency inspections should be conducted every 1–2 years until an intervention decision is made.
  - This inspection tier requires a robust evaluation program that may include invasive testing, subsurface investigation, deformation measurements, corrosion and degradation measurements, sampling and laboratory evaluation, and back-calculation or engineering models to simulate and forecast asset performance.

- Tier 3. Asset Monitoring
  - This step is recommended for assets undergoing progressive failure and high-risk levels.
  - Steps may include instrumentation and/or higher frequency Tier 2 inspection visits.
  - Interpretation of data and analysis requires specialized techniques to support a fast-paced intervention plan.

Risk Evaluation

Risk evaluation is an integral part of the entire GAM program and will be incorporated in multiple steps. This section provides a general overview, and Chapter 4 provides additional details. The simplest definition of risk is the impact of uncertainty on objectives, which is to maintain assets in acceptable condition to perform and serve their intended purpose in the network. Accordingly, it is important to define *condition* and *performance*. In this framework, “asset condition” is a measure of

the physical state of the asset in relation to its degradation compared to the newly constructed state. Fundamentally, a condition will always deteriorate unless maintained or improved, and this condition can be an indicator of a higher probability of failure or can represent a failure state. “Asset performance” is a measure of the impact of asset condition on its functionality and TAM objectives for asset condition, safety impacts, and mobility and economic consequences (NCHRP Research Report 903). These measures can include multiple components such as deformation, closure times, user and agency maintenance costs, detour lengths, service life, and other serviceability measures.

Risk evaluation can be performed using qualitative, semi-quantitative, or quantitative analysis approaches. Risk analysis provides an estimation of the probability (or likelihood) of a disruptive event, including accelerated deterioration, occurrence, and the corresponding consequences of that event on the agency and users.

In a semi-quantitative procedure, risk evaluation can be performed by constructing risk matrices for each asset type. A semi-quantitative risk evaluation procedure yields a relative ranking outcome or ordinal risk indices and a corresponding risk matrix to illustrate the different scales of the risk scores. Accordingly, the ordinal risk indicators do not reflect the absolute difference in the risk or consequences. In a more involved quantitative risk evaluation, the analysis requires defining the probability distributions of the asset deterioration in the future given its current condition and the probability distributions of the consequences. Determining these distributions, especially the consequences, can be an involved process and requires a combination of statistical and probabilistic analysis, practical judgment, and past knowledge. The details of these procedures will be explained in greater detail in Chapter 4. However, the results of risk assessment at the asset and program levels are very important inputs to determine the level of investigation and the required inspection cycles.

Data Collection Cycles

As discussed in the tiered data collection system, the data collection cycles are dependent on asset condition and risks, among other parameters. However, since the Illinois GAM program is under development, it is proposed that IDOT establish a control group of assets. The control group includes representative assets with different ages and conditions in various geologic settings and areas within the state. These assets will be inspected at a higher frequency, maybe every other year, for a period to help IDOT understand and quantify the deterioration mechanisms, rates of deterioration, and different asset performance models. This concept is similar to that used in the Long-Term Pavement Performance or Long-Term Bridge Performance programs. The number of control assets should be limited to assess feasible implementation.

STEP 3: CONDITION EVALUATION

Identify Deterioration and Damage Accumulation Mechanisms

To develop the condition evaluation procedures, it is important to identify and understand the deterioration processes impacting the assets. These deterioration mechanisms can be characterized using a set of parameters reflecting the accumulated damage or change in the engineering characteristics of the asset, as defined below:

- **Deterioration mechanism** is the underlying processes and/or changes in the geomaterials and the asset elements that lead to the overall deteriorating condition and performance of the asset.

- **Parameter** is the measurable or observable value/index that describes the severity of the deterioration condition or controls the deterioration mechanism.

- **Damage** is the change in the physical properties within the asset indicating reduced capacity or changes leading to progressive serviceability or strength failure.

Below is a summary of the deterioration mechanisms of the physical independent geotechnical assets included in the study.

Soil Cut Slopes

Four major deterioration mechanisms have been identified that significantly impact the performance of soil slopes, as discussed below.

- **Erosion**: Some soil cut slope materials are prone to erosion or piping when exposed to the surface and subsurface water volumes. For example, uniform fine-grained granular soils commonly erode. The extent of erosion may be surficial or deep-seated within the slope.

- **Time-related changes in the slope geomaterial properties**: Serviceability and strength distresses in soil cut slopes routinely occur during their service lives. These failures often are caused by changes to the cut slope materials, which affect changes to strength and modulus. For example, many slopes become unstable due to stress reductions from soil removal to create the cut and longer-term environmental factors (air and water). The engineering properties of soil cut slopes are affected by stress changes due to current and previous construction activities or the absorption of water with time.

- **Adjacent construction influence**: Soil cut slopes can be adversely affected by adjacent construction due to increases or reductions of vertical and lateral stresses. The stress reduction is routinely addressed by the appropriate design and construction of excavation support systems. Stress increases cannot be avoided, but, rather, they are managed through instrumentation and monitoring as well as underpinning portions of the existing embankment. As a result, construction of adjacent facilities may be concurrent with new slope construction or during the slope's post-construction service life and can have a direct and significant effect on service, or strength limit states.

- **Disruptive events**: Specific soil-cut slope behavior is extremely variable under seismic loading events compared to other geotechnical assets. The variability is a function of existing safety margin, subsurface water, and cut-slope soil engineering properties. Soil cut slopes can be significantly affected by flooding and scouring when constructed directly adjacent to streams. Cut slopes are rarely designed to resist other extreme events.

Earth-Retaining Structures

Seven deterioration mechanisms, as presented below, have been identified that significantly impact the performance of retaining walls. The interpretation and details of the mechanisms and their impact may vary by wall type. Additional discussions on deterioration mechanisms can be found in NCHRP (2023) Report 1041.

- Increase in earth pressure loads
- Internal or external drainage deficiencies
- Corrosion and deterioration of reinforcements or facing and wall components
- Increase in water pressure or volume
- Time-related changes in geomaterial and foundation material support
- Adjacent construction influence
- Disruptive events such as flooding result in changes of both load (increase) and resistance (reduction)

Embankments

Five deterioration mechanisms have been identified that significantly impact the performance of soil and rock embankments:

- Time-related changes in embankment and foundation geomaterials (including delayed effects of consolidation)
- Internal embankment material erosion
- Increase in water pressure or volume
- Adjacent construction influence
- Disruptive events such as flooding result in changes of both load (increase) and resistance (reduction)

Rock Slopes

Four deterioration mechanisms have been identified that significantly impact the performance of rock slopes:

- Erosion and weathering
- Time-related changes in the slope geomaterial properties including fissures and weak planes

- Adjacent construction influence
- High-impact disruptive events that are sudden, such as seismic events, extreme precipitation, and wildfire

Chapter 3 provides further discussion on distress parameters, damage inspection, and condition rating.

STEP 4: PERFORMANCE MODELING AND NETWORK IMPACTS

Performance is a measure of the impact of asset condition on its functionality and TAM objectives for asset condition, safety impacts, and mobility and economic consequences (NCHRP Research Report 903). Based on that general definition, the number of possible performance measures can be significantly large for a very comprehensive system. Excessively detailed performance measures can lead to excessive complexity and slow down the implementation and applicability of a GAM program. Performance measures can be addressed at the following levels: individual asset, asset family (soil slopes, rock slopes, embankment, MSE walls, and other retaining walls), and overall GAM program.

Figure 3 presents potential internal performance objectives of geotechnical assets (spokes) under four major outward-facing objectives (the rim of the wheel): maintenance of system, safety, mobility, and economic vitality. The outward-facing objectives are critical for executive level and public communication. It is also important to relate performance objectives to a level of risk (LOR), which can present a consistent measure to better communicate the impact of geotechnical asset condition and performance to executives and other non-geotechnical stakeholders. Moreover, LOR allows a comparison of performance between different asset families and helps to overcome expected challenges to early GAM implementation where the concept of "service" provided by geotechnical assets can be ill-defined (NCHRP Research Report 903).

Below are proposed performance measures that are direct inputs into LOR and risk measures, as will be discussed in Chapter 4. The performance measures are divided into measures per level: individual asset, asset family, and program. Note that asset family-level and program-level measures use the same metrics as asset-level measures; however, they are aggregated across all assets within the family or program, respectively, rather than evaluated for a single asset. Measures with high potential for early implementation are shown in bold with an [H]. This will help IDOT to select the most pertinent measures and reduce the complexity of performance evaluation and reporting.

- Individual asset-level measures
    - **Condition performance rating (detailed in Chapter 3) [H]**
    - **Agency maintenance cost [H]**
    - **Injuries and fatalities to users and staff [H]**
    - **Detour length [H]**
    - Total closure time
    - Traffic delays

- User maintenance cost
- Life cycle cost savings

- Asset family and program-level measures.
  - **Percent of assets in acceptable condition (matching the measure for pavements and bridges in the Illinois Transportation Asset Management Plan, TAMP) [H]**
  - **Total agency maintenance cost [H]**
  - **Injuries and fatalities to users and staff [H]**
  - **Total detour length [H]**
  - **Maintenance and repair backlog [H]**
  - System reliability
  - Total closure time
  - Traffic delays
  - User maintenance cost
  - Life cycle cost savings

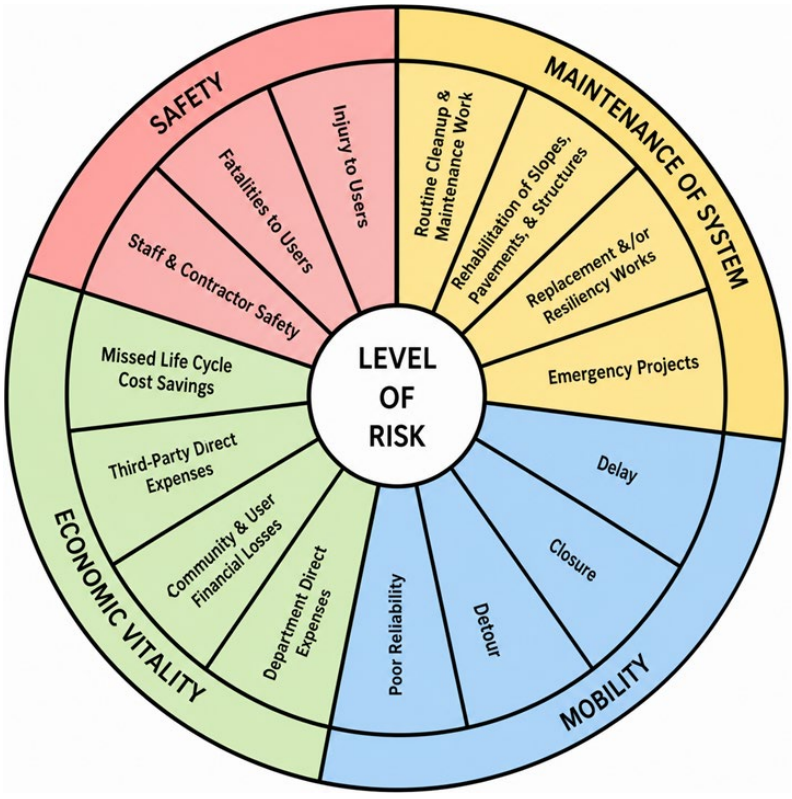


Figure 3. Diagram. Level of risk performance metric for communicating risk from geotechnical assets.

Source: Reproduced from NCHRP Research Report 903 Volume 2

Relate Asset Performance to Network Performance

Individual asset performance measures are used collectively to determine the overall network performance and agency objectives. The connection between an individual asset performance to overall network performance can be an involved process. It requires simulations of multiple scenarios to quantify how individual asset performance impacts network performance (e.g., how maintenance plans for deteriorated assets would impact the overall network's reliability and beyond).

Performance and Condition Deterioration Modeling

Most deterioration processes are continuous, reflecting progressive failure and a gradual decaying process. Such processes can be modeled using continuous deterioration models like the sketch shown in Figure 4. Continuous deterioration models can be derived by fitting regression models to empirical data or by analyzing the time-dependent behavior of the asset and its components using analytical models.

However, most condition rating systems, including the one developed in this framework, will follow a discrete scale with finite condition states. In Figure 4, the right graph depicts an asset in a condition state s_1 at initial time t_1. The asset can then transition into two possible condition states s_2 or s_i at future time t_2. This discrete description does not imply leaps in deterioration, but it captures the change in conditions states after a period of time. Such a condition scale is best modeled using discrete probabilistic models such as Markov Chain models. Chapter 5 provides additional details.

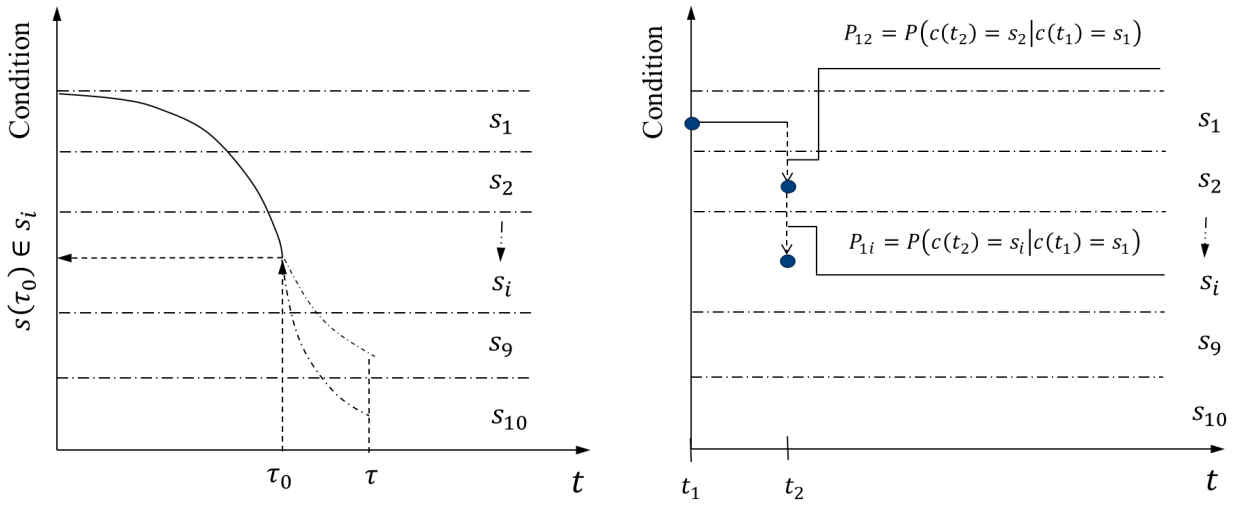


Figure 4. Schematic. Continuous deterioration in asset conditions over time (left), and a discrete representation of change in the asset condition state over time (right).

STEP 5: INVESTMENT STRATEGIES AND PROJECT PRIORITIZATION

In this framework, investment strategies and project prioritization will be executed in dTIMS as part of the overall transportation asset management system. This section provides general recommendations to support the future implementation of GAM.

Define Potential Maintenance and Rehabilitation Activities

Maintenance and rehabilitation activities for geotechnical assets are typically sparse and not always well developed. Below are some potential maintenance activities for different assets. The complete list of maintenance and rehabilitation activities varies depending on the type of distress, surrounding conditions, local practices, and agency preferences, among other factors.

- Soil Slopes and Embankments
    - Slope Stabilization by Excavation (Re-Sloping): Removal of soil from the head of a slide, reducing the height of the slope, backfilling with lightweight material, installing benches, flattening or reducing slope angle, or other slope modification
    - Strengthening Slopes: Geosynthetic reinforcement, rock-fill buttresses, gabions, shear keys; excluding re-sloping
    - Ground Improvement: Soil nailing, soil mixing, or micropiles
    - Surface and Subsurface Drainage Improvements: Horizontal drains, trench drains, weep systems, regrading
    - Vegetation Management: Planting of resilient deep-rooted species, removal of excess vegetation, control or removal of invasive species
    - Erosion Control
    - Instrumentation and Monitoring: Inclinometers, piezometers, surface survey points
    - Repair of Local Failures: Scarp filling, void grouting, utility crossing repair
    - Install a retaining wall or other soil retention system.
- Rock Slopes
    - Reinforcement: Rock bolting, dowels, tied-back walls, shotcrete, buttresses, drainage, and shot-in-place buttresses
    - Major Rehabilitation: Re-sloping, trimming, and scaling
    - Protection Measures: Widened ditches, install mesh or catch fences, warning fences, rock sheds or other barriers between the roadway and slope to prevent falling rocks from reaching the pavement
- Retaining Walls
    - Address erosion at the base of the wall and at wall limits

- Repair of cracks and reseal joints to limit water infiltration
- Repair or improve drainage or install pressure-relief measures, which may include permeable joint seals, weep drains, or horizontal relief drains
- Repair of spalling, cracking, and corrosion damage on facing units (concrete, masonry, or steel)
- Repointing mortar joints in stone or masonry walls
- Re-leveling, re-seating, or shimming of copings and parapets
- Replacement or supplementation of corroded tiebacks, soil nails, or rock anchors (verified with proof testing)
- Installation or refurbishment of weep holes, lateral drains, and pressure-relief features
- Backfill stabilization or grouting behind the wall where loss of fines or voids are detected

- MSE Walls
  - Address erosion at the wall base and at the wall limits
  - Address loss of backfill through wall face panel joints and seal joints
  - Control of vegetation growing through panel joints and on the top of the backfill zones
  - Repair of cracks and spalls of the MSE wall panels
  - Reset displaced copings and parapet units and clean and level bearing surfaces
  - Reseal joints to limit water infiltration
  - Repair or improve drainage, or install pressure-relief measures which may include permeable joint seals, weep drains, or horizontal relief drains
  - Reconstruct localized facing and reinforced zones
  - Installation of restraint and reinforcement systems
  - Reset panels and adjust shims; grout pads may be used to correct alignment
  - Install joint fillers and sealants
  - Backfill stabilization or grouting behind the wall where loss of fines or voids are detected

Life Cycle Cost Analysis

An integral part of the investment strategies is establishing a process for life cycle cost analysis (LCCA). LCCA provides a common basis for comparing candidate maintenance and rehabilitation alternatives over a defined planning horizon, so that long-term cost implications, rather than only initial cost, drive the choice between options. The deterioration inputs required for LCCA are developed in Chapter 5, and the asset condition and risk inputs that inform these analyses are described in Chapters 3 and 4, respectively. LCCA rests on the following inputs:

- Deterioration process of the asset over time
- Benefits of the maintenance and rehabilitation activities listed above
- Agency and user costs associated with an asset's life cycle, including planned maintenance
- Planning horizon and discount rate used to bring future costs to a common reference point

Analysis Period

The analysis period defines the time frame over which costs and benefits are accumulated and compared. The period should be long enough to capture meaningful asset deterioration and to include at least one major rehabilitation event for the alternatives under consideration. The same analysis period should be applied to all alternatives within a given comparison so that results are directly comparable. The selected period is typically informed by the assumed design or service life of the dominant asset family in the analysis.

Discount Rate

The discount rate is used to convert future costs to present values so that alternatives with different cost timing can be compared on a common basis. Discount rates should follow current federal or agency guidance and be documented along with the source year. Note that LCCA outcomes can be highly sensitive to developed discount rates over long planning periods, common for geotechnical assets. Where reasonable, sensitivity analysis of discount rates should be performed and reported.

Cost Categories

LCCA should account for all relevant costs incurred over the analysis period. These typically include the following items:

- Agency costs for initial construction or major rehabilitation, routine and periodic maintenance, and end-of-service rehabilitation or replacement
- User costs associated with delay, detour, or incidents during maintenance and rehabilitation activities
- Residual or salvage value remaining at the end of the analysis period (if any)

IDOT cost estimates should be drawn from documented cost data where available, preferably agency-specific projects. If required, values from outside sources may be used where Illinois-specific data are not yet available. Where possible, more refined data, such as region or district data, should be used due to local price sensitivities. The source and basis of each cost estimate should be recorded as part of LCCA.

Treatment of Uncertainty

LCCA inputs, especially for geotechnical assets with poorly understood life cycles, are subject to uncertainty, including variation in deterioration rates, timing of interventions, and unit costs. Two approaches are commonly used and should be considered: deterministic LCCA, which uses point estimates and produces a single result per alternative, and probabilistic LCCA, which uses distributions for key inputs and produces a range of outcomes. Generally, deterministic LCCA is appropriate when historical data are limited and the outputs are interpreted as a relative comparison, while probabilistic LCCA is more appropriate when characterizing risk between alternatives. As with the discount rate and cost categories, the chosen approach and the rationale should be documented as part of the LCCA.

Analysis Outputs

LCCA produces several measures that support comparison of alternatives. These often include the following items:

- Net present value of total cost over the analysis period
- Equivalent uniform annual cost
- Benefit/cost ratio relative to a baseline alternative
- Sensitivity results showing how outputs vary with key inputs such as the discount rate and analysis period

These outputs support the comparison of candidate projects in the project prioritization process.

Limitations of Use

The state of LCCA practice for geotechnical features is not yet mature, and several limitations must be acknowledged when developing LCCA strategies, interpreting data, and applying results.

- Awareness has grown that many geotechnical features require periodic maintenance during their service lives. The traditional view that they are constructed once and have an indefinite service life is no longer common.
- Necessary maintenance activities are broadly agreed upon, but the frequency, extent, and type of maintenance for each asset family are far less understood. Further activities may be significantly impacted by design and region-specific factors poorly characterized in LCCA.

- A robust understanding of when to maintain, reconstruct, or replace each asset family has not yet been developed. Implementation of a statewide GAM program will help develop an agency-specific understanding of these practices.

For these reasons, LCCA outputs for geotechnical assets should be interpreted as one input among several factors rather than as a definitive ranking. The next section describes how these outputs are combined with asset criticality, condition, and budgetary factors to prioritize projects within the IDOT TAM/GAM system.

Project Prioritization

Building on the cost estimates produced by the LCCA, project prioritization will be performed using the TAM system tool, dTIMS. The selection process targets assets that require maintenance and rehabilitation over a planning period to maximize agency and user benefits given budgetary and planning constraints.

Prioritization Factors

Several factors can impact project prioritization and which objective function to use. Some factors include:

- Current asset condition and performance measures
- Forecasted condition and performance over the planning period
- Maintenance and rehabilitation cost and effectiveness
- Asset criticality
- Available budgets

Selection Approach

Benefits estimated in this step are viewed at the network level, accounting for the contribution of individual projects to overall network performance rather than only their effect on the individual asset. Prioritizing only the assets in worst condition is not always the most cost-effective approach, because it discounts the benefits of preventive maintenance and the gains achievable by varying maintenance frequency across the network. A balanced program, therefore, typically combines preservation work on assets still in acceptable condition with rehabilitation or reconstruction of assets that have reached or exceeded their service thresholds.

Program Updates

The prioritized program is not a one-time output; it should be reviewed and updated as new inspection data, revised cost estimates, and changes in budget or agency priorities become available. Documenting the rationale for inclusion or deferral of each candidate project supports continuity across cycles and provides an audit trail for the prioritization decisions.

STEP 6: COMMUNICATION

Data Summaries and Dashboards

Communication is one of the most critical steps in any asset management program. Use the outward-facing performance measures discussed under Step 4 to improve GAM program outcomes and to meet IDOT objectives. In addition, use of the developed data collection tool in Survey123 can produce summary charts to display the total number of assets and the condition rating distribution across the network.

GAM Program Committee

A sustainable GAM program requires a committee to guide it. The committee's responsibilities are:

- Evaluate the GAM program's progress and needs.
- Establish and maintain a collaborative culture and communication within the agency to help the program succeed.
- Reassess and update the program's objectives and goals.
- Discuss the needed financial and human resources.
- Discuss and communicate the ROI from the GAM program.

STEP 7: UPDATES AND PROGRAM IMPROVEMENTS

Step 7 closes the workflow loop by reviewing program performance, identifying gaps and risks associated with the program, and feeding those findings back into the preceding steps.

Gap and Risk Assessment

The first aspect of gap analysis is to investigate performance gaps between current and planned or desired performance. Performance gaps may indicate that targets, inspection cycles, or maintenance strategies established in earlier steps should be revisited. In addition to quantitative performance gaps, a reasonable objective is to bridge the communication gap between agency executives and the geotechnical asset manager within IDOT. This communication gap can include:

- Lack of awareness of existing geotechnical assets
- Future asset maintenance needs if assets are not managed proactively
- The criticality of geotechnical assets and their role in supporting other assets that carry traffic
- Safety and serviceability impacts of underperforming or failing geotechnical assets

These impacts are often the most consequential and a focus of executive-level communication.

Feedback Into the Workflow

Findings from this step should feed back into the earlier steps of the workflow, for example:

- Step 1 (Identify and Locate Assets): Add asset families or refine identification procedures based on observed gaps in the inventory.
- Step 2 (Risk-Based Data Collection): Adjust tier assignments or inspection cycles where data collection has proven insufficient.
- Step 3 (Condition Evaluation): Refine the rating scales or distress definitions where inspector feedback indicates ambiguity.
- Steps 4 and 5 (Performance Modeling, Investment Strategies): Update performance models and life cycle cost inputs as more inspection data accumulates.

Documenting these adjustments and the rationale behind them provides continuity across program cycles and a clear record of how the IDOT GAM program has evolved.

CHAPTER 3: DATA COLLECTION AND ASSET INSPECTION PROCEDURES

SCOPE AND INSPECTION TIERS

Data collection and visual inspection are integral parts of the GAM program and are addressed across multiple steps. As introduced in Chapter 2, the data collection framework is organized into tiers that reflect increasing levels of investigation effort and detail. The focus of this chapter is on Tier 0 (network scanning and inventory) and Tier 1 (asset condition evaluation), which form the foundation of the program's risk-based approach to managing geotechnical assets. Tier 0 activities, including the desk study and windshield survey, establish the preliminary asset inventory. Tier 1 activities, which consist of structured visual inspections using asset-specific rating sheets, provide the condition data required to support deterioration modeling (Chapter 5), risk assessment (Chapter 4), and investment planning (Chapter 2).

Tiers 2 and 3, which involve subsurface investigation, instrumentation, and detailed engineering analysis, are beyond the scope of this chapter. As described in Chapter 2, those procedures are reserved for assets identified as high risk or exhibiting progressive deterioration during Tier 1 inspection. The procedures presented in this chapter are intended as a practical starting point for statewide implementation and are expected to be refined as field experience accumulates and the program matures.

In addition to cycle-based inspections, out-of-cycle inspections may be initiated by the geotechnical asset manager following major disruptive events affecting a corridor, including significant flooding, freeze-thaw cycles, seismic events, or other conditions consistent with the deterioration mechanisms identified in Chapter 2. The scope and tier of these event-triggered inspections will depend on the affected assets and the nature of the event.

The drainage rating categories in this chapter apply to drainage features that are integral to a rated asset, such as slope ditches, wall weep drains, and outlet structures associated with the asset under inspection. Stand-alone drainage features are not included in the initial Illinois GAM scope: Culverts greater than 6 ft in diameter are managed under the bridge management program, and smaller culverts are deferred from initial implementation, as described in Chapter 1.

DESK STUDY AND INSPECTION PLANNING

Data collection begins with Tier 0 network scanning and inventory. The approach used in the pilots in this study, and as recommended for early implementation, starts with a desk study to identify the location of potential geotechnical assets to be included in the program. The desk study may focus on the following items:

- Illinois State Geological Survey—Statewide Maps. The maps can include a range of geological features, including coal industry maps, indicating underground risks; surface topography maps, showing areas with potential slopes; and other details.

- Illinois State Geological Survey—Illinois County Geologic Map Series. The maps can include detailed LiDAR maps, sinkhole distribution, and associated karst features, indicating underground risks, surficial geology maps, and other details.

- Aerial Photos and Satellite Imagery—Google Earth and Maps or other platforms if available. After identifying the general areas of interest, aerial photos can be used to search for soil and rock slopes, embankments, retaining walls, or other assets. Moreover, aerial photos can help to identify accessibility to the assets.

The outcomes from the desk study inform the network scanning program with potential locations, routes, schedule, asset types, traffic levels, and route names.

Desk studies are typically conducted by a geotechnical engineer or experienced engineering technician prior to field mobilization. The deliverable is a corridor map and accompanying table recording the anticipated location (route, milepost range, direction), probable asset type, approximate dimensions where estimable from imagery, and any noted access or safety concerns. IDOT project records and bridge management records in ISIS (Illinois Structure Inventory System) may supplement desk study findings with historical construction dates, wall types, or prior maintenance records; however, as noted in Chapter 2, reviewing historical records alone is generally not the most efficient approach for initial inventory development.

Following the desk study, a windshield survey confirms and refines the preliminary asset list by driving the corridor and making direct observations. During the review of the pilot corridors in this study, the research team used desk study outputs to guide the windshield survey, which significantly reduced the time required to establish the initial inventory. The combined desk study and windshield survey constitute the Tier 0 network scan and are expected to be repeated for new corridors as the program expands statewide.

During the field survey, assets extending beyond one-tenth of a mile should be subdivided into 0.1 mile segments and recorded as separate records, following the segmentation rule established in Chapter 2 (Step 1). For continuous features such as long retaining walls or extended embankments, each segment is treated as an independent asset for inspection and rating purposes unless the inspector determines that the feature is best handled as a single asset with comments documenting the rationale. Newly identified assets receive a unique identification number using the IHIS-based scheme described in Chapter 2, combining the key route ID, milepost of the segment midpoint, route direction, and asset type abbreviation.

INSPECTOR SAFETY

Before discussing the inspection procedures, inspector safety must be addressed. Visual inspection of geotechnical assets along active highways involves exposure to traffic, fall hazards on slopes and at the top of retaining walls, rockfall exposure at rock slopes, and uneven terrain. All inspections must follow IDOT traffic control procedures applicable to the corridor and roadway type, and inspectors must use appropriate personal protective equipment, including high-visibility apparel, hard hats where overhead hazards are present, and sturdy footwear suitable for off-pavement work. Inspectors

should not access portions of an asset that present immediate hazards (active rockfall, unstable scarps, steep unprotected slope faces) without a site-specific work plan. In such cases the asset condition should be evaluated from a safe vantage point, documented with photos, and flagged for a follow-up assessment by personnel with appropriate equipment.

VISUAL INSPECTION

Following the desk study, Tiers 0 and 1 visual inspection procedures developed in this study are based on a field inspection. The inspection procedures discussed in this chapter are summarized using a rating system developed to capture the risks and impacts of assets' conditions. The rating scale and procedures for soil slopes and embankments, retaining walls, and MSE walls are somewhat similar due to the common influence of soil behavior and impacts on the asset. Rock slopes have unique deterioration mechanisms leading to a unique rating system and inspection procedures. Despite the differences between the inspection and rating procedures, all rating systems yield a 1 to 5 condition score scale.

Visual inspection procedures focus on using surficial distresses as an indicator of underlying asset conditions. Additional inspections may be required to properly assess the deterioration of the asset as described in the tiered data collection process in Chapter 2.

The four asset families included in this chapter use parallel inspection structures with differences in the number and type of rated categories. Table 4 summarizes the inspection components for each asset family as implemented in the Survey123 application. The asset-specific procedures are described in the following subsections.

Table 4. Summary of Inspection Components by Asset Family

Asset Family	Component Categories	Drainage Rated	Condition Scale
Soil Slopes and Embankments	10 component categories (foundation, surface distress, material loss, movement indicators, etc.) and 6 drainage categories	Yes (separate section)	1 to 5 (good to very poor)
Rock Slopes	Hazard categories (6) and risk categories (5) per the Rockfall Hazard Rating System (RHRS) framework	Implicit via ditch effectiveness rating	1 to 5 with condition index 0 to 100
Retaining Walls (Non-MSE type)	9 wall component categories and 5 drainage categories	Yes (separate section)	1 to 5 (good to very poor)
MSE Walls	13 wall system component categories, 4 metallic reinforcement categories, and 5 drainage categories	Yes (separate section)	1 to 5 (good to very poor)

Soil Slopes and Embankments Inspection

The inspection procedure begins by recording general information (Figure 5). Some information can be pre-populated or will be automatically captured by Survey123, such as traffic levels, weather, GPS coordinates, and speed limit. Although all general information inputs are important, the most critical inputs to capture are the speed limit, average annual rainfall, and roadway width due to their impact on the risk to public safety and the criticality of the asset.

Illinois Department of Transportation

Soil Slopes and Embankments Inspection System

General Information

Legend	
	Input required
	Conditional: Input not required but can be provided
	Input not required / calculated automatically

SECTION 1 | GENERAL INFORMATION	
Inspector *	
Asset Type *	Slope/Embankment
Assessment Date *	
Asset Location (lat, lon) *	
Slope / Embankment ID	
Route ID	
Route Type	
Start Milepost	
End Milepost	
Travel Direction	
County Name	
Road Name	
Speed Limit (mph) *	
Roadway Width (ft) *	
AADT *	
Average Annual Rainfall (in)	
Surface Condition	
Weather	
Temperature (deg F)	
Inspection Limitations / Accessibility Notes	
Requires Maintenance?	
Maintenance Needed - Description	
Requires Detailed Inspection?	
Detailed Inspection - Description	

SECTION 2 | ASSET CHARACTERISTICS	
Asset Length (ft) *	
Asset Inclination (H:V ratio, e.g., 2 for 2:1)	
Maximum Height (ft)	
Typical Height (ft)	

** Required field in the Survey123 application. Asset characteristics apply as relevant to the asset family; inclination applies to slopes and embankments, and exposed height applies to slopes, embankments, and MSE walls.*

Figure 5. Screenshot. General information for soil slopes and embankments inspection.

The inspection procedure for soil slope and embankment components is shown in Figure 6 and drainage conditions are shown in Figure 7. The rating scores for all categories in Figure 6, except slope or embankment material loss, have good, marginal, and poor scoring options. Each rating corresponds to a numerical score starting with 1 for good condition, 2 for marginal condition, and 3 for poor condition. Slope or embankment material loss has only two possible ratings due to the criticality of that distress and its corresponding deterioration mechanism and consequences. Hence, any material loss should be assigned a poor rating.

The scores are then averaged with equal weight assigned for all categories. An adjusted overall rating may also be used if critical or extensive distress is observed or if an observation indicates a more severe overall condition than the arithmetic average implies. In such cases, the inspector should document the basis for the adjusted rating in the comments field and recommend the appropriate follow-up action, which may include escalation to a Tier 2 inspection or notification to the geotechnical asset manager. In addition, an asset should be flagged for more frequent or detailed invasive inspection if a distress or multiple distresses show progressive deterioration, which can indicate a more critical condition or a more immediate need for maintenance to prevent impacts on other elements, deterioration mechanisms, and neighboring assets. The inspector should provide comments and photos as well as recommend additional inspection needs.

Soil Slopes and Embankments Inspection System

Slope Embankment Components Distress

	CATEGORY OBSERVATIONS	RATING	SCORE	COMMENTS
1. Foundations				
1	G: Negligible local or differential settlement, near the slope/embankment base	Good	1	
2	M: Local or differential settlement within permissible and tolerable limits (settlement < 2.0 inch), minor cracks near the slope/embankment base			
3	P: Local or differential settlement exceeding permissible or tolerable limits; and/or cracks at slope or embankment base			
0	Not Applicable			
2. Foundation Erosion and Scour				
1	G: Insignificant erosion along the slope or at the slope or embankment base	Marginal	2	
2	M: Moderate erosion along the slope or at the slope/embankment base			
3	P: Significant erosion along the slope or at the slope or embankment base			
0	Not Applicable			
3. Utilities				
1	G: No observable broken utility lines, no utility pipe leakage, and no damage or significant tilt to surrounding utility poles or masts	Poor	3	
2	M: Moderate movement or deformation of utility lines, utility poles, or mast			
3	P: Observable broken utility lines or utility pipe leakage or significant damage or deformation to utility poles or masts			
0	Not Applicable			
4. Surface Distress				
1	G: No bulging or displacement along the slope face or at the embankment crest or pavement surface	Marginal	2	
2	M: Moderate cracks or displacements along the slope face or at the embankment crest or pavement surface			
3	P: Significant bulging or excessive cracks/ displacements along the slope face or at the embankment crest or pavement surface			
0	Not Applicable			
5. Barrier and Guard Rail				
1	G: Insignificant barrier or guard rail displacement or cracks	Good	1	
2	M: Permissible barrier or guard rail displacement or cracks			
3	P: Offset/ displacement of barrier or guard rail can affect performance			
0	Not Applicable			
6. Slope or Embankment Material Loss				
1	G: No Slope or Embankment Material Loss	Good	1	
3	P: Presence of Slope or Embankment Material Loss			
0	Not Applicable			
7. Apparent Material Saturation				
1	G: Almost dry or dry	Good	1	
2	M: Moist			
3	P: Almost saturated or saturated			
0	Not Applicable			
8. Localized Horizontal Movement (cracks in slope-embankment/pavement) Parallel to the Slope/Embankment				
1	G: Absence of localized shear failure in the slope/embankment	Poor	3	
2	M: Presence of localized shear failure in the slope/embankment (permissible cracks < 1 inch)			
3	P: Presence of localized shear failure in the slope/embankment (wide cracks > 1 inch)			
0	Not Applicable			
9. Localized Vertical Movement (cracks in slope-embankment/pavement)				
1	G: Negligible settlement	Marginal	2	
2	M: Localized settlement within allowable limits (settlement < 2.0 inch)			
3	P: Localized settlement exceeding allowable limits (settlement > 2.0 inch)			
0	Not Applicable			
10. Shallow Surface Failure/Depressions near Top of Slope or Embankment				
1	G: Insignificant - No shallow surface failures or depressions near the top of slope or embankment; any minor surface irregularity is stable and not enlarging.	Marginal	2	
2	M: Moderate - Isolated shallow depressions, minor scarps, or tension cracks near the top of slope or embankment, limited in extent and not affecting the roadway.			
3	P: Significant - Continuous scarp or slump affecting the crest or roadway, or depressions that are enlarging, indicating active near-surface instability.			
0	Not Applicable			

GROUP RATING SUMMARY			
Average Rating (scored categories only)	**Marginal**	**1.80**	
Mode Rating	**Good**	**1.00**	
Type Adjusted Overall Rating (enter only if overriding the average)			
Select Overall Rating Type	Average		
Group Overall Rating	**Marginal**	**1.80**	

Figure 6. Screenshot. Soil slopes and embankments components inspection sheet.

Soil Slopes and Embankments Inspection System

Drainage

	CATEGORY OBSERVATIONS	RATING	SCORE	COMMENTS
1. Soil Erosion				
1	G: No erosion	Poor	3	
2	M: Minor surficial erosion not reaching the slope toe			
3	P: Soil erosion at the base or crest of the slope or along the side slopes			
0	Not Applicable			
2. Vegetation				
1	G:Vegetation growth is consistent and lush along the side slopes	Marginal	2	
2	M: Vegetation growth is generally intact with several barren patches along the side slopes			
3	P: Vegetation growth is inconsistent along the side slopes with significant bare areas			
0	Not Applicable			
3. Drainage Systems (Surface and Subsurface)				
1	G: No observable surface or subsurface drainage problems	Good	1	
2	M: Presence of surface and subsurface drainage problems that can be addressed by routine maintenance			
3	P: Presence of surface and subsurface drainage problems that cannot be addressed by routine maintenance			
0	Not Applicable			
4. Water Accumulation (top of slope)				
1	G: No water accumulation at the top of the slope (e.g., no water ponding)	Good	1	
2	M: Water accumulation at the top of the slope (e.g., water ponding) that can be addressed by routine maintenance			
3	P: Water accumulation at the top of the slope (e.g., water ponding) that cannot be addressed by routine maintenance			
0	Not Applicable			
5. Water Accumulation (bottom)				
1	G: No water accumulation at the base of the slope (e.g., no water ponding)	Good	1	
2	M: Water accumulation at the base of the slope (e.g., water ponding) can be addressed by routine maintenance			
3	P: Water accumulation at the base of the slope (e.g., water ponding) cannot be addressed by routine maintenance			
0	Not Applicable			
6. Gutter / Ditch Condition				
1	G: Gutters and ditches are clear or contain only minor accumulation; flow is not impeded	Good	1	
2	M: Sediment or debris accumulation partially impedes flow or indicates active surface loss from the slope; can be addressed by routine maintenance			
3	P: Gutters or ditches are blocked or filled; flow is impeded or accumulation indicates significant ongoing material loss; cannot be addressed by routine maintenance			
0	Not Applicable			

GROUP RATING SUMMARY			
Average Rating (scored categories only)	**Marginal**	**1.50**	
Mode Rating	**Good**	**1.00**	
Type Adjusted Overall Rating (enter only if overriding the average)			
Select Overall Rating Type	Average		
Group Overall Rating	**Marginal**	**1.50**	

Figure 7. Screenshot. Soil slopes and embankments drainage inspection sheet.

Rock Slopes Inspection

Risk-based rock slope assessments have been refined within GAM programs since the Alaska Department of Transportation and Public Facilities developed the initial Unstable Slope Management Program between 2011 and 2017. The current approach has been tested and implemented in several other states and includes the collection of Rockfall Hazard Rating System (RHRS) data and other supporting information. Collection of RHRS data helps with several facets of rock slope management: using the RHRS score as a common communication tool for geotechnical personnel, collection of size and extent information, and relative risk factors (sight distance, road width, annual average daily traffic, etc.) that others within IDOT may find useful. Use of this proven approach is recommended for Illinois and is described below.

Inventorying and Initial Inspection

Rock slopes are typically inherently unstable, and most produce rockfalls in differing amounts and at various times, though event frequency can vary from rarely to almost constantly. These events

represent safety concerns that can cause accidents and disrupt mobility and local economies. They can also place inordinate demands on maintenance operations and budgets and create safety concerns for maintenance staff. All rock slopes that could potentially generate rockfall requiring maintenance attention, even on an infrequent basis, are initially categorized in two of three categories. Slopes meeting the third classification may be entered into the database to achieve a complete inventory, but transportation agencies may choose to exclude them due to their small size, setback from the road, relative stability, and the negligible hazard and risk posed to public safety.

Rock slopes will be divided into three classifications—A, B, and C—based on the potential and/or history of rockfall reaching the roadway. Each rock slope will be assigned a classification based on an initial inspection. Slopes in Class A have the highest likelihood of producing rockfall that impacts the road and will receive detailed field assessment by an experienced geotechnical engineer or engineering geologist. Slopes in Class B will receive detailed assessment when on a high-volume or otherwise critical route (for instance, above 4,000 annual average daily traffic [AADT]). Slopes in Class C will be included in the inventory but will not receive detailed assessment. All slopes are typically excavated above road grade; however, adjacent natural rockfall-prone slopes that pose a hazard to the right-of-way, the public, and/or require maintenance action should also be entered into the database. The three slope classifications are defined below, and Table 5 summarizes the screening-level determination of rock slope classification based on rockfall potential and catchment effectiveness.

The field data collection platform should allow the collection of beginning and ending stations, geographic coordinates, comments, approximate length and height, site photos, and the A, B, or C classification.

Class A—Rockfall from these slopes have a moderate to high likelihood of reaching the road. There is either a limited catchment area or a record of regular and active rockfall activity. A mitigated rock slope may also be included in this category if mitigation was completed in response to a history of required maintenance and rockfall activity.

Class B—Rockfall from these slopes have a low likelihood of reaching the roadway but may occur based on inspector judgment. These sites typically have moderate rockfall potential, low rockfall history, and good catchment areas. There may be records of occasional maintenance in the past. Traffic volume is a straightforward metric to serve as the basis of when a Class B slope should receive detailed assessment. Risk factors, such as sight distance, detour length, and commercial truck traffic, could be the subject of additional study regarding these potential moderate-risk slopes.

Class C—Rockfall from these slopes is unlikely to reach the road. The general classification of a C slope is one where the slope height is shorter than 15 ft and shorter than the roadside ditch width. Rockfall from a C slope would have no reasonable way to reach the road or require maintenance.

Table 5. Initial Inspection Determination of Rock Slope Classification Based on Rockfall Potential and Ditch Effectiveness

		Historic Failure Frequency or Potential		
		High	Moderate	Low
Likelihood of Rockfall Affecting the Road	High	Class A	A	A
	Moderate	A	A	B
	Low	A	B	C

Figure 8 presents the risk categories rating sheet. Risk categories capture roadway geometry and usage information to assess the relative likelihood of disruption, damage, or injury after a rockfall event. The categories capture risks for both roadway users and maintenance personnel. Each unstable rock slope is evaluated in five risk-rating categories. Each category is worth a maximum of 100 points, so the maximum possible risk-rating score for a rock slope is 500 points.

Figure 9 presents a section from the rock slopes hazard categories rating sheet. The hazard evaluation incorporates observations for rockfall, which is an indicator of the deterioration level for the rock slope. Moreover, the evaluation takes into consideration the slope height and ditch effectiveness, which reflects the hazard levels from rockfall activities. All categories are then converted to numerical scores that can be summed to an overall hazard score. It is highly recommended to refer to the figure and visual description of the different ratings for the hazard categories provided in Appendix C during field inspection. In addition, it is recommended that inspectors practice inspection prior to formal data collection to develop their inspection consistency and knowledge. Scores from the risk-rating categories are combined with those from the hazard-rating categories to calculate the final RHRS score and condition state for a site, as shown in Figure 10.

Appendix C provides additional details on rock-slope inspection procedures including the calculations for different scores such as vehicle risk score, roadway width score, and others.

CATEGORY		ENTRY	SCORE	COMMENTS
1. AADT				
AADT (carried from General Information)		**4900.00**		
Computed exponent x		**2.214**	**11.4**	
Enter AADT on the General Information sheet. The value shown here is carried over and is not edited on this sheet.				
2. Average Vehicle Risk				
Percent of time a vehicle is present (computed)		**297.00**		
Computed exponent x		**11.879**	**100.0**	
Average vehicle risk is computed from AADT, asset length, and posted speed as entered on the General Information sheet.				
3. Decision Sight Distance				
Measured minimum sight distance (ft)		1000.00		
Required sight distance (ft), by posted speed		**875.00**		
Computed exponent x		**0.286**	**1.4**	
Required decision sight distance is set by the posted speed limit: 25 mph / 375 ft, 30 / 450, 35 / 525, 40 / 600, 45 / 675, 50 / 750, 55 / 875, 60 / 1000, 65 / 1050.				
4. Roadway Width				
Roadway width (ft), carried from General Information		**27.00**		
Computed exponent x		**2.125**	**10.3**	
5. Rockfall-Related Maintenance Frequency				
3	Normal: Only routine, scheduled ditch maintenance is required on an infrequent (3-5 year) basis	Normal	**3**	
9	After Storm: Maintenance staff only actively patrol for rock on the roadway after extreme storm events			
27	Seasonal: Maintenance staff routinely patrol for rocks on the road during typical 'high rockfall' seasons (fall, winter, spring)			
81	Year-round: Maintenance staff routinely patrol for rock year-round			
RISK CATEGORY TOTAL				
	TOTAL RISK SCORE		**126.1**	

Figure 8. Screenshot. A section from the rock slopes risk categories rating sheet.

CATEGORY AND OBSERVED CONDITION		ENTRY	SCORE	COMMENTS
1. Block Size or Event Volume		Size		
Block size (ft)		6		
Event volume (yd3)				
Computed exponent x		**6**	**100**	
Select the measurement type in the ENTRY column beside the heading above, then enter the corresponding measurement. Use block size where individual blocks are typical of the observed rockfall and event volume where a mass of blocks dominates. Where it is unclear which applies, select Both, rate the site with both equations, and record the higher of the two scores (manual Figure 121 and Table 23).				
2. Slope Height				
Slope height (ft)		145		
Computed exponent x		**6**	**100**	
3. Ditch Effectiveness				
3	Good: All or nearly all failing rocks are retained in the catch ditch	Good	3	
9	Moderate: Falling rocks are expected to occasionally reach the roadway			
27	Limited: Falling rocks are expected to frequently reach the roadway			
81	None: No ditch, or ditch is totally ineffective			
4. Geologic Character - complete Case 1 or Case 2, whichever governs. Case 1 applies where joints or bedding control stability. Case 2 applies where differential erosion controls.				
4a. Case 1 - Structural Condition				
3	Favorable: Slope contains jointed rock with no or very few adversely oriented joints			
9	Random: Slope contains randomly oriented joints creating a variable pattern			
27	Discontinuous: Rock slope exhibits a prominent joint pattern with an adverse orientation			
81	Continuous: Rock slope joint pattern with an adverse orientation and joint lengths greater than 10 feet			
4b. Case 1 - Rock Friction				
3	Rough and Irregular: The surfaces of the joints are rough, and the joint planes are irregular			
9	Undulating: Rough but without the interlocking ability, judged on the macro scale			
27	Planar: Macro smooth and micro rough joint surfaces			
81	Clay Infilling or Slickensides: Low friction soil materials separate the rock surfaces, and presence of slickensided			
4c. Case 2 - Structural Condition				
3	Few: Minor differential erosion features that are not distributed throughout the slope			
9	Occasional: Minor differential erosion features that are widely distributed throughout the slope			
27	Many: Differential erosion features that are large and numerous throughout the slope			
81	Major: Severe cases of dangerously eroded overhangs, or significantly over-steepened rock or talus slopes			
4d. Case 2 - Differential Erosion Rate				
3	Small: Erosion features take many years to develop	Moderate	9	
9	Moderate: The difference in erosion rates allows erosion features to develop over a period of a few years			
27	Large: The difference in erosion rates allows noticeable changes in the slope to develop annually			
81	Extreme: The difference in erosion rates allows rapid and continuous development of erosion features			
5. Rockfall Activity				
3	Few: Rockfalls occur only a few times a year (or less), or only during severe storms.	Few	3	
9	Occasional: Rockfall occurs regularly. Rockfall can be expected several times per year and during most storms.			
27	Many: Rockfall occurs frequently during a certain season, such as the wet period, or the winter freeze/thaw			
81	Constant: Rockfalls occur frequently throughout the year			
6. Water on Slope				
3	Well: Slope is dry or well drained; little to no water on the slope face	Moderately Well	9	
9	Moderately Well: Intermittent or seasonal water on the slope; moderately well drained			
27	Moderately Poor: Water usually on the slope; poorly drained, with persistent seepage			
81	Poor: Water continuously on the slope; very poorly drained or flowing water present			

HAZARD CATEGORY TOTAL			
Geologic Character Score (governing case)		**9.0**	
TOTAL HAZARD SCORE		**224.0**	

Figure 9. Screenshot. A section from the rock slopes hazard categories rating sheet.

SLOPE CLASSIFICATION	
Rock Slope Class	**B**
Failure Type	**Raveling/Talus**

COMBINED RISK SCORE		
Hazard Categories Total	**224.0**	
Risk Categories Total	**126.1**	
COMBINED RISK SCORE	**350.1**	

ROCKFALL CONDITION STATE		
Category	**Field Rating**	**Condition Index (0-100)**
Ditch Effectiveness	**3**	**100.0**
Rockfall Activity	**3**	**100.0**
Average	**3.0**	**100.0**

Rockfall Condition State	**Good**	
Rockfall Condition Score (1 to 5)	**1**	

Figure 10. Screenshot. Summary of inspection ratings and final scores for rock slopes.

The condition index is a linear continuum from 100 for the best condition to 0 for the worst condition. That scale is evenly divided into five condition state categories, with corresponding condition scores from 1 to 5. The condition index is a combination of the potential for a rockfall event

and the ability of the roadside ditch to contain the rockfall event and prevent it from reaching the roadway. The RHRS Ditch Effectiveness and Rockfall History categories provide these components. Table 6 presents the condition state category descriptions.

The condition index is useful to illustrate nuances within condition state. For instance, a slope with an index score of 100 indicates a totally effective ditch and very low rockfall activity, while a slope with an index score of 87 can indicate a less effective ditch but an equally low rockfall activity and no history of rockfall reaching the road. These two slopes are in condition state 1 (good) with different ditch effectiveness. Neither site would likely warrant mitigation, and, therefore, it is reasonable to be within the same condition state 1 classification.

Table 6. Rock Slope Condition Category Descriptions

Condition Score	Condition State	Cond. Index Range	Description
1	**Very Good**	**100–80**	Rock slope produces little to no rockfall and has no history of rocks reaching the road. Little to no maintenance needs to be performed due to rockfall activity. Rockfall mitigation measures, if present, are in new or like new condition.
2	**Good**	**80–60**	Rock slope produces occasional rockfall that may rarely reach the road. Some maintenance needs to be performed on a scheduled basis due to rockfall activity to address safety. Mitigation measures, if present, are in generally good condition, with only surficial rust or minor apparent damage.
3	**Fair**	**60–40**	Rock slope produces many rockfalls with rock occasionally reaching the road. Maintenance is required biannually or annually to maintain safety. Mitigation measures, if present, appear to have more significant corrosion or damage to minor elements. Preventative maintenance or replacement of minor mitigation components is warranted.
4	**Poor**	**40–20**	Rock slope produces constant rockfall with rocks frequently reaching the road. Maintenance is required annually or more often to maintain ditch performance. Much of the required maintenance response is unscheduled. Mitigation measures, if present, are generally ineffective due to significant damage to major components or apparent deep corrosion.
5	**Very Poor**	**20–0**	Rock slope produces constant rockfall, and nearly all rockfall reaches the road. Virtually no rockfall catchment exists or is effective. Maintenance must respond to rockfalls regularly, possibly daily during adverse weather. If present, nearly all mitigation measures are ineffectual due to deferred maintenance, significant damage, or obvious deep corrosion.

Retaining Walls Inspection

The general retaining wall inspection procedure follows the general procedure for soil slopes and embankments inspection, as shown in Figure 11 and Figure 12. The procedure is intentionally generic so that it applies consistently across wall types encountered in the Illinois network, including gravity walls, cantilever walls, sheet pile walls, and crib walls, and does not require the inspector to make detailed structural assessments. More specific inspection procedures are available for MSE walls,

which are addressed separately in the following section. Wall component ratings assess the physical condition of elements constituting the wall structure and its connection to the surrounding ground. Drainage ratings assess the functionality of drainage elements, which are critical because drainage deficiencies are among the most frequently cited contributing factors in retaining wall failures. The rating categories and their good/moderate/poor thresholds follow the same framework described for soil slopes and embankments above, applied to wall-specific components. The weights applied to drainage elements in the summary sheet (Figure 13) reflect the role of drainage distresses as observable indicators of underlying conditions. These weights are proposed values that should be reviewed as inspection records accumulate.

	CATEGORY OBSERVATIONS	RATING	SCORE	COMMENTS
1. Foundation				
1	G: Negligible local or differential settlement, near the wall base	Marginal	2	
2	M: Local or differential settlement within permissible and tolerable limits (settlement can vary longitudinally between 1 in and 4 in depending on the wall type)			
3	P: Local or differential settlement exceeding permissible or tolerable limits; and/or cracks at wall base			
0	Not Applicable			
2. Foundation Erosion and Scour				
1	G: Insignificant erosion along the slope or at the wall base	Good	1	
2	M: Moderate erosion along the slope or at the wall base that does not undermine the foundation			
3	P: Significant erosion undermining the wall base or foundation; or scour at the base of water-crossing			
0	Not Applicable			
3. Utilities				
1	G: No observable broken utility lines, no utility pipe leakage, and no damage or significant tilt to surrounding utility poles or masts	Good	1	
2	M: Moderate movement or deformation of utility lines, utility poles, or masts			
3	P: Observable broken utility lines or utility pipe leakage or significant damage or deformation to utility poles or masts			
0	Not Applicable			
4. Surface Distress				
1	G: No bulging or displacements along the wall face or at the embankment crest or pavement surface	Marginal	2	
2	M: Moderate cracks or displacements along the wall face or at the embankment crest or pavement			
3	P: Significant bulging or excessive cracks/ displacements along the wall face or at the embankment crest or pavement surface			
0	Not Applicable			
5. Barrier and Guard Rail				
1	G: Insignificant barrier or guard rail displacement or cracks	Good	1	
2	M: Permissible barrier or guard rail displacement or cracks			
3	P: Offset/ displacement of barrier or guard rail can affect performance			
0	Not Applicable			
6. Material Saturation				
1	G: Almost dry or dry	Marginal	2	
2	M: Moist			
3	P: Almost saturated or saturated			
0	Not Applicable			
7. Localized Horizontal Movement (cracks in wall/pavement) Parallel to the Wall				
1	G: Absence of localized shear failure in the wall	Good	1	
2	M: Presence of localized shear failure in the wall (permissible cracks < 1.0 inch)			
3	P: Presence of localized shear failure in the wall (wide cracks > 1.0 inch)			
0	Not Applicable			
8. Localized Vertical Movement (cracks in wall/pavement)				
1	G: Negligible settlement	Good	1	
2	M: Localized settlement within allowable limits (settlement < 1.0 inch)			
3	P: Localized settlement exceeding allowable limits (settlement > 1.0 inch)			
0	Not Applicable			
9. Shallow Surface Failure/Depressions near Top of Wall				
1	G: Insignificant - No depressions or shallow failures behind the wall top; any minor surface irregularity is stable and not enlarging.	Marginal	2	
2	M: Moderate - Isolated depressions, sinkhole-like features, or tension cracks behind the wall top, limited in extent and not affecting the roadway.			
3	P: Significant - Depressions or shallow failures behind the wall top that are extensive or enlarging, or that affect the roadway, indicating active void development or internal erosion in the fill.			
0	Not Applicable			

GROUP RATING SUMMARY			
Average Rating (scored categories only)	**Good**	**1.44**	
Mode Rating	**Good**	**1.00**	
Type Adjusted Overall Rating (enter only if overriding the average)			
Select Overall Rating Type	Average		
Group Overall Rating	**Good**	**1.44**	

Figure 11. Screenshot. Retaining wall components inspection sheet.

CATEGORY OBSERVATIONS		RATING	SCORE	COMMENTS
1. Soil Erosion				
1	G: No erosion	Good	1	
2	M: Minor surficial soil erosion at the base or crest of the wall that does not undermine the wall or expose the foundation			
3	P: Soil erosion at the base or crest of the wall that undermines the wall or exposes the foundation			
0	Not Applicable			
2. Vegetation				
1	G: Vegetation growth is consistent and lush along the side slopes above or below the wall	Marginal	2	
2	M: Vegetation growth is generally intact with several barren patches along the slopes above or below the wall			
3	P: Vegetation growth is inconsistent along the slopes above or below the wall			
0	Not Applicable			
3. Drainage Systems (Surface and Subsurface)				
1	G: No surface or subsurface drainage problems	Good	1	
2	M: Presence of surface and subsurface drainage problems that can be addressed by routine			
3	P: Presence of surface and subsurface drainage problems that cannot be addressed by routine			
0	Not Applicable			
4. Water Accumulation (top of wall)				
1	G: No water accumulation at the top of the wall (e.g., no water ponding)	Good	1	
2	M: Water accumulation at the top of the wall (e.g., water ponding) can be addressed by routine maintenance			
3	P: Water accumulation at the top of the wall (e.g., water ponding) cannot be addressed by routine maintenance			
0	Not Applicable			
5. Water Accumulation (bottom)				
1	G: No water accumulation at the base of the wall (e.g., no water ponding)	Good	1	
2	M: Water accumulation at the base of the wall (e.g., water ponding) can be addressed by routine maintenance			
3	P: Water accumulation at the base of the wall (e.g., water ponding) cannot be addressed by routine maintenance			
0	Not Applicable			

GROUP RATING SUMMARY			
Average Rating (scored categories only)	**Good**	**1.20**	
Mode Rating	**Good**	**1.00**	
Type Adjusted Overall Rating (enter only if overriding the average)			
Select Overall Rating Type	Average		
Group Overall Rating	**Good**	**1.20**	

Figure 12. Screenshot. Retaining wall drainage inspection sheet.

Figure 13 presents the summary sheet to calculate the total performance condition rating and the corresponding condition states. Similar summary sheets are provided for soil slopes and embankments and MSE walls. The total performance rating is calculated as a weighted average rating for wall components and drainage. The weights shown in Figure 13 are selected to reflect the uncertainty and risk levels associated with the wall components and drainage elements. Distresses due to drainage elements reflect underlying conditions faster, while distresses in the wall components can lag from the underlying condition deterioration and may show at a later deterioration stage. The proposed weights can be updated in the future if inspection data support a revision to these values.

Retaining Wall Inspection System

Summary Sheet

Inspector:	
Date:	
County:	
Roadway Width (ft):	
Wall ID:	
Route ID:	
Route Type:	
Start Milepost:	
End Milepost:	
Travel Direction:	
Speed Limit (mph):	
AADT:	
Average Annual Rainfall (in):	
Asset Length (ft):	

Legends

	Input required
	Conditional: Input not required but can be provided
	Input not required / calculated

WEIGHTED TOTAL PERFORMANCE RATING

Group / Element	Relative Weight	Performance Rating	Condition	Weighted Rating		
Wall Components	20	1.44	Good	28.88		
Drainage	10	1.20	Good	12.00		
Totals	30			40.88		

TOTAL PERFORMANCE RATING	1.36	Very Good	

CONDITION STATE AND RECOMMENDED ACTION

Rating	Condition State	Recommended Action
< 1.50	Very Good	Wall is Safe, no action needed, and schedule field assessment in 5 years
1.50 - 2.00	Good	Wall is Safe, routine maintenance may be needed, and schedule condition assessment in 5 years
2.01 - 2.50	Marginal	Wall may be Safe but requires field inspection (performance state assessment) within 3 years to verify condition
2.51 - 2.75	Poor	Wall may be potentially Unsafe and may require immediate replacement or rehabilitation
> 2.75	Very Poor	Wall is Unsafe and likely requires immediate replacement or rehabilitation

Figure 13. Screenshot. Retaining wall inspection summary sheet.

MSE Walls Inspection

Mechanically stabilized earth walls are among the most prevalent wall types in the Illinois highway network. Given the complexity of their structural components, a more specific and thorough inspection procedure was developed for MSE walls compared to the generic retaining wall procedure. Figure 14 presents the inspection sheet for the wall component, which evaluates the wall facing, coping, geotextile joints, reinforced backfill zone, reinforcement elements, and adjacent utilities shown in Figure 16. Inspectors should review typical MSE construction diagrams and other visuals like Figure 16 before beginning the wall component assessment to ensure familiarity with the components being rated. Note that the saturation of the backfill, especially behind the reinforced zone, is considered in the wall component inspection, since it presents a direct risk to the component separate from the risk of water building up behind the wall due to poor drainage.

Following the wall component inspection, the metallic reinforcement components are evaluated based on the distresses related to their deterioration such as local facing displacement, bulging / bowing, and visible (facing unit) corrosion, as shown in Figure 15. The inspection observations shown in Figure 15 can be applicable to non-metallic reinforcements except for the corrosion observation, which can be entered as “not applicable” and excluded from the rating.

	CATEGORY OBSERVATIONS	RATING	SCORE	COMMENTS
1. Foundations				
1	G: Negligible local or differential settlement, no cracks near the base or in leveling pad, no marginal materials	Poor	3	
2	M: Local or differential settlement within permissible limits (settlement < 2.0 inch), minor cracks near the base			
3	P: Local or differential settlement exceeding permissible limits; and/or cracks in the leveling pad			
0	Not Applicable			
2. Foundation Erosion and Scour				
1	G: Insignificant erosion to berm with sufficient wall embedment depth	Marginal	2	
2	M: Moderate erosion to the berm that reduces cover but does not expose the leveling pad or undermine embedment			
3	P: Erosion exposing the leveling pad or undermining embedment; or scour at the base of water-crossing walls			
0	Not Applicable			
3. Surrounding				
1	G: No salt deposits or concrete efflorescence near the wall; and no signs of impact-related damage	Good	1	
3	P: Presence of salt deposits or concrete efflorescence near the wall; or signs of impact-related damage			
0	Not Applicable			
4. Utilities				
1	G: No observable broken utility lines, no utility pipe leakage, and no damage or significant tilt to surrounding utility poles or masts	Poor	3	
2	M: Moderate movement or deformation of utility lines, utility poles, or masts			
3	P: Observable broken utility lines or utility pipe leakage or significant damage or deformation to utility poles or masts			
0	Not Applicable			
11. Localized Horizontal Movement (cracks in retained fill/pavement) Parallel to the Wall				
1	G: Absence of localized shear failure in the reinforced backfill	Good	1	
2	M: Presence of localized shear failure in the reinforced backfill (permissible cracks < 0.25 inch)			
3	P: Presence of localized shear failure in the reinforced backfill (wide cracks > 0.25 inch)			
0	Not Applicable			
12. Localized Vertical Settlement (cracks in retained fill/pavement)				
1	G: Negligible settlement	Good	1	
2	M: Localized settlement within allowable limits (settlement < 2.0 inch)			
3	P: Localized settlement exceeding allowable limits (settlement > 2.0 inch)			
0	Not Applicable			
13. Shallow Surface Failure/Depressions near Top of Wall				
1	G: Insignificant - No depressions or shallow failures behind the wall top; any minor surface irregularity is stable and not enlarging.	Good	1	
2	M: Moderate - Isolated depressions, sinkhole-like features, or tension cracks behind the wall top, limited in extent and not affecting the roadway.			
3	P: Significant - Depressions or shallow failures behind the wall top that are extensive or enlarging, or that affect the roadway, indicating active void development or internal erosion in the fill.			
0	Not Applicable			

GROUP RATING SUMMARY			
Average Rating (scored categories only)	**Marginal**	**1.62**	
Mode Rating	**Good**	**1.00**	
Type Adjusted Overall Rating (enter only if overriding the average)			
Select Overall Rating Type	Average		
Group Overall Rating	**Marginal**	**1.62**	

Figure 14. Screenshot. Partial MSE wall system component inspection sheet.

	CATEGORY OBSERVATIONS	RATING	SCORE	COMMENTS
1. Reinforcement or Facing Displacement				
1	G: No facing connection rupture or reinforcement pullout	Poor	3	
3	P: Facing connection rupture or reinforcement pullout			
0	Not Applicable			
2. Overall (Vertical and Horizontal) Alignment				
1	G: Negligible facing displacement and no loose or detached units	Marginal	2	
2	M: Facing displacement within permissible limits			
3	P: Facing displacement beyond permissible limits and/or presence of loose or detached units			
0	Not Applicable			
3. Local Facing Displacement				
1	G: No displacement on the facing	Good	1	
2	M: Displacement on the facing within permissible limits			
3	P: Excessive displacement on the facing			
0	Not Applicable			
4. Reinforcement or Connection Corrosion				
1	G: No corrosion; no rust staining on the facing; no measurable section loss of reinforcement or	Good	1	
3	P: Observable corrosion: rust staining on the facing, corrosion at exposed connections or reinforcement, or measurable section loss (10% or more rusted surface)			
0	Not Applicable			

GROUP RATING SUMMARY			
Average Rating (scored categories only)	**Marginal**	**1.75**	
Mode Rating	**Good**	**1.00**	
Type Adjusted Overall Rating (enter only if overriding the average)			
Select Overall Rating Type	Average		
Group Overall Rating	**Marginal**	**1.75**	

Figure 15. Screenshot. MSE metallic components inspection sheet.

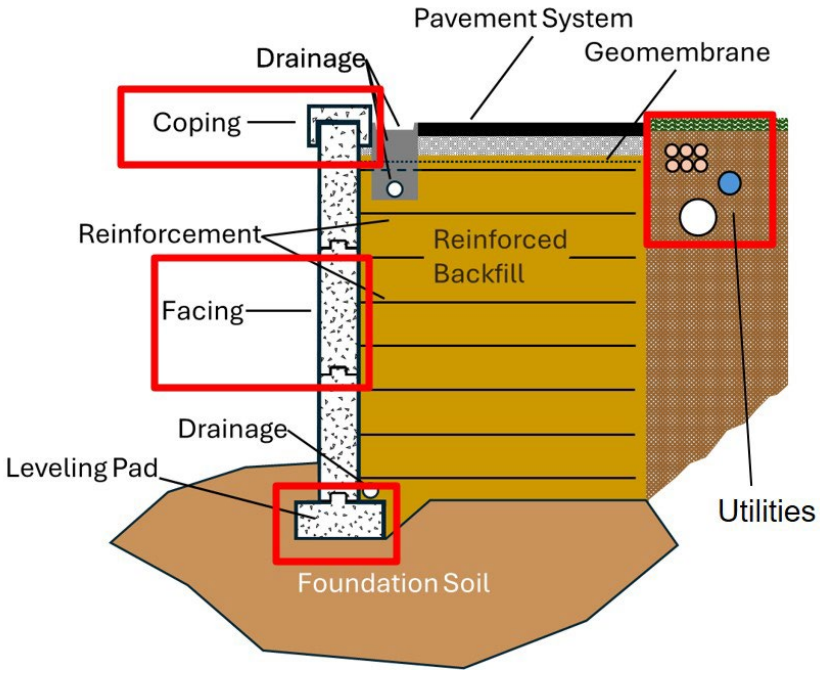


Figure 16. Illustration. Parts of MSE wall reported in the wall component inspection sheet.

INSPECTION APPLICATION

To facilitate inspection in the field, an application was developed in Survey123 to allow for interactive inspection and capturing images in the field. Survey123 for ArcGIS is a data collection tool designed to create, share, and analyze surveys. Users may design smart forms tailored for field data collection while integrating spatial data. With its user-friendly interface, Survey123 allows organizations to gather information efficiently, from basic text inputs to complex geospatial features. Survey123 offers two ways to create a survey:

- **Survey123 Web Designer**: A no-code platform for creating simple surveys
- **Survey123 Connect**: A desktop application for advanced users, providing flexibility to design dynamic surveys with XLSForm, enabling features like logic, calculations, and data validation

Survey123 Connect, used for this project, is more powerful and provides flexibility and complex survey structures. This section provides a summary of the application and its implementation in the field. Appendix D provides additional details on the application.

Reference Map

Implementation of IDOT's GAM field data collection involves a systematic two-step process: the creation of a reference map and the development of a customized survey. These steps ensure the efficient and accurate gathering of geotechnical asset data. The reference map is a foundational component of the survey, designed to serve as the base map for data collection. This map plays a crucial role in automating the population of essential road information, including road name, county name, and AADT. The reference map was developed by integrating multiple publicly accessible

feature layers from the IDOT GIS database. These layers include high-resolution spatial data and attribute information, ensuring comprehensive coverage and accuracy.

To facilitate the direct population of traffic data from the reference map to the survey form, it is necessary for the user either to select the relevant feature or for their current location to fall within the area of the feature. However, due to traffic data being represented as a line feature layer, it is difficult for users to select a line feature to populate necessary information during field data collection. It is particularly difficult for users to select accurately on mobile devices in field. To address this issue, the traffic line layer was transformed into a polygon layer by generating a 750 ft buffer zone on both sides of each line feature. This buffer effectively creates a polygonal representation of the traffic layer, significantly improving usability during field operations. The transformation ensures that users can automatically populate traffic-related information, such as AADT, whenever their current location falls within the buffered area.

Structure of Survey

The survey is specifically designed to collect information on geotechnical assets as defined by IDOT and the research team. These assets include rock slopes, slopes/embankments, MSE walls, and generic walls. To ensure precise and quantitative evaluation, multiple categories were established for each asset type, enabling a detailed assessment of their current condition. Survey123 allows users to capture multiple photos during data collection, and it creates hierarchical data structures. The survey architecture includes a parent layer, general information, details about the asset, and four child layers/tables corresponding to the four asset types. Each child layer has an image table to accommodate photographs taken during field inspections.

The parent layer is designed to collect general information for the assets, which is the same for all asset types, as shown in Figure 17. The general information page includes 26 questions, with some questions automatically populating if the location matches data in the reference map. After inputting general information, the application will direct users to other layers for inspection observations, depending on the asset type. An important use of the application is uploading photos and adding comments during the inspection to document observations and explain the decision made. The photos will also provide a reference for inspection records at different times to show the changes in asset condition and distresses.

As change detection between inspection cycles depends on consistent photographic records, photos captured through Survey123 should retain their GPS location and timestamp metadata. Inspectors are not recommended to edit, crop, or re-shoot photos in a way that strips this metadata and should aim to capture follow-up photos from approximately the same vantage points used in prior inspections to support direct visual comparison of the asset over time. These records support the deterioration modeling described in Chapter 5. Inspection records are submitted to the ArcGIS server upon submission of the Survey123 form when cellular connectivity is available. Where records are completed offline or where connectivity is intermittent, inspectors should verify successful upload at the end of each field shift to ensure records are available to the geotechnical asset manager for the QA review described below. Submitted records are visible in both the Form and Feature Layer files on the ArcGIS server as described in the User and Developer Guide.

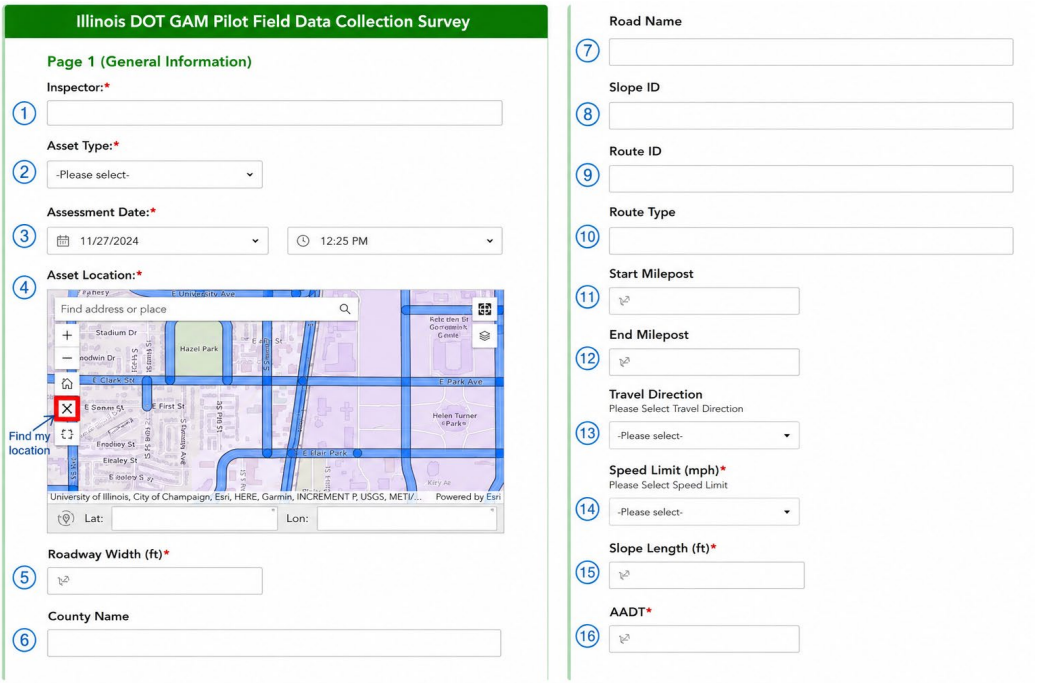


Figure 17. Screenshot. Survey123 general information.

Survey123 Field Guidance and Quality Assurance

Practical deployment considerations are an integral part of implementing the data collection platform effectively in the field and are addressed in the guidance below. As noted in the platform description and schema overview above, the system is designed to support structured, repeatable data collection across the geotechnical asset inventory. The guidance in this section supplements that overview by addressing field-specific considerations not covered elsewhere in this report. Additional technical details, including XLSForm configuration and server-side publishing steps, are provided in the User and Developer Guide in Appendix D.

Device and Connectivity Requirements

The Survey123 application is designed for use on any ESRI compatible mobile device with GPS capability. A cellular data connection (LTE or better) is required to auto-populate AADT and road-name fields from the reference map and to submit records to the ArcGIS server. Where cellular connectivity is unavailable, which is anticipated in some rural corridors or in areas of large vertical variation, inspectors may have to complete fields manually and photograph the asset as noted in Chapter 6. The demonstrative application developed during this study was not configured for fully offline operation. The Survey123 field application supports cached (offline) data collection, and consistent with the Pilot 2 recommendation this capability should be enabled for production deployment. Reference-map auto-population (county, road name, AADT, and rainfall) requires a live connection regardless of offline caching, so these fields must be completed manually when working offline and verified during the QA review. Until offline caching is enabled and verified, the inspector should carry a hard-copy backup of the relevant inspection Excel sheet and use it if the device loses power or connectivity.

Inspector Training and Consistency

Before conducting formal data collection, inspectors should complete at least one practice inspection session to develop familiarity with the rating scale. Rating variability between inspectors is a recognized source of uncertainty in visual condition assessment programs. To reduce this variability: (1) calibration sessions should be conducted at program initiation, with two or more inspectors independently rating the same assets and resolving disagreements through documented discussion; (2) a minimum of three photographs per asset should be captured: one wide-angle view, one close-up of the worst-condition element, and one of the drainage conditions; and (3) inspectors conducting rock slope assessments should review Appendix C and have prior experience in geologic characterization or complete a supervised field orientation with a licensed engineering geologist or geotechnical engineer.

Data Quality Assurance

As described in Chapter 2, a quality assurance review should be completed within five business days of field data collection while observations are fresh. The QA review should be performed by a geotechnical engineer or experienced technician not present during the inspection. They should confirm that all required general information fields are complete, the GPS asset location is consistent with the route and milepost entries, photographs are sufficient in number and quality to support the recorded ratings, component ratings are internally consistent, and any adjusted overall ratings or follow-up flags are accompanied by documented rationale. Records failing QA review should be returned to the responsible inspector for correction before being finalized in the geodatabase. A log of QA actions should be maintained as part of the asset record to support future program audits.

USE OF COLLECTED DATA

Data collected through the procedures described support the subsequent steps of the Illinois GAM workflow. Individual asset condition scores and component ratings feed the asset-level and family-level performance metrics introduced in Chapter 2 (Step 4). The condition data also serve as the primary input to the risk assessment procedures described in Chapter 4, where assets are evaluated against probability and consequence scales to support project prioritization. The numerical condition scores accumulated over multiple inspection cycles provide the dataset required to fit and refine the deterioration models presented in Chapter 5. Given the limited historical inspection data currently available for Illinois geotechnical assets, the data collected through the procedures in this chapter will be foundational to the long-term development of agency-specific performance models and to demonstrating the return on investment of the GAM program.

CHAPTER 4: RISK ASSESSMENT AND MANAGEMENT

RISK AND UNCERTAINTY

Risk evaluation and management are integral parts of the entire geotechnical asset management (GAM) program and will be incorporated in multiple steps. As mentioned in Chapter 2, the simplest definition of risk is *the impact of uncertainty on objectives.* The primary objective is to maintain geotechnical assets and the assets they support in acceptable condition, or in a good state of repair, to serve their intended purpose in the network and maximize agency and user benefits. Uncertainty in this framework encompasses a wide range of possible components, from random events to variable conditions and varying planning activities. The focus, however, should be on uncertainties and the associated risks that can be measured and/or managed and mitigated. Some common and critical sources of uncertainty include:

- Random processes and conditions or stressors and asset responses, such as uncertain disruptive events, and instability or damage to the assets corresponding to these events. That randomness in many cases is due to the complexity of these events and the asset response, leading to chaotic behavior. An example can be floods or repeated rain events and their impact triggering progressive failure of geotechnical assets.

- Spatial and temporal variability in the asset condition with limited data to characterize that variability or models describing its behavior to allow for accurate forecast and prediction. The variability can be built in the asset during construction, such as compaction of earth-retaining system (ERS) backfills, or due to natural variability, such as spatial variability in soil characteristics and underground condition of a slope. Other sources of variability can be the varying degradation rates of structural elements, such as corrosion of mechanically stabilized earth (MSE) walls reinforcement, which significantly vary depending on the local surrounding conditions.

- Uncertainty of future budgets, changes in asset management goals, project prioritization and construction planning, available human resources and knowledge management issues, and performance requirements. These uncertainties can have a significant impact on agencies' ability to maintain assets due to shifting priorities or practical constraints, leading to delayed maintenance and worsening asset conditions.

RISK MANAGEMENT

Risk management can be generally defined as the practice of identifying and analyzing risk sources and the planning and organization required to control or minimize their consequences. As mentioned in Chapter 2, risk management can incorporate qualitative, semi-quantitative, or quantitative analysis approaches. Risk analysis provides an estimation of the probability (or likelihood) of a disruptive event, including accelerated deterioration, occurrence, and the corresponding consequences of that event on the agency and users.

The risk management process can be summarized in six major stages (Figure 18). The circular layout emphasizes that risk management is a continuous and iterative process, with each step feeding into the next.

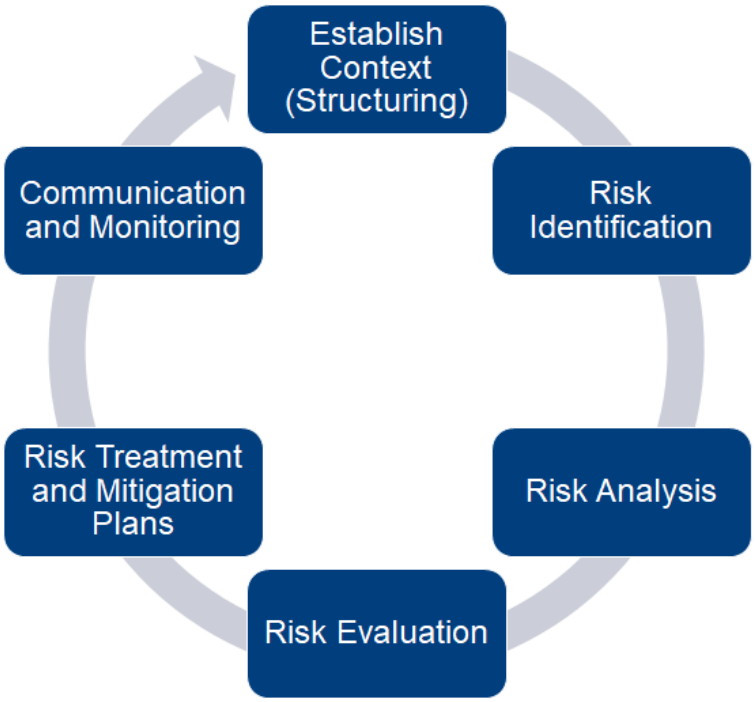


Figure 18. Flowchart. Risk management process.

Source: Modified from FHWA (2017)

The process outlined in Figure 18 can be applied systematically by following the 13 steps described in the following sections. This framework is modified from the Strategic Highway Research Program 2 project "Managing Risk in Rapid Renewal Projects" (NCHRP, 2012). Figure 19 presents a screenshot of the risk management tool developed for this project to facilitate implementation of the risk management process. The steps can be applied for either asset-level and asset family-level assessment and management and fed into the overall GAM program-level risk assessment and management. Moreover, the steps can be adapted for qualitative, semi-quantitative, and quantitative or probabilistic approaches. However, the tool is focused on qualitative and semi-quantitative analysis. The inputs and values shown in the figures within the risk management steps are illustrative and do not represent actual measurements or recommended estimates.

Risk management is an iterative process and requires participation and input from different groups and stakeholders within an agency. It is recommended to maintain multiple versions of the same analysis as new input is incorporated. Moreover, it is recommended that the GAM team conduct risk management workshops regularly to update the risk register and identify new risks as well as revise and update risk levels as new data become available. During these workshops, the team should also revise and update mitigation strategies and their effectiveness as well as DOT priorities and objectives.

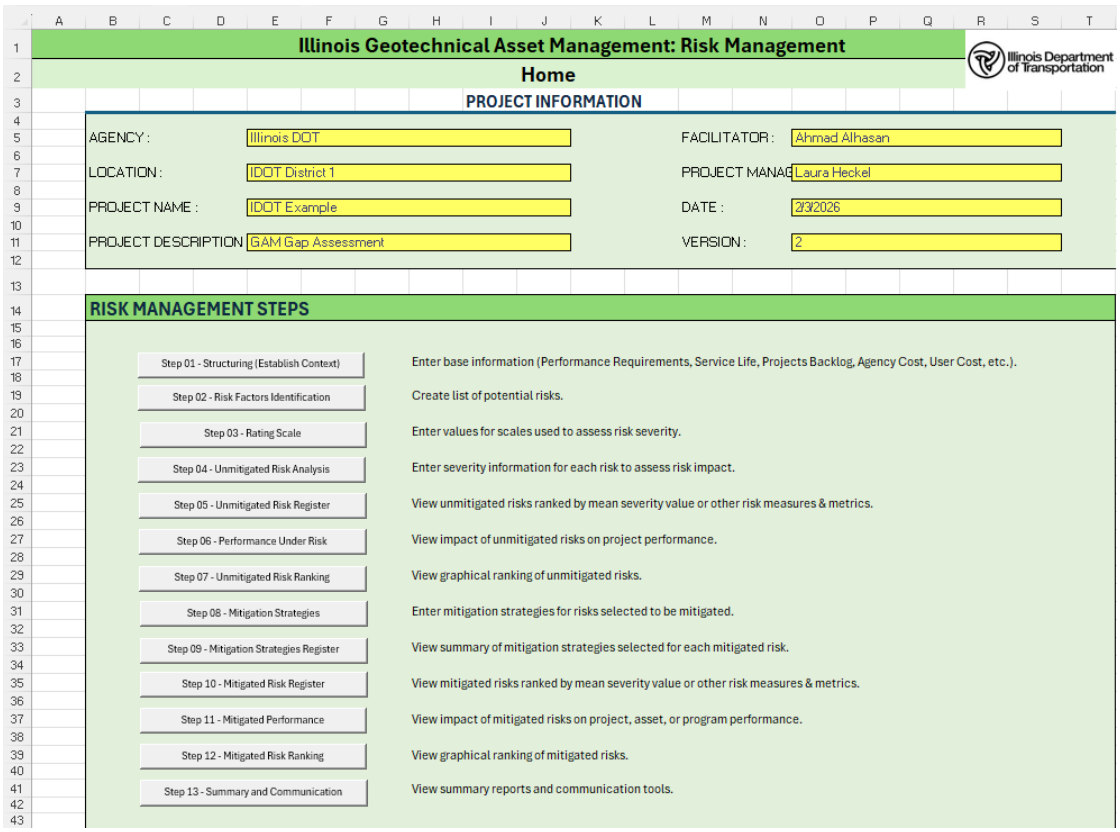
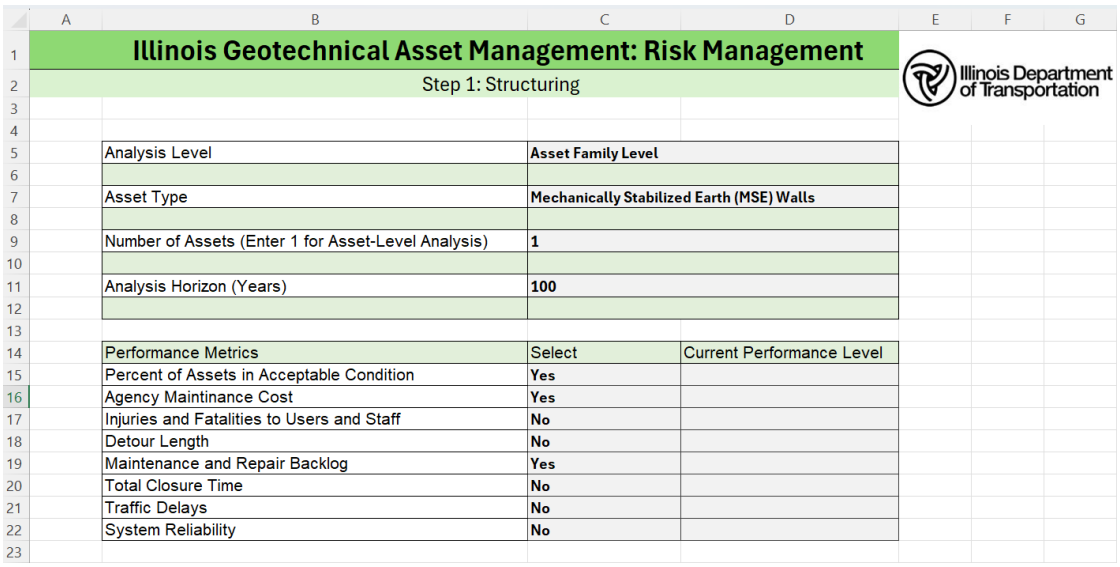


Figure 19. Screenshot. Risk management tool cover page.

Step 1: Structuring (Establishing Context)

This step defines the basic information related to risk assessment and management. As shown in Figure 20, this step defines the analysis level, asset types under consideration, analysis period (also referred to as the analysis horizon), and performance metrics under consideration and their current values. The selection of performance metrics is critical to rank the risks by their likelihood and consequences based on preferred metrics. Some performance metrics may be measured at the individual-asset level to estimate a network-level distribution or metric such as the distribution of assets' condition rating. In that case, knowing the current distribution allows for more accurate future forecasting of the network performance over the analysis period.



Illinois Geotechnical Asset Management: Risk Management

Step 1: Structuring

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Analysis Level	**Asset Family Level**
Asset Type	**Mechanically Stabilized Earth (MSE) Walls**
Number of Assets (Enter 1 for Asset-Level Analysis)	**1**
Analysis Horizon (Years)	**100**

Performance Metrics	Select	Current Performance Level
Percent of Assets in Acceptable Condition	**Yes**	
Agency Maintinance Cost	**Yes**	
Injuries and Fatalities to Users and Staff	**No**	
Detour Length	**No**	
Maintenance and Repair Backlog	**Yes**	
Total Closure Time	**No**	
Traffic Delays	**No**	
System Reliability	**No**	

Figure 20. Screenshot. Step 1 sheet from the risk management tool.

Step 2: Risk Factors Identification

Risk identification provides a general and comprehensive list of all potential risk factors that can impact the individual asset, asset family, and GAM program at large. Risk factors are the events or sequence of events and processes that impact the condition or functionality of an asset. It is recommended to create a list of independent risk factors using the risk management tool shown in Figure 21; however, some factors may be interrelated. Moreover, if the risk has been handled in previous analysis or accepted without the need for further analysis it can be retired and excluded from further analysis and prioritization.

Generally, risk factors can be grouped under one of three categories: intrinsic, extrinsic, and operational risks. The list below provides some common risk factors in each category that can be considered in early implementation activities. The provided categories and lists are not comprehensive and can be revised and updated.

- **Intrinsic Risk**—related to uncertainties in the asset behavior due to changes or deviation in the asset conditions and performance due to deterioration or variation from the assumed conditions during its design and construction. Some examples include:
  - Poor drainage
  - Accelerated corrosion and deterioration of reinforcements and stabilizing elements
  - Erosion, scour, and fines migration
  - Poor construction leading to deviations in the as-built conditions from design
- **Extrinsic Risk**—related to uncertainties of the surrounding conditions or disruptive events that impact asset conditions and performance. Some examples include:

- Adjacent construction impacts on the asset
- Floods, wildfires, and other climate-related disruptive events
- Frequent heavy rain and other high-frequency climate stressors
- Vehicle collision and impact loads
- Changes in loading conditions or surrounding environmental conditions

- **Operational Risks**—encompasses all non-physical risk factors and stressors that can impact an agency's ability to maintain assets in acceptable or target conditions and performance. Some examples include:
  - Lack of funding
  - Staff shortage
  - Changing IT requirements and challenges to implement tools
  - Knowledge management challenges due to loss of data and records or changes in staff
  - Shifting requirements and priorities
  - Limited local specialty consultants and contractors to execute projects

Illinois Geotechnical Asset Management: Risk Management

Step 2: Risk Factors Identification

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Risk Label	Description of Risk	Retire
I-1	Poor Drainage	No
I-2	Corrosion and deterioration of reinforcements or facing and wall components	No
I-3	Time-related changes in geomaterial and foundation material support	Yes
I-4	Poor Backfill Compaction	No
I-5	Foundations Erosion and Scour	No
E-1	Flood and drought cycles	Yes
O-1	Staff Shortage	No
O-2	IT Requirements	No

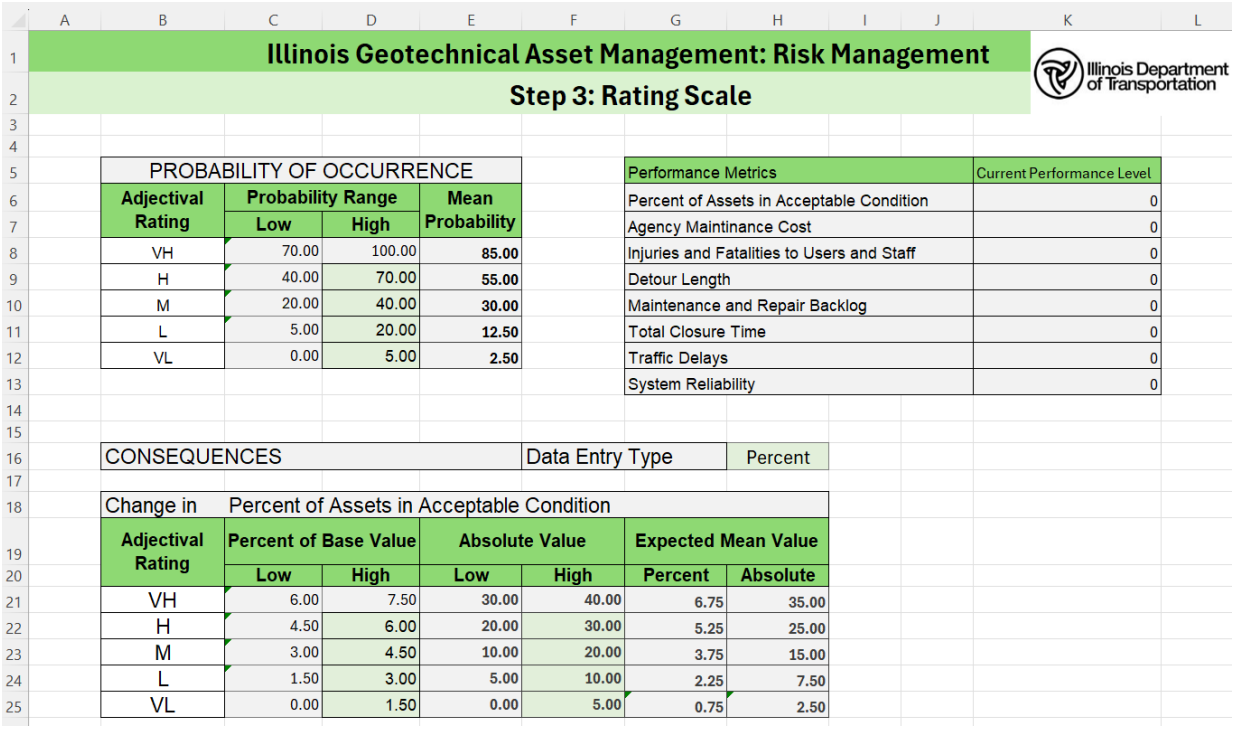
Figure 21. Screenshot. Step 2 sheet from the risk management tool.

Step 3: Rating Scale

Once the risk factors are identified, a rating scale is established to quantify the probability of these risk factors occurring and their consequences on the selected performance metrics, as shown in Figure 22. The scale defined in this step can be replaced with direct numerical inputs in Step 4. This step facilitates the estimation of occurrence probabilities and the impact levels on performance metrics if no data are available or only a wide range of inputs can be evaluated. It is recommended that the scale be developed following the Delphi method by soliciting input from a panel of technical experts during the risk management workshop. The rating scale for the performance metrics can be expressed as a percentage change or an absolute value change from the baseline conditions at the

end of the analysis period. The use of percentage change can be easier to estimate since the absolute value requires more accurate data from the network and historical records.

When developing the rating scale, it is important to consider the analysis level. For example, performing risk evaluation for an individual asset showing significant deterioration levels, supporting a critical road segment with high traffic levels, and near a flood vulnerable area will have a stricter rating scale with higher probability of occurrence and more significant consequences compared to a typical asset in the network. Alternatively, a network-level analysis should consider the population and use the mean values representing that population.



Illinois Geotechnical Asset Management: Risk Management

Step 3: Rating Scale

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PROBABILITY OF OCCURRENCE			
Adjectival Rating	Probability Range		Mean Probability
	Low	High	
VH	70.00	100.00	**85.00**
H	40.00	70.00	**55.00**
M	20.00	40.00	**30.00**
L	5.00	20.00	**12.50**
VL	0.00	5.00	**2.50**

Performance Metrics	Current Performance Level
Percent of Assets in Acceptable Condition	0
Agency Maintinance Cost	0
Injuries and Fatalities to Users and Staff	0
Detour Length	0
Maintenance and Repair Backlog	0
Total Closure Time	0
Traffic Delays	0
System Reliability	0

CONSEQUENCES	Data Entry Type	Percent

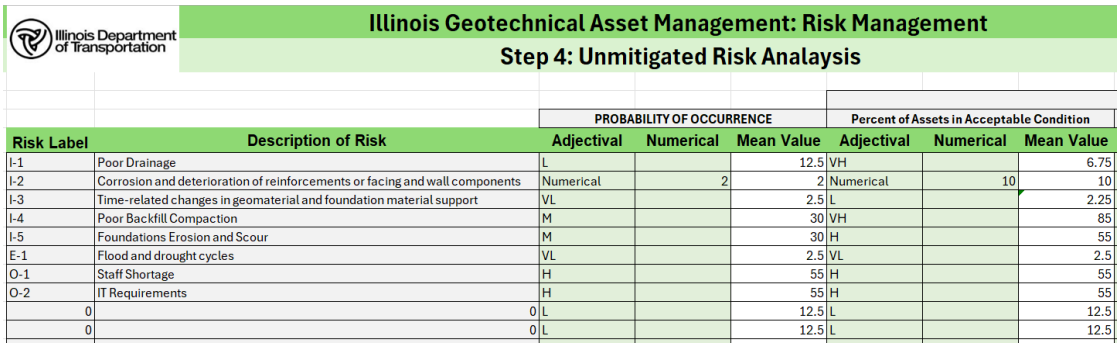
Change in	Percent of Assets in Acceptable Condition					
Adjectival Rating	Percent of Base Value		Absolute Value		Expected Mean Value	
	Low	High	Low	High	Percent	Absolute
VH	6.00	7.50	30.00	40.00	6.75	35.00
H	4.50	6.00	20.00	30.00	5.25	25.00
M	3.00	4.50	10.00	20.00	3.75	15.00
L	1.50	3.00	5.00	10.00	2.25	7.50
VL	0.00	1.50	0.00	5.00	0.75	2.50

Figure 22. Screenshot. Step 3 sheet from the risk management tool.

Step 4: Unmitigated Risk Analysis

Risk analysis can be qualitative, semi-quantitative, or quantitative. The tool in this framework implements a semi-quantitative technique, as illustrated in Figure 23. The probability of occurrence and consequence impacts are based on the rating scale defined in Step 3 or by entering numerical values estimated from the Delphi method or quantitative analysis.

The analysis uses mean values for the occurrence probabilities and consequences. A more complete analysis will require probability distributions for the risk factors occurrence and a corresponding response function describing the consequences for different severity levels of the risk factors. A detailed analysis will provide a complete probability distribution of the consequences, which can then be used to estimate a range of risk summary measures. The use of mean values is a reasonable starting point for risk management implementation; however, it is limited due to the assumptions underlying the definitions and limited available data.



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Illinois Geotechnical Asset Management: Risk Management

Step 4: Unmitigated Risk Analysis

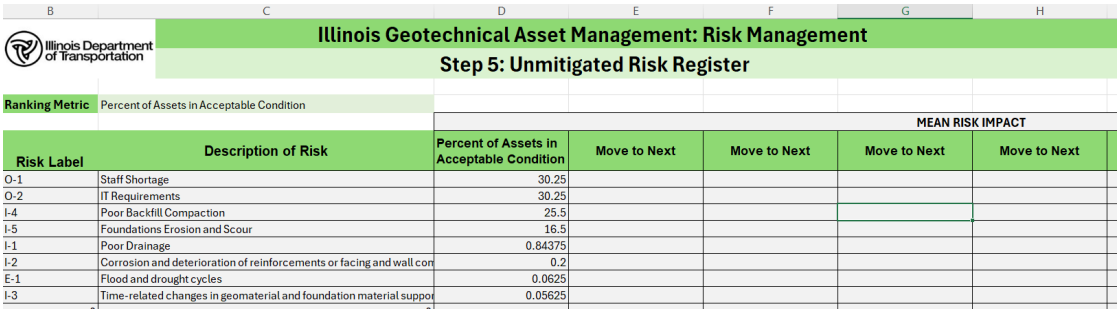
		PROBABILITY OF OCCURRENCE			Percent of Assets in Acceptable Condition		
Risk Label	Description of Risk	Adjectival	Numerical	Mean Value	Adjectival	Numerical	Mean Value
I-1	Poor Drainage	L		12.5	VH		6.75
I-2	Corrosion and deterioration of reinforcements or facing and wall components	Numerical	2	2	Numerical	10	10
I-3	Time-related changes in geomaterial and foundation material support	VL		2.5	L		2.25
I-4	Poor Backfill Compaction	M		30	VH		85
I-5	Foundations Erosion and Scour	M		30	H		55
E-1	Flood and drought cycles	VL		2.5	VL		2.5
O-1	Staff Shortage	H		55	H		55
O-2	IT Requirements	H		55	H		55
0	0	L		12.5	L		12.5
0	0	L		12.5	L		12.5

Figure 23. Screenshot. Step 4 sheet from the risk management tool.

Step 5: Unmitigated Risk Register

This step summarizes the risks and ranks them using mean risk impact values, which are defined as the product of the mean probability of occurrence and the mean consequences, as shown in Figure 24. This definition is a simplified statistical measure assuming independence of the risks and uniform event severity and consequences. These assumptions can be applicable for simple ranking analysis, typically referred to as uninformed distribution when there are no or limited historical records.

The analysis in Steps 4 and 5 will require future improvements and updates as additional data are provided to capture the proper probability distributions and the range of impacts. Accurate estimations will be critical for budgeting and planning activities beyond relative risk ranking.



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Illinois Geotechnical Asset Management: Risk Management

Step 5: Unmitigated Risk Register

Ranking Metric Percent of Assets in Acceptable Condition

			MEAN RISK IMPACT			
Risk Label	Description of Risk	Percent of Assets in Acceptable Condition	Move to Next	Move to Next	Move to Next	Move to Next
O-1	Staff Shortage	30.25				
O-2	IT Requirements	30.25				
I-4	Poor Backfill Compaction	25.5				
I-5	Foundations Erosion and Scour	16.5				
I-1	Poor Drainage	0.84375				
I-2	Corrosion and deterioration of reinforcements or facing and wall con	0.2				
E-1	Flood and drought cycles	0.0625				
I-3	Time-related changes in geomaterial and foundation material suppor	0.05625				

Figure 24. Screenshot. Step 5 sheet from the risk management tool.

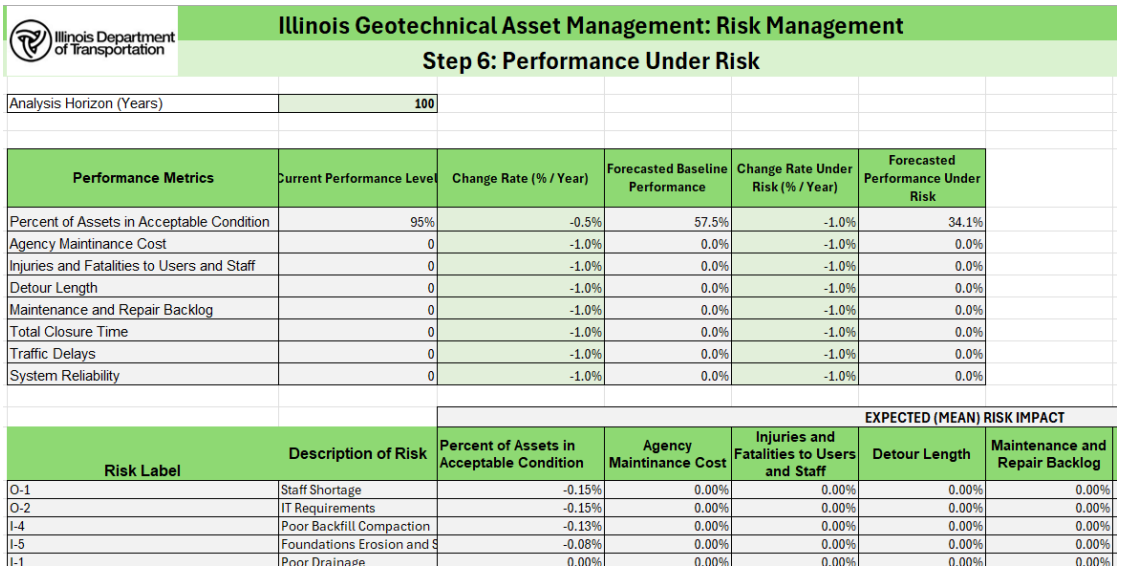
Step 6: Performance Under Risk

The performance of the asset(s) included in the analysis is evaluated over the analysis period as shown in Figure 25. Performance is modeled by forecasting the selected metrics with a simple change rate model. Additional detailed deterioration models are described in Chapter 5. Use of the simple power law or a linear trend can be sufficient for an overall risk estimate. The future forecast using the baseline scenario should incorporate the typical current maintenance level or the typical operational conditions expected throughout the period.

The impact of risk on performance over time is estimated based on the evaluated mean risk impact on the different performance metrics. The mean risk impact is expressed as a percentage change in performance metrics from the baseline. Forecasted performance includes the performance metrics at

the end of the analysis period accounting for the combined effects of all risks. The difference between the baseline forecast and the forecast under risk is the mean loss in performance.

The numbers shown in Figure 25 and previous steps are illustrative and do not represent actual measurements or recommended estimates.



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Illinois Geotechnical Asset Management: Risk Management

Step 6: Performance Under Risk

Analysis Horizon (Years)	100

Performance Metrics	Current Performance Level	Change Rate (% / Year)	Forecasted Baseline Performance	Change Rate Under Risk (% / Year)	Forecasted Performance Under Risk
Percent of Assets in Acceptable Condition	95%	-0.5%	57.5%	-1.0%	34.1%
Agency Maintinance Cost	0	-1.0%	0.0%	-1.0%	0.0%
Injuries and Fatalities to Users and Staff	0	-1.0%	0.0%	-1.0%	0.0%
Detour Length	0	-1.0%	0.0%	-1.0%	0.0%
Maintenance and Repair Backlog	0	-1.0%	0.0%	-1.0%	0.0%
Total Closure Time	0	-1.0%	0.0%	-1.0%	0.0%
Traffic Delays	0	-1.0%	0.0%	-1.0%	0.0%
System Reliability	0	-1.0%	0.0%	-1.0%	0.0%

		EXPECTED (MEAN) RISK IMPACT				
Risk Label	Description of Risk	Percent of Assets in Acceptable Condition	Agency Maintinance Cost	Injuries and Fatalities to Users and Staff	Detour Length	Maintenance and Repair Backlog
O-1	Staff Shortage	-0.15%	0.00%	0.00%	0.00%	0.00%
O-2	IT Requirements	-0.15%	0.00%	0.00%	0.00%	0.00%
I-4	Poor Backfill Compaction	-0.13%	0.00%	0.00%	0.00%	0.00%
I-5	Foundations Erosion and S	-0.08%	0.00%	0.00%	0.00%	0.00%
I-1	Poor Drainage	0.00%	0.00%	0.00%	0.00%	0.00%

Figure 25. Screenshot. Step 6 sheet from the risk management tool.

Step 7: Unmitigated Risk and Performance Plots

This step provides a visual representation of the identified risk factors in terms of their impact on the selected performance indices, as presented in Figure 26. The graphic to the right compares the drop in performance over time for three cases: the baseline with no risks included, the three most impactful risks, and the combined impact of all risks. This plot provides the ability to visualize the total benefit gained from reducing risks, which can be represented as the area between the baseline performance curve and the performance curve including the risk.

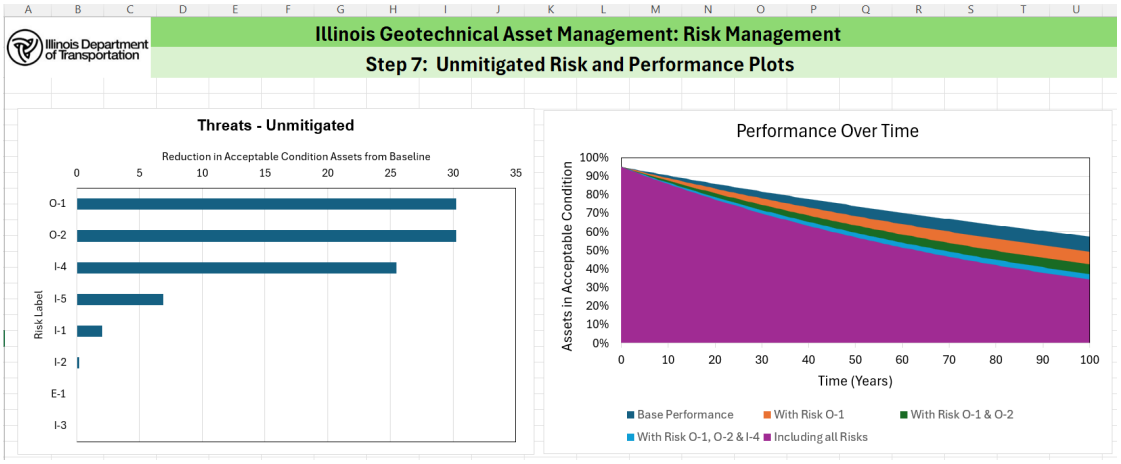
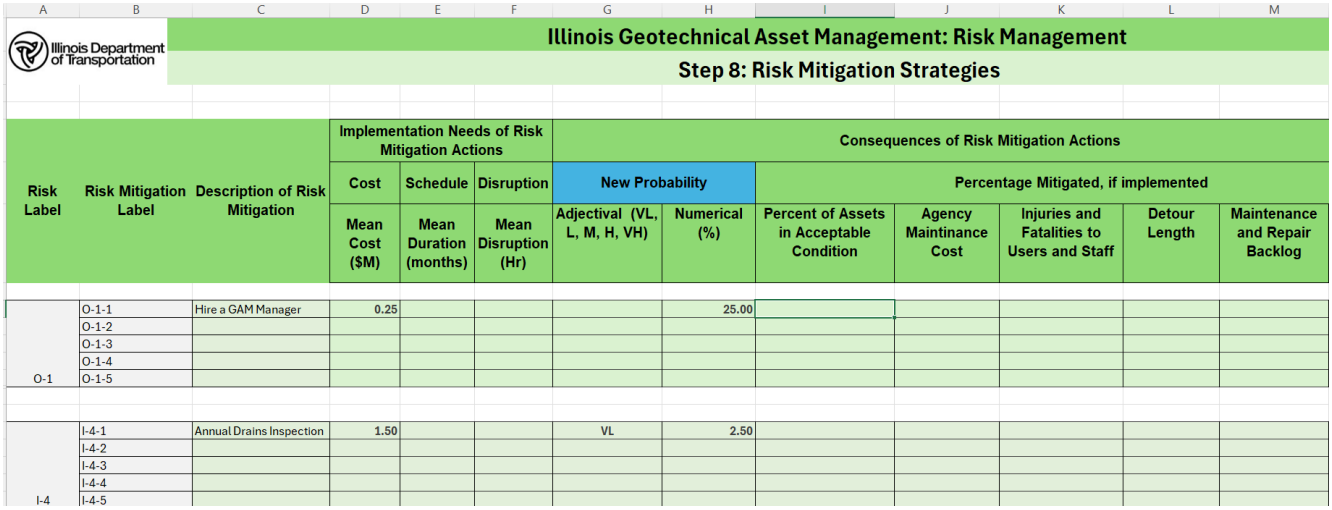


Figure 26. Screenshot. Step 7 sheet from the risk management tool.

Step 8: Risk Mitigation Strategies

Several strategies can be evaluated to mitigate each risk, as illustrated in Figure 27. Each proposed strategy will have a corresponding impact on probability, consequences, or both. For example, hiring additional staff will reduce the probability of staff shortage but will not reduce the impact of consequences, unless the hired staff improve the process since the consequences assume that the risk factor occurred. Alternatively, some strategies can help reduce the consequences and not necessarily the probability of occurrence. For example, improving slope catchment areas or installing barriers will help reduce the consequences, especially safety, but may not necessarily impact the probability of occurrence. In addition to estimating the impact of mitigation strategies, the implementation needs are evaluated in this step, including direct cost, human resources, and other factors.



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Illinois Geotechnical Asset Management: Risk Management

Step 8: Risk Mitigation Strategies

Risk Label	Risk Mitigation Label	Description of Risk Mitigation	Implementation Needs of Risk Mitigation Actions			Consequences of Risk Mitigation Actions						
			Cost	Schedule	Disruption	New Probability		Percentage Mitigated, if implemented				
			Mean Cost ($M)	Mean Duration (months)	Mean Disruption (Hr)	Adjectival (VL, L, M, H, VH)	Numerical (%)	Percent of Assets in Acceptable Condition	Agency Maintinance Cost	Injuries and Fatalities to Users and Staff	Detour Length	Maintenance and Repair Backlog
O-1	O-1-1	Hire a GAM Manager	0.25				25.00					
	O-1-2											
	O-1-3											
	O-1-4											
	O-1-5											
I-4	I-4-1	Annual Drains Inspection	1.50			VL	2.50					
	I-4-2											
	I-4-3											
	I-4-4											
	I-4-5											

Figure 27. Screenshot. Step 8 sheet from the risk management tool.

Step 9: Mitigation Strategies Register

Once all strategies are identified, they will be summarized based on their impact on probabilities and consequences, as shown in Figure 28, and ranked based on their risk reduction as a percentage of the total risk. If multiple strategies are applied, especially to the same risk factor, the impacts may need some reduction coefficient due to the correlation and dependencies between these mitigation strategies. For example, the need for robust software tools and improved IT processes may not be as critical if proper staff can improve communication and processes. Therefore, hiring additional staff may also mitigate some IT risks.

Mitigation strategy effectiveness can be evaluated using a benefit-cost ratio in addition to the risk reduction in performance measures. The estimation of benefits should consider multiple components and estimation of both monetary and non-monetary benefits in the long term. For example, maintaining a higher percentage of assets in acceptable condition with preventive maintenance will lead to reduced rehabilitation and major maintenance costs, less disruption, and improved safety in the long term. In this step, the feasible mitigation strategies with highest impacts can be selected and responsibilities assigned to ensure their effective executions.

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Illinois Geotechnical Asset Management: Risk Management

Step 9: Mitigation Strategies Register

Risk Label	Risk Description	Risk Mitigation Label	Description of Risk Mitigation	Implementation Needs of Risk Mitigation Actions			Consequences of Risk Mitigation Actions							
				Cost	Schedule	Disruption	New Probability		Percentage Mitigated, if implemented					
				Mean Cost ($M)	Mean Duration (months)	Mean Disruption (Hr)	Adjectival (VL, L, M, H, VH)	Numerical (%)	Percent of Assets in Acceptable Condition	Agency Maintinance Cost	Injuries and Fatalities to Users and Staff	Detour Length	Maintenance and Repair Backlog	
O-1	Staff Shortage	O-1-1	Hire a GAM Manager											
I-1	Poor Drainage	I-4-1	Annual Drains Inspection											

Figure 28. Screenshot. Step 9 sheet from the risk management tool.

Step 10: Mitigated Risk Register

This step provides an updated risk register after applying risk mitigation strategies, as shown in Figure 29. This allows users to assess the residual risks and the ranking of the remaining risk factors in future evaluations.

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Illinois Geotechnical Asset Management: Risk Management

Step 10: Mitigated Risk Register

Chart Area

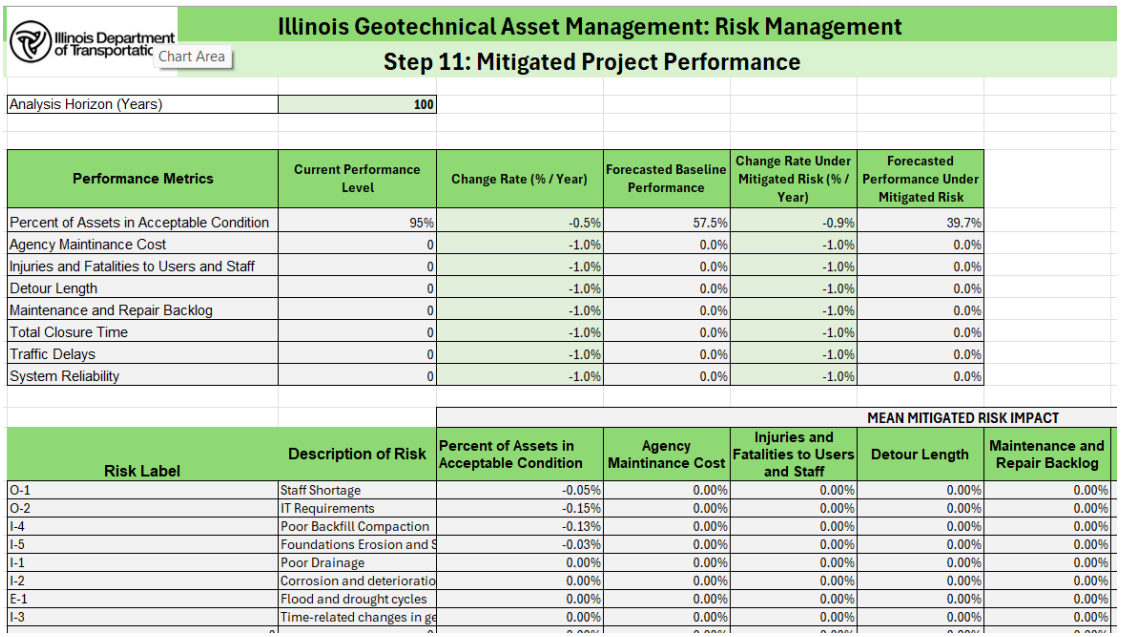
Ranking Metric Percent of Assets in Acceptable Condition

		MEAN MITIGATED RISK IMPACT				
Risk Label	Description of Risk	Percent of Assets in Acceptable Condition	Move to Next	Move to Next	Move to Next	Move to Next
O-2	IT Requirements	30.25				
I-4	Poor Backfill Compaction	25.50				
O-1	Staff Shortage	13.75				
I-5	Foundations Erosion and Scour	6.88				
I-2	Corrosion and deterioration of reinforcements or facing and wall con	0.20				
I-1	Poor Drainage	0.17				
E-1	Flood and drought cycles	0.06				
I-3	Time-related changes in geomaterial and foundation material suppor	0.06				

Figure 29. Screenshot. Step 10 sheet from the risk management tool.

Step 11: Mitigated Project Performance

This step provides an update to project performance evaluated over the analysis period, as shown in Figure 30. The performance is modeled by forecasting the selected metrics with a simple change rate model. The impact of risk on performance is evaluated after applying the mitigation strategies. The ranking and impacts of risk will shift based on the applied mitigation strategies.



Illinois Department of Transportation

Chart Area

Illinois Geotechnical Asset Management: Risk Management

Step 11: Mitigated Project Performance

Analysis Horizon (Years)	100

Performance Metrics	Current Performance Level	Change Rate (% / Year)	Forecasted Baseline Performance	Change Rate Under Mitigated Risk (% / Year)	Forecasted Performance Under Mitigated Risk
Percent of Assets in Acceptable Condition	95%	-0.5%	57.5%	-0.9%	39.7%
Agency Maintinance Cost	0	-1.0%	0.0%	-1.0%	0.0%
Injuries and Fatalities to Users and Staff	0	-1.0%	0.0%	-1.0%	0.0%
Detour Length	0	-1.0%	0.0%	-1.0%	0.0%
Maintenance and Repair Backlog	0	-1.0%	0.0%	-1.0%	0.0%
Total Closure Time	0	-1.0%	0.0%	-1.0%	0.0%
Traffic Delays	0	-1.0%	0.0%	-1.0%	0.0%
System Reliability	0	-1.0%	0.0%	-1.0%	0.0%

		MEAN MITIGATED RISK IMPACT				
Risk Label	Description of Risk	Percent of Assets in Acceptable Condition	Agency Maintinance Cost	Injuries and Fatalities to Users and Staff	Detour Length	Maintenance and Repair Backlog
O-1	Staff Shortage	-0.05%	0.00%	0.00%	0.00%	0.00%
O-2	IT Requirements	-0.15%	0.00%	0.00%	0.00%	0.00%
I-4	Poor Backfill Compaction	-0.13%	0.00%	0.00%	0.00%	0.00%
I-5	Foundations Erosion and S	-0.03%	0.00%	0.00%	0.00%	0.00%
I-1	Poor Drainage	0.00%	0.00%	0.00%	0.00%	0.00%
I-2	Corrosion and deterioratio	0.00%	0.00%	0.00%	0.00%	0.00%
E-1	Flood and drought cycles	0.00%	0.00%	0.00%	0.00%	0.00%
I-3	Time-related changes in ge	0.00%	0.00%	0.00%	0.00%	0.00%

Figure 30. Screenshot. Step 11 sheet from the risk management tool.

Step 12: Mitigated Risk Project Performance Plots

This step provides a visual representation of the ranked risk factors following mitigation in terms of their impact on the selected performance indices for assets in acceptable condition, as shown in Figure 31. These plots visualize the total benefit gained from reducing risks, which can be represented as the area between the baseline performance curve and the performance curve including the risk.

Step 13: Summary and Communications

The tool provides a wide range of tables and plots related to performance measures aligned with agency objectives and TAM metrics. These tables are summarized to provide an effective communication tool that illustrates the benefits of the GAM program and the risks due to a limited proactive GAM program.

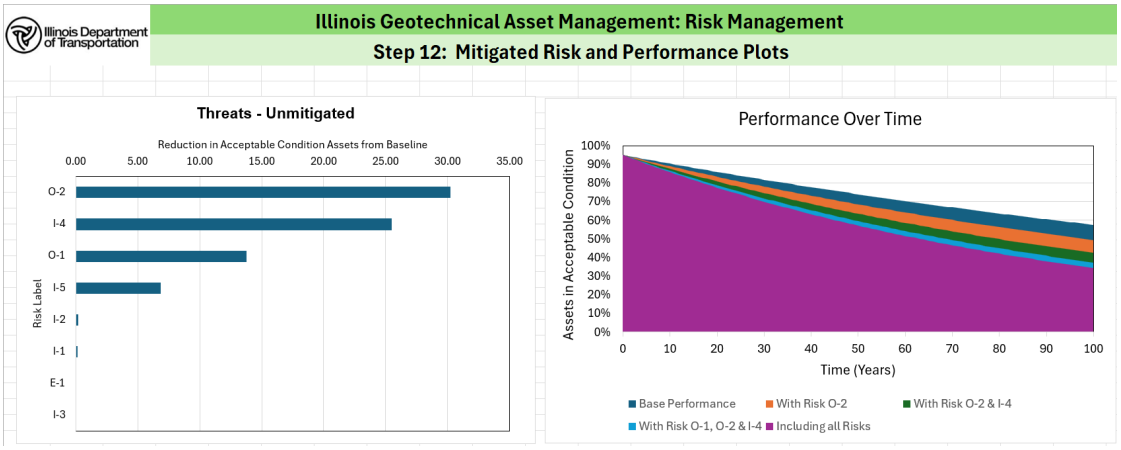


Figure 31. Screenshot. Step 12 sheet from the risk management tool.

CHAPTER 5: DETERIORATION MODELS

Deterioration models are mathematical models that describe the change in asset condition over time. These models can be deterministic or probabilistic. Deterministic models typically assume a continuous and predictable deterioration trend if all variables are captured and modeled properly, as illustrated in the left graph in Figure 32. When fitting deterministic models with empirical observations, they will not be free of variability. The assumption, however, is that the variability is minimal and can be described as randomness around the fitted trend due to measurement uncertainty or lack of observations for some variables. These models are effective to assess deterioration of measurable physical quantities with relatively understood mechanistic behavior (Madanat et al. 1995). Moreover, the models can provide a baseline to estimate the change in average condition rating of a population of assets for planning purposes.

In contrast, probabilistic models estimate the probability distribution of the asset condition over time. These models are well suited to describe the condition rating of geotechnical assets due to the discrete condition rating system described in Chapter 3. A discrete rating system has greater uncertainty due to its holistic nature and variations in the inspection process between inspectors (Madanat et al. 1995, Piratla et al. 2017). One commonly used deterioration model in transportation infrastructure asset management, including geotechnical assets, is the Markov Chain Model (Cesare et al. 1992). Discrete Markov models represent the possible condition ratings as different states an asset can have at a given time and transition probability matrices to describe the deterioration rate, as illustrated in the graph to the right in Figure 32. One limitation of typical Markov models with time-independent transition probabilities is their inability to account for asset age or the time the asset performs in a specific condition state. Despite this limitation, Markov models provide a solution for deterioration modeling for asset management applications and can be improved using time-dependent transition probability matrices.

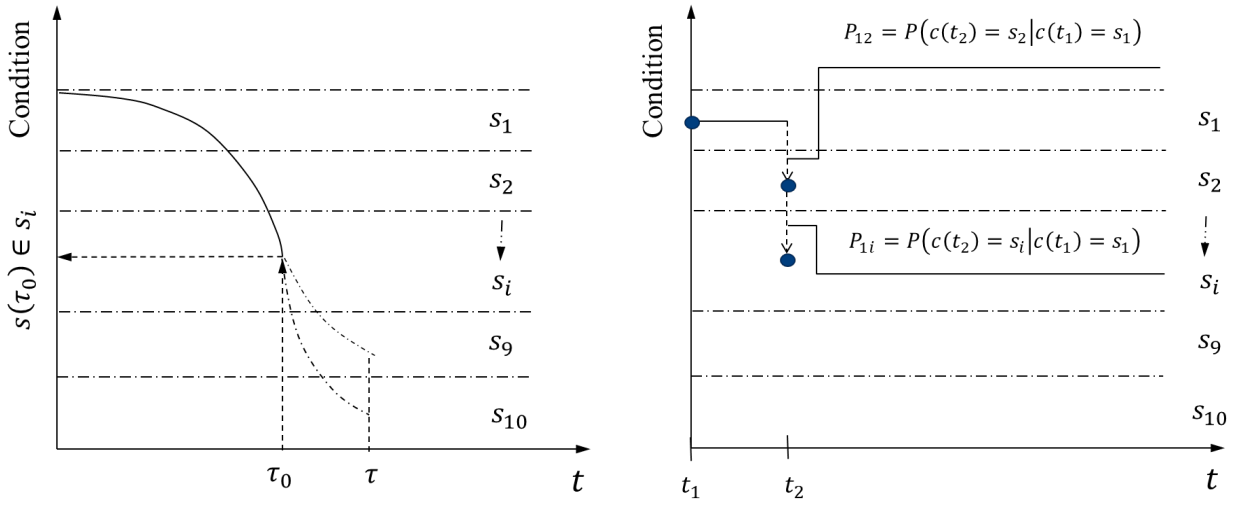


Figure 32. Schematic. Continuous deterioration in asset conditions over time (left) and a discrete representation of change in the asset condition state over time (right).

DATA PREPROCESSING AND QUALITY ASSURANCE

As introduced in Chapter 2, geotechnical assets will be assigned a unique identification number (ID). Maintaining a clear and traceable record of the IDs and updates to the naming convention is critical to create time records for assets' condition. The next step after exporting condition data records is to restructure and preprocess the data. To use the data in the deterioration modeling tool, the records for individual assets should be organized consecutively from the earliest inspection year to the most recent. These records should include the unique asset ID, which captures the asset type, inspection year, condition rating on the numerical or condition state scale, and age of the asset. Identifying the age could be a challenge for natural or some modified slopes that do not have a clear construction date. In this case, independent models can be used as we will discuss within the Markov deterioration models section. It is also important to identify improvements in condition due to major maintenance and reconstruction activities. Evaluating maintenance effectiveness is an important aspect of deterioration modeling but requires detailed records over time to assess these impacts. Other challenges can include missing condition rating records, variability due to different inspectors and inspection conditions over time, and changes in condition rating scales and procedures.

DETERIORATION MODELING TOOL

A tool was developed to facilitate fitting and use of deterioration models, as shown in Figure 34. The tool requires data input structured as described in the previous section. The models discussed in this report are linear and exponential functions under deterministic models and Markov models under probabilistic models. Other models could be explored in the future when additional data are available. It is recommended that deterioration modeling be performed for a group of assets. The group can be an asset family or a subset of the asset family with similar characteristics such as size, loading conditions, geomaterials properties, or other characteristics expected to have an impact on asset performance.

Linear Deterioration Model

Both linear and exponential functions are deterministic models capturing the change in condition rating over time. These models require an age input, which is defined as the time since construction or the latest major rehabilitation or modification for natural slopes. The same process can also be used to quantify the deterioration of individual asset elements—for example, protection elements installed on natural rock slopes, which have a clearer age definition. The equation in Figure 33 represents a linear model describing the condition rating *CR* at a given age *t*, as a function of the average condition rating at construction CR_{con} for the asset group minus the annual deterioration rate β. The equation also includes a variable term ϵ, which represents the variability in the condition group ratings from the predicted mean line $CR_{\mathrm{Con}} - \beta\ t$. The mean line can be approximated as the average condition rating of the group at a given age.

$$CR = CR_{\mathrm{Con}} - \beta\ t + \epsilon$$

Figure 33. Equation. Linear deterioration model of condition rating.

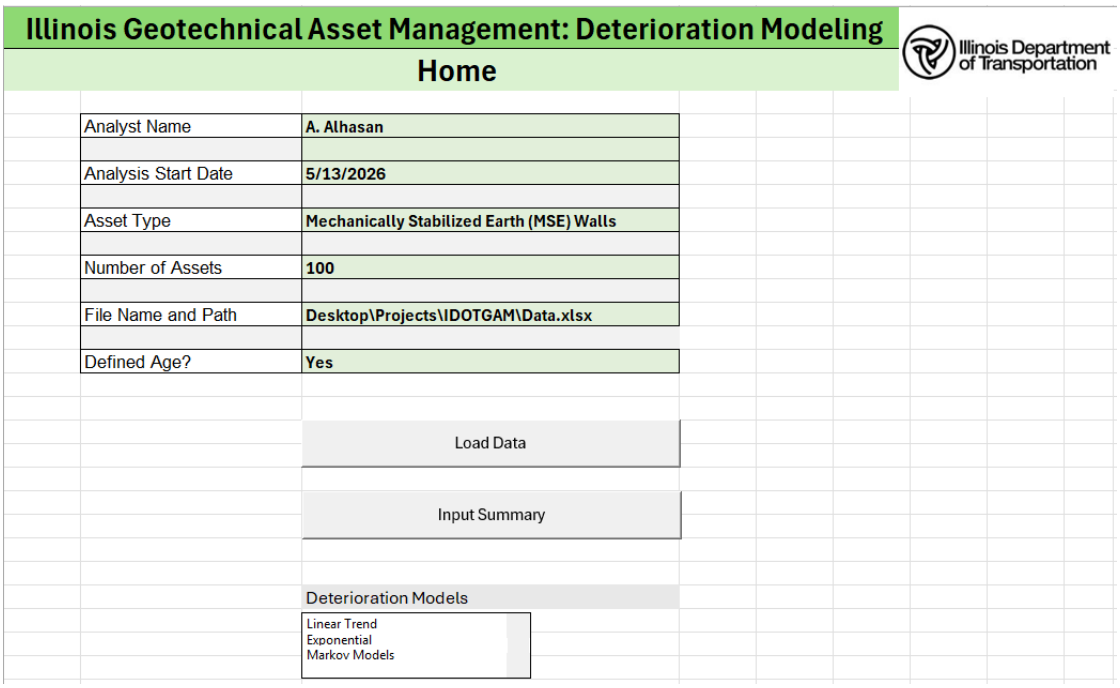


Figure 34. Screenshot. Deterioration modeling tool home page.

Fitting the linear model in Figure 33 includes several assumptions, including the continuous numerical scale for the average rating. Therefore, it is recommended to use the numerical scale developed to summarize the performance ratings, as discussed in Chapter 3. For rock slopes, the condition state element score can be used for deterioration modeling. Alternatively, if only condition states are available (poor to good or very poor to very good), the states can be represented by discrete condition scores from 1 to 5, where 1 is the lowest condition state. Using this discrete condition score scale, the average condition scores for the group at a given age can have any value within the scale boundaries.

Based on the lack of condition rating data available for geotechnical assets in Illinois, the baseline deterioration model can be assumed to begin at the maximum condition rating or condition score at age zero and drop to the lowest condition rating or score at the end of its design life. For example, the lowest condition state for MSE walls is very poor, corresponding to a condition score of 1.

Example Implementation: Linear Deterioration Model

To illustrate implementation of linear deterioration modeling, synthetic data were generated for 100 MSE walls with 25 years of inspection records, capturing the assets between age 50 to 75 years. The data were generated to follow a linear trend that starts at an average condition score of 5 at age zero and drops to a condition score of 1 at 100 years (corresponding to a typical design life), as presented in Figure 35. The slope value of 0.04 equals the difference between the maximum and minimum condition score values divided by the assumed service life: $5 - 1/100 = 0.04$.

$$CR = 5 - 0.04\,t$$

Figure 35. Equation. Linear deterioration model to generate synthetic dataset 1.

As illustrated in Table 7, the condition scores are integer values; however, the average score for the population is a continuous measure from 1 to 5. Figure 36 presents a scatter plot of the average scores estimated from the data generated for 100 assets, with a fitted linear deterioration model shown as the gray dashed line. The model parameters are slightly different from the assumed equation to generate the data.

Table 7. Condition Scores for 5 Assets and the Average of All 100 Assets for the Linear Model Synthetic Data

Age (Years)	Asset 1	Asset 2	Asset 3	Asset 4	Asset 5	Average Score
50	2	4	1	1	3	3.08
51	4	2	3	4	2	2.92
52	4	2	1	4	1	2.97
53	3	1	1	5	2	2.77
54	1	5	3	4	4	2.9
55	1	2	5	4	2	2.78
56	3	2	2	1	3	2.73
57	2	3	4	3	4	2.6
58	2	4	5	2	4	2.59
59	1	4	1	2	3	2.78
60	3	3	1	2	1	2.49
61	4	4	3	1	4	2.57
62	2	1	4	3	4	2.51
63	4	4	2	4	4	2.58
64	4	4	3	3	4	2.29
65	2	1	3	4	2	2.58
66	1	2	1	0	4	2.31
67	3	2	3	3	4	2.25
68	2	2	1	2	1	2.26
69	4	4	2	1	1	2.36
70	3	4	4	0	2	2.29
71	2	2	0	1	3	2.04
72	2	4	2	1	3	2.25
73	0	0	2	2	2	2.2
74	2	3	4	3	3	2.15
75	2	1	3	3	2	2.09

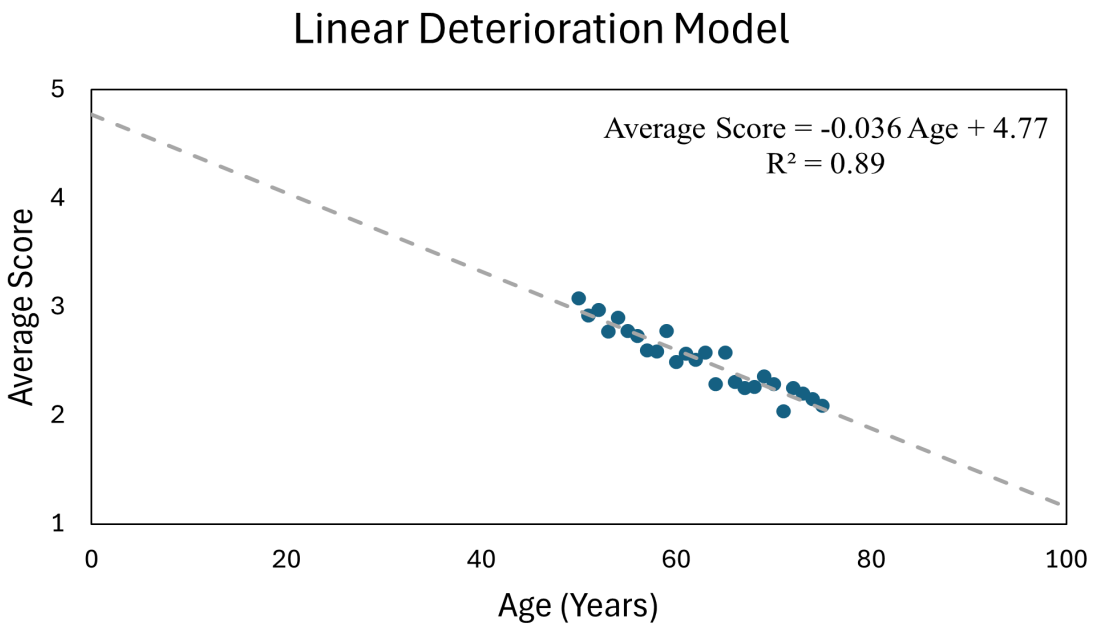


Figure 36. Graph. Scattered synthetic data with a fitted linear deterioration model.

Exponential Deterioration Model

The equation in Figure 37 presents a simple exponential deterioration model describing the condition rating *CR* at a given age *t*, as a function of the average condition rating at construction CR_{con} multiplied by a time-dependent exponential decay function.

$$CR = CR_{\mathrm{Con}} e^{-\beta\, t} + \epsilon$$

Figure 37. Equation. Exponential deterioration model of condition rating.

Example Implementation: Exponential Deterioration Model

To illustrate implementation of exponential deterioration modeling, synthetic data were generated for 100 MSE walls with 25 years of inspection records capturing the assets between age 50 to 75 years. The data were generated to fit closely to an exponential trend that starts at an average condition score of 5 at age zero and drops to a condition score of 1 at 100 years (corresponding to a typical design life), as presented in Figure 38. The exponent parameter β can be estimated as $\beta = -\ln\frac{1}{5}/100 \approx 0.016$.

$$CR = 5e^{-0.016\, t}$$

Figure 38. Equation. Exponential deterioration model to generate synthetic dataset 2.

As illustrated in Table 8, the condition scores are integer values; however, the average score for the population is a continuous measure from 1 to 5. Figure 39 presents a scatter plot of the average scores estimated from the data generated for 100 assets, with a fitted exponential deterioration model shown as the gray dashed curve.

Table 8. Condition Scores for 5 Assets and the Average of All 100 Assets for the Exponential Model Synthetic Data

Age (Years)	Asset 1	Asset 2	Asset 3	Asset 4	Asset 5	Average Score
50	4	1	3	3	1	2.67
51	4	2	3	3	4	2.76
52	3	3	2	3	1	2.59
53	1	1	3	2	3	2.61
54	3	2	2	4	3	2.65
55	3	3	2	3	4	2.56
56	2	2	2	4	2	2.6
57	2	2	2	3	3	2.32
58	2	2	2	1	2	2.31
59	3	2	2	1	2	2.36
60	2	3	2	2	4	2.34
61	3	2	2	2	2	2.41
62	2	4	2	3	1	2.25
63	3	3	3	2	2	2.2
64	2	1	1	1	1	2.33
65	2	3	4	4	4	2.39
66	3	2	2	2	2	2.15
67	2	3	1	2	4	2.09
68	2	3	2	3	1	2.21
69	1	3	1	2	2	2.13
70	2	1	2	1	2	2.04
71	1	3	1	3	2	2.15
72	3	2	1	2	2	2.17
73	1	2	3	1	2	2.14
74	1	1	1	1	2	2.1
75	3	2	2	1	2	1.84

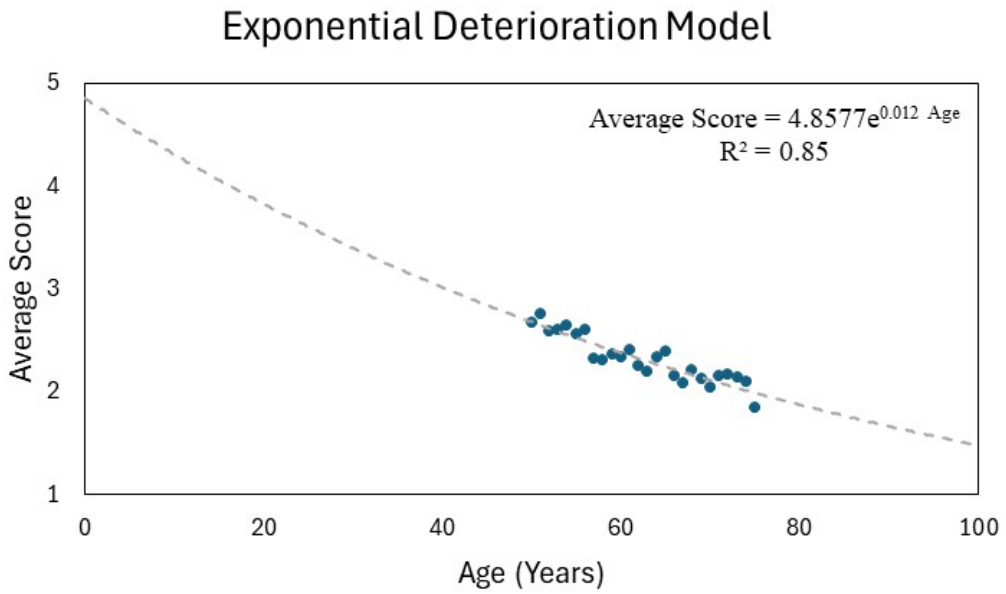


Figure 39. Graph. Scattered synthetic data with a fitted exponential deterioration model.

Markov-Based Deterioration Models

A Markov chain process describes the transition of a system from one state to another state as a stochastic (probabilistic) process with known transition probabilities. In a first-order Markov model, the transition probabilities quantify the chances of a system remaining in its current state or transitioning to a different state after one time step given the system's current state. A system that depends on the current state only is called a memoryless system, where the history of the system does not influence its future state. In geotechnical asset deterioration modeling, the possible condition scores (1 to 5) correspond to the states in a Markov process. Moreover, the time step in this study is one year. Accordingly, one can describe a row vector of probabilities (P) quantifying the probability of a system staying in its current condition state, with condition score i, or transition to other condition states after one time step (Δt), typically one year, conditional on its current condition states, as outlined in Figure 40.

$$P(CR_{t+\Delta t} = j | CR_t = i) = [p_{i1} \quad p_{i2} \quad p_{i3} \quad p_{i4} \quad p_{i5}]$$

Figure 40. Equation. Row vector of transition probabilities for a five condition-state system.

where p_{i1} is the probability that the future asset score ($CR_{t+\Delta t}$) is j = 1 given its current state (CR_t) is equal to i. More importantly, the row vector of probabilities defines the probability mass function (PMF) of the future condition of an asset given its current condition state.

To account for the transition probabilities given the five possible condition states, one can compile the multiple row vectors into a transition probability matrix (TPM), defined as P as in Figure 41.

$$P = \begin{pmatrix} p_{55} & \cdots & p_{50} \\ \vdots & \ddots & \vdots \\ p_{05} & \cdots & p_{ij} \end{pmatrix}$$

Figure 41. Equation. Transition probability matrix for a five condition-state system.

where the first subindex i in the matrix elements corresponds to the current condition rating, and the second subindex j corresponds to the future condition rating. Accordingly, the first element in the TPM (i.e., p_{55}) is the probability that an asset with a condition rating score 5 remains in the same condition state after one year. Note that the subindexes of the matrix elements are different from the standard matrix notation, where the first index corresponds to the row number and the second index corresponds to the column number. Typically, the TPM is upper triangular since assets are not supposed to transition to a higher condition state without maintenance. Moreover, most models constrain the possible transitions in one year to staying in the current condition state or dropping one condition state, as shown in Figure 42. The last element in the matrix is equal to one since assets in the lowest condition state cannot deteriorate further, so it will have a probability of 1.

$$P = \begin{pmatrix} p_{55} & p_{54} & 0 & 0 & 0 \\ 0 & p_{44} & p_{43} & 0 & 0 \\ 0 & 0 & p_{33} & p_{32} & 0 \\ 0 & 0 & 0 & p_{22} & p_{21} \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Figure 42. Equation. One-step deterioration constraint TPM.

To find the transition probabilities after n years given the current condition state, the new transition probability matrix is defined as the product of the TPM, Figure 41, n times, as shown in Figure 43.

$$P^n = \begin{pmatrix} p_{55} & \cdots & p_{50} \\ \vdots & \ddots & \vdots \\ p_{05} & \cdots & p_{ij} \end{pmatrix}_1 \begin{pmatrix} p_{55} & \cdots & p_{50} \\ \vdots & \ddots & \vdots \\ p_{05} & \cdots & p_{ij} \end{pmatrix}_2 \ldots \begin{pmatrix} p_{55} & \cdots & p_{50} \\ \vdots & \ddots & \vdots \\ p_{05} & \cdots & p_{ij} \end{pmatrix}_n$$

Figure 43. Equation. n-steps transition probability matrix.

Since the rows in the TPM are PMFs for future transitions, the expected value of the asset score PMF after n years given its current condition can be calculated using the equation in Figure 44. The expected value is not the most probable condition state, but the centroid of the PMF of the condition after n years. The average condition rating score for a population of assets is an estimator of the expected value.

$$E(CR_{t+\Delta t} | CR_t, \Delta t = n) = qP^n R; \text{ where } R = \begin{pmatrix} 5 \\ \vdots \\ 1 \end{pmatrix}$$

Figure 44. Equation. Expected value of asset condition score after n-steps.

where q is a condition state row vector with a value of 1 for the column corresponding to the current condition state and zero for the other entries. Accordingly, if an asset has a rating of 3, the third element of the condition state vector is equal to 1 while the other four entries are equal to zero. R is a column vector with all condition states in the corresponding row number.

Example Implementation: Markov Deterioration Model

Table 9 presents an example of a transition probability matrix with a constraint to allow one condition state deterioration in one year. The probabilities in the matrix are a rough estimate based on published literature on MSE wall deterioration but are not presented as recommended input values. Based on the TPM in Table 9, an asset in a condition state 5 has a probability of 0.97 to remain in the same condition state the next year and a probability of 0.03 to drop to the next lower condition state. Moreover, the summation of entries in each row should add to 1 representing the total probabilities for that asset.

Table 9. Example TPM for Geotechnical Assets with 5 Condition States

		Future Condition State (1-Year Step)					Total Probability
		5	4	3	2	1	
Current Condition State	5	0.97	0.03	0	0	0	1
	4	0	0.92	0.08	0	0	1
	3	0	0	0.91	0.09	0	1
	2	0	0	0	0.9	0.1	1
	1	0	0	0	0	1	1

As shown in Table 10, for the same asset group with the TPM shown in Table 9, an asset with a condition state 5 after 50 years of service will have a probability of 0.21 to stay in condition state 5, a probability of 0.12 to be in condition state 4, a probability of 0.13 to be in condition states 3 or 2, and a probability of 0.40 to be in condition state 1. The probabilities in each row still add to 1; however, the numbers shown in Table 10 are rounded, leading to a slightly different summation.

Table 10. Example TPM for Geotechnical Assets with 5 Condition States after 50 Years

		Future Condition State (50-Year Step)					Total Probability
		5	4	3	2	1	
Current Condition State	5	0.21	0.12	0.13	0.13	0.40	1
	4	0	0.01	0.05	0.09	0.84	1
	3	0	0	0.01	0.03	0.96	1
	2	0	0	0	0	1.00	1
	1	0	0	0	0	1.00	1

For the same asset group, the expected condition score value for an asset in condition state 5 after 50 years of service can be estimated using the equation in Figure 45.

$$E(CR_{50}|CR_0 = 5) = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} 0.21 & 0.12 & 0.13 & 0.13 & 0.40 \\ 0 & 0.01 & 0.05 & 0.09 & 0.84 \\ 0 & 0 & 0.01 & 0.03 & 0.96 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 5 \\ 4 \\ 3 \\ 2 \\ 1 \end{pmatrix} = 2.6$$

Figure 45. Equation. Expected value of asset condition score after 50 years starting at condition score 5.

Following the process to estimate the expected values each year, the deterioration curves representing the average condition score for a group of assets starting at condition scores 5 and 4 after 100 years are shown in Figure 46.

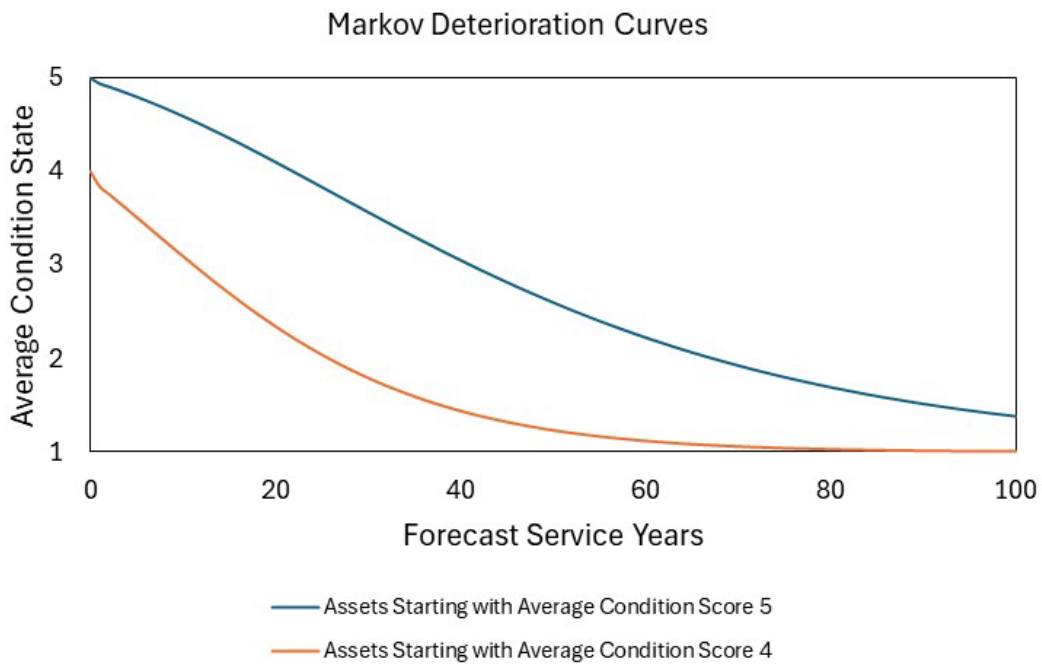


Figure 46. Graph. Deterioration curves for assets value of asset condition score after 50 years, starting at condition score 5.

Estimating TPM for Markov-Based Deterioration Models

Estimating the TPM for geotechnical assets can be performed using a wide range of approaches, including fitting historical condition data records with age, cross-sectional analysis, and engineering analysis and judgment. The selection of the approach depends on several factors, including data availability.

Estimating TPM using historical records is the most data-intensive approach. To estimate the transition probability matrix, the expected value of the condition scores rating at a given age $t = n$ years is compared to the average condition scores at the same age for all the assets in the group. The sum of the absolute differences between the expected value and the average condition rating (W) is then minimized by changing the values of the TPM, as shown in Figure 47.

$$\min_{P} W = \sum_{t=1}^{N} \left| \frac{1}{K} \sum_{k=1}^{K} CR_{tk} - q_0 P^t R \right|$$

Figure 47. Equation. Objective function to estimate TPM from condition score records.

Where N is the maximum expected service life in years, CR_{tk} is the condition score of asset k at age t, K is the number of assets, and q_0 is the initial condition state row vector at age 0.

Alternatively, cross-sectional analysis can be used to estimate the individual probabilities in the TPM as the ratios of assets remaining or transitioning between states each year. For example, for N assets

in a group, assume the number of assets with condition score 5 are equal to $N_{5,t=0}$ at year 0. In the next year, some assets, $N_{5\to4,t=1}$, will transition to condition score 4 while the other assets $N_{5\to5,t=1}$ will have condition score 5. In this case the equations in Figure 48 can be used as an estimate of the transition probabilities of these assets. This approach does not require prior knowledge of the assets' age.

$$p_{5,5} = \frac{N_{5\to5,t=1}}{N_{5,t=0}}, and\ p_{5,4} = \frac{N_{5\to4,t=1}}{N_{5,t=0}}$$

Figure 48. Equation. Transition probabilities estimated from cross-sectional analysis.

With limited historical records, the individual probabilities can be estimated based on the experience, engineering analysis, published literature, and judgment of a panel of experts. This approach can be a practical alternative for early applications. However, it should be handled carefully, and the estimates should be updated as additional data are available.

CHAPTER 6: SUMMARY, GAPS, AND RECOMMENDATIONS

SUMMARY

This study provides a flexible and holistic geotechnical asset management (GAM) framework and workflow. To date, many GAM frameworks proposed in practice have focused on creating an asset inventory and inspection procedures. Although data collection and inspection procedures are the core of GAM, a functional and robust GAM program should address other components such as risk management as well as deterioration and performance modeling to be effectively integrated with other transportation asset management (TAM) programs and achieve agency objectives.

The framework is divided into seven major steps, discussed in Chapter 2. These steps are organized sequentially. However, progress in different steps may vary in early implementation stages. The inspection procedures discussed in Chapter 3 were simplified to allow for smoother adoption and implementation. The inspection procedures should be updated and reassessed routinely to address gaps and shortcomings and to incorporate other objective engineering measurements.

Chapter 4 discusses the risk management framework and the developed risk management tool. The framework is modified from the Strategic Highway Research Program 2 project "Managing Risk in Rapid Renewal Projects" (NCHRP, 2012). In the future, the framework and tool can be advanced to apply full-scale quantitative risk management. The risk management workflow is divided into 13 steps, with some steps being visual summaries. Chapter 5 provides a detailed discussion on deterioration modeling and the procedures to fit and use deterioration models to forecast future conditions.

GAPS AND IMPLEMENTATION NEEDS

Based on the study's findings and two pilot studies, several gaps have been identified. The discussion below presents several high-priority gaps and needs.

- **GAM and TAM Integration**: The integration of GAM into the Illinois Department of Transportation's (IDOT's) overall TAM systems and programs is key to GAM's future success and implementation. The team has taken into consideration the overall TAM process and checked that data records and analyses follow IDOT's procedures. We also worked with IDOT to identify the major inputs needed for future integration. Full GAM integration will require several iterations and the involvement of multiple human resource disciplines.

- **Performance Models**: Performance models capture the change in asset condition and performance, which can be presented by performance measures, over time. These models are critical for many reasons:

    - Forecasting future improvement strategy needs

    - Estimating risks associated with geotechnical assets

- Estimating the impact of deterioration and improved geotechnical assets on network performance

- Estimating the benefits attained from the GAM program and improvement strategies

- Prioritizing the list of projects planned for detailed evaluation

Based on the current limited historical records of the assets inspected, there are needs to adjust the rating systems as well as to derive performance models and deterioration curves. Each need should be updated as additional data are developed.

- **Inspection Procedures**: The research team developed inspection procedures, summarized in Chapter 3. These inspection sheets summarize the different asset conditions using a rating scale related to the performance and risks associated with the condition. Although the rating system is based on a thorough evaluation of existing literature and the team's experience with GAM systems across other states, the rating systems should be reviewed periodically and revised and improved as appropriate as they are implemented statewide. The rating systems will also need routine reevaluation before they become sufficiently mature to capture the most dominant deterioration mechanisms and risks associated with the assets' deterioration.

- **Data Collection Software Tools**: The research team has developed and tested an online data collection tool specialized for Illinois GAM in ArcGIS Survey123. Based on the detailed inspection sheets and the need to upload asset photos to support visual inspection, the online tool requires strong internet connection. The team faced challenges uploading inspection data at a few sites. However, the tool can be adjusted to work offline in the future. The tool does require additional evaluation, improvement, and refinement in addition to a need to explore alternative specialized tools that satisfy the Illinois GAM program needs.

- **Human Resources and Stewardship**: The implementation of a GAM program requires human resources to support the different components, as discussed below. The role and responsibilities of these individuals will overlap, and there is a need for effective collaboration and communication to achieve consistent workflow.

    - **Field Inspectors**: These individuals will perform asset field inspection. The inspectors should be trained in inspection procedures and data entry practices in the field and in the office. The number of required inspectors will depend on the implementation plan and the geographic extent the program will cover.

    - **Geotechnical Asset Manager**: The manager is responsible for coordinating and planning the inspection program, leading the quality control and assurance of inspection data, leading the development of performance models, leading the assessment of improvement strategies and project prioritization, facilitating risk management activities, supporting the IT team in managing and integrating data within the overall TAM, and reporting to the TAM agency stewards. With the extensive number of task activities, the geotechnical asset manager may need the support of additional staff.

- **IT Support**: IT support includes the maintenance and management of software tools, geospatial data integration and management, data governance processes and plans, and GAM system integration with other TAM systems. The extent of IT support is a dynamic process and includes a broad range of needs.

- **GAM Program Stewards**: GAM programs impact multiple asset management programs. This broad impact requires strong communication and input from multiple offices and programs within the agency. Different owner agencies manage stewardship differently, and each has a unique approach.

- **Risk Management**: The risk management process developed in this study is generic and provides the processes and recommended definitions for future GAM implementation at the asset and program levels. The inputs and implementation of risk management require several refinements and iterations to develop a mature process that effectively communicates the major risks.

- **Network Data Collection Tools**: Despite advancements in remote sensing, high-speed image acquisition, and other data-capturing tools, there remains a major gap in highway-speed data collection for geotechnical assets. This can be attributed to many challenges:

  - Many geotechnical assets are outside the line of sight for many devices, such as embankments below the road grade or high soil slopes and rock cuts.

  - The resolution of devices may not always be sufficient to capture cracks or other asset distresses.

  - The acquired data require accurate georeferencing to perform change detection with time, which can be a challenge for network-level data.

  - There are no consistent procedures for automated image and remote-sensing data processing and analysis to detect and assess the assets' conditions.

RECOMMENDATIONS

This report has provided several recommendations. This section summarizes major recommendations and provides suggested implementation steps.

- Create a data inventory structure even if initially it only contains a few entries. The structure should be implemented within different tools, different transportation asset components and systems, and the primary asset management system, which is currently dTIMS. Implementation of this recommendation will allow IDOT to assess the practicality of the different definitions for data structure and recommended procedures as well as to identify challenges to be addressed.

- Establish an early GAM working group that includes different stakeholders benefiting from GAM. This working group may change over time and will oversee early implementation and

assess the benefits, improvement needs, and most effective implementation steps. The group will also focus on communicating the benefits of the program on IDOT objectives and strategic goals.

- Conduct an implementation pilot program. The implementation pilot program can focus on high vulnerability and critical corridors with diverse geotechnical assets and conditions. The program should extend over multiple years, starting with a focused implementation of the tools and procedures recommended in this study for one cycle, followed by an assessment of that implementation for appropriate revisions and updates to the tools and procedures. This pilot should include development of a core database that can be used to develop performance and deterioration models.

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APPENDIX A: LITERATURE REVIEW AND WORKSHOP

LITERATURE REVIEW

Introduction

This literature review provides a background and summary of the current practices and advancements in geotechnical asset management (GAM) and the benefits of using GAM. The review focuses on the use of GAM specific to transportation systems and transportation assets. GAM programs are evolving, and agencies are in the early stage of adopting and formalizing their programs. Some agencies have introduced management systems for specific geotechnical assets such as slope management systems and incorporated these within their transportation asset management (TAM). Based on the literature review, there are several benefits and reasons to establish a GAM program that is unique and separate from other transportation assets including:

- Transportation asset management systems (TAMS) have traditionally overlooked geotechnical assets and subsurface features.
- Geotechnical assets and features have a foundational impact on all other physical transportation and infrastructure assets included in network asset management.
- The widespread impact of geotechnically based hazards plays a major role in local and network level resiliency.
- A better understanding of these assets provides an improved understanding of an agency's risk profile.
- Increased access to information for both physical and non-physical geotechnical assets (i.e. data) may aid in improved asset design and decreased construction time, expense, and change orders.
- A GAM program can reduce the life cycle cost of geotechnical assets.

Taxonomy

Transportation Assets

As identified by the Federal Highway Administration (FHWA), a transportation asset is a physical feature including vehicles, facilities, equipment, and fixed infrastructure used in or by a transportation agency (Biton, Reovan, & Bressette, 2019) (U.S. DOT Volpe National Transportation Systems Center, 2019). The national park service (NPS) which manages an extensive list of properties across the country provides a similar definition of an asset as, "a physical structure or grouping of structures, land features, or other tangible property that has a specific service or function" (U.S. Department of the Interior, National Park Service, 2018). This understanding of an asset as a physical feature or set of features is shared across state and local transportation agencies to the extent that

American Association of State Highway and Transportation Officials (AASHTO) has adopted a similar definition of an asset as “physical transportation infrastructure”.

These definitions are consistent with the historical intent of transportation asset management (TAM) as required by US law since 2012, with FHWA and individual state agencies limiting the consideration of assets to features under the intended use of a TAM system. These systems are focused on the operation, maintenance, and improvement of said assets under MAP-21 requirements (U.S. Department of Transportation, Federal Highway Administration, 2019). Even data associated with these assets, such as inspection reports, were viewed as part of the asset and not an independent or free-standing asset (U.S. DOT Volpe National Transportation Systems Center, 2019). As a result of this use-driven data approach, FHWA and other transportation agencies have consistently, albeit unintentionally, limited the consideration of assets to those physical features which are clearly visible, readily inspected, and user-oriented, such as pavements and bridge superstructures (NCHRP, 2019a, 2019b, 2019c).

More recently, AASHTO, FHWA, and several state agencies have identified the unintended limitation of asset types as a potential deficiency in operations. These agencies have subsequently developed guidelines and recommendations to further incorporate assets including ancillary assets, such as non-pavement systems, bridge substructures, and other assets broadly considered geotechnical assets (NCHRP, 2019a, 2019b, 2019c). Despite the inclusion of additional assets, both the FHWA and state agencies continue to limit the consideration of assets to physical features. This limitation is not unreasonable considering the lack of widespread and practical knowledge on the use of non-physical assets or data which is not derived directly from the assessment of a physical asset. Non-physical assets can include a wide range of data and information adding value to the agency such as project data, historical geotechnical records, site characterization data, and monitoring and inspection records.

Geotechnical Assets

Explicit identification of assets which should be defined as “geotechnical assets” is important to better document which features, and information should be recorded and in what manner. Like the general term *asset*, determination of what should be considered a *geotechnical asset* has varied by agency. The focus for geotechnical assets is often on physical features and condition assessments which directly quantify asset performance. A general definition of geotechnical assets can include all assets constructed on, in, or of soil and rock (National Cooperative Highway Research Program, 2023). This definition can be expanded further to include non-physical assets as discussed in the following subsection. Although many geotechnical and foundational assets can be included in a GAM program, there are several considerations affecting the agencies’ decision when selecting and defining the geotechnical assets to be included. One of these considerations is the ownership of the asset. For example, some agencies include structural foundations and geotechnical assets, such as embankments and earth retaining systems (ERS), adjacent or leading to a bridge as part of their bridge management system. Moreover, the selection of the assets depends on the maturity of the GAM program. Many agencies start with the most widespread assets which have clear inspection, condition, or performance evaluation procedures. (Anderson, Schaefer, & Nichols, 2016) introduced a taxonomy chart including a wide range of assets.

According to NCHRP Research Report 903, Geotechnical Asset Management for Transportation Volume 2: Implementation Manual, a geotechnical asset can be defined as, "an embankment, slope, retaining wall, or constructed subgrade that contributes to the performance of your transportation system." Moreover, report 903 states that, "These assets also contribute to the performance of the many culverts, pipes, and utilities that penetrate these engineered structures. Geotechnical components, such as ground reinforcements in a wall or embankment, groundwater drainage features, rock bolts, and structure foundations, are the improvements within many geotechnical or other structure assets that help the asset function through routine loading and extreme events" (Federal Highway Administration, 2013). Several similar definitions are reported in individual research papers and state agency studies addressed in NCHRP Report 903, Volume 1.

Based on the various GAM programs and research reviewed, a unique attribute of GAM is the heterogeneity of the geotechnical assets included in the program. The performance, condition rating systems and intended objectives, and serviceability measures of geotechnical assets vary based on the asset type. In summary, the definition of geotechnical assets to be included in a GAM program is a decision the agencies make based on the asset's criticality, ownership, risks and consequences of not managing the assets, and the maturity of the GAM program. Some agencies with more mature GAM programs will be able to accrue greater return on investment by including a larger number of assets and asset families. However, some agencies just starting their GAM program may elect to initially establish a smaller pilot or test program before handling a large number of assets from different asset types and families.

Non-physical Assets

During the last five years, several state agency publications maintain this exclusionary language with minor modifications or with limited inclusions of non-physical assets as deemed appropriate by the agency. As summarized below, these inclusions commonly relate to asset performance or an established geohazard, like geotechnical monitoring data. Colorado DOT, Alaska DOT (Thornley & Cannon, 2016), Vermont DOT, Ohio DOT, Idaho DOT, and the City of Cincinnati all have developed some of the earliest geotechnical asset databases for this type of geotechnical assets (Torres, et al., 2022) (Waseem, Tappenden, St Michel, & Skirrow, 2022).

- Missouri DOT (MoDOT) developed a prototype GAM program which includes both an asset inventory, asset rating system, condition assessment, and risk assessment for slopes (rock and soil), retaining walls, engineered embankments, subgrades and/or subgrade improvements, and subsidence (Mines, Beckstrand, Bunn, & Landslide Technology, Inc., Development of a Geotechnical Asset Management Collection and Rating Program for Missouri Department of Transportation, 2022).

- Georgia DOT (GDOT) performed a study on the state of the practice for GAM within the US and defined a geotechnical asset as being embankments, slopes (both natural and excavated), retaining walls, and bridge foundations; similar to those defined in NCHRP 903 (Federal Highway Administration, 2013) (Torres, et al., 2022).

- Alberta Transportation (AT; Canada) developed a GAM program considering geotechnical assets like those outlined under NCHRP 903 including slopes, embankments, retaining walls and both natural and construction subgrades (Waseem, Tappenden, St Michel, & Skirrow, 2022).

- Washington State DOT (WSDOT) developed GAM through their geotechnical office which included the collection of subsurface and geologic soils data, laboratory test results, unstable slope information, and geotechnical inspection reports for constructed geotechnical assets (Fish, Trople, & Struthers, 2019).

While agencies continue to develop their TAM and GAM programs to prioritize physical assets, a more inclusive list of assets has seen increased acceptance. Broader asset definitions have been established by AASHTO, USACE, ISO and other organizations for both general and transportation assets. These inclusive definitions incorporate physical features and non-physical data, or information broadly related to management systems. This growth in use of an inclusive asset definition generally corresponds to practitioners developing better understanding of how to quantify (e.g., justify) the impact of data on TAM, GAM, and the overall decision-making processes. Examples of this inclusionary language include:

- AASHTO states that any resource which can produce value-added opportunities for an agency is generally an asset, including corporation information, individuals, and equipment and materials (American Association of State Highway and Transportation Officials, 2013).

- US Army Corps of Engineers (USACE) Civil Works adopting the ISO 55000 definition of an asset as “anything that provides value to the organization”. However, USACE, like many state agencies recognizes that the initial focus of their strategic plan is on physical assets (U.S. Corps of Engineers Civil Works, 2022).

- ISO 55000 provides the inclusive definition of an asset as, “item, thing or entity that has potential or actual value to an organization; value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities” (International Organization for Standardization, 2016).

As agencies identify the benefits of the inclusive asset definition several state DOTS have also initiated projects to address this inclusionary understanding without an explicit change in geotechnical asset definition(s). This change appears to be occurring more rapidly as agencies identify the benefit of additional data collection for the individual asset and for network level management decisions. This expansion has occurred both in areas of structures previously considered to be of lower importance (e.g., light standards) and geohazard mitigation. Data collection examples under this inclusive definition include:

- Maryland DOT (MDOT) incorporating precipitation data with LiDAR terrain data and soil maps for risk management of slopes (Maryland Department of Transportation, 2023).

- Minnesota DOT (MnDOT) incorporating ground penetrating radar (GPR) and Falling-Weight Deflectometer (FWD) data for validation to supplement in-situ moisture sensors and to improve moisture monitoring for pavement foundations. Like MDOT, MnDOT notes the use GPR as a tool along with FWD for monitoring of pavement structural capacity both during and after extreme environmental events (Calhoon, Zegeye, Velasquez, & Calvert, 2022).

- MnDOT incorporating instrumentation data including inclinometer, piezometer, pressure cell, shape accel array, and other available data and natural hazard features including areas of known karst formations, seepage faces, and identified slides (Minnesota Department of Transportation, n.d.).

- Colorado DOT (CDOT) incorporating Interferometric Synthetic Aperture Radar (InSAR) monitoring of ground deformations along trial corridors for risk-based GAM planning (Fergason, Panda, & Williamson, 2014).

- Kansas and Wyoming DOTs (KDOT, WYDOT) incorporating geotechnical exploration data with existing TAM systems through their existing logging software (gINT) (University of Kansas Center for Research, Incorporated, 2021).

Agencies who have implemented a more inclusive definition of geotechnical assets, including geohazards and laboratory testing, were noted in this literature review. The inclusion of these additional assets also supports the holistic view of what should be considered as an asset, based in part on an agency's ability to utilize and assign value to individual assets. In some cases, the inclusion of additional assets in a GAM was a clarification of asset type or intra-agency ownership and not a strictly novel asset agency wide. Moreover, handling non-physical assets could be under other data governance and management procedures and not included directly as a GAM asset.

Transportation Asset Management Systems

Determination and selection of the appropriate assets is an important factor in asset management and collectively for the development of a transportation asset management (TAM) system. Like the restrictive definition of an asset the understanding of asset management for transportation is legally founded in US law under MAP-21, subsequent laws, and agency directives (U.S. Department of Transportation, Federal Highway Administration, 2012). MAP-21 defines asset management as:

> […] a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost. (23 USC. 101(a)(2), MAP-21 § 1103).

While MAP-21 maintains a restrictive definition, the inclusionary understanding of assets and asset management continue to move into practice and are exemplified in ISO 55000, 55001, and 55002 standards. These standards have also been accepted and used as a basis of development in the

International Infrastructure Management Manual (IIMM), referenced by the USACE Institute for Water Resources, Best Practices in Asset Management (2013-R-08) and USACE Civil Works Strategic Asset Management Plan (Institute for Water Resources, 2013) (U.S. Corps of Engineers Civil Works, 2022).

Geotechnical Asset Management Programs

GAM development and implementation are generally framed like TAM system development, with unique needs and attributes due to the heterogeneity of the geotechnical assets. Based on the various GAM programs and research reviewed in this study, a unique attribute of GAM is the heterogeneity of the geotechnical assets included in the program. Unlike pavements, the performance, condition rating systems, and intended objectives and serviceability measures of geotechnical assets vary based on the asset type. For example, rigid pavement and flexible pavements have different deterioration mechanisms, construction practices, and design, yet their performance measures can be harmonized by considering ride quality or a pavement condition index. In contrast, two geotechnical assets such as MSE walls and rock slopes have different condition measurements focused on physical conditions and not performance requirements reflecting serviceability impacts on the network. Therefore, and at a high level, the performance and serviceability requirements for both pavement families can be compared and prioritized in an asset management system. However, it is more challenging to compare and prioritize the performance requirements and metrics across some geotechnical assets' families.

Modelling a GAM program as close to TAM as possible will help agencies develop and implement GAM programs. Agencies can rely on existing technologies and intra-agency experience to identify which assets are best suited for preliminary collection and to enable rapid inventory development. Agencies may be able to use their existing transportation asset database or a general asset database as a GAM starting point by selecting already managed assets and reclassifying them as geotechnical assets. The review of existing assets may also be used as a method to identify underlying or supporting assets, features, or structures which may be classified as geotechnical assets but were not previously managed (Beckstrand and Mines, 2017b). A general GAM implementation workflow as presented in NCHRP Report 903 is presented below.

The initial development of a GAM database may be readily followed by expansion of existing TAM programs to include assets of interest or assets identified during the initial development as areas of concern. In reviewed cases, agencies new to GAM programs tended to defer to NCHRP 903 to identify the physical assets in their GAM as a starting point. In part this is because these assets have well defined performance metrics, more reliable return on investment (ROI) calculations, and direct impact on public safety and mobility. In many cases these assets are also considered to have higher levels of risk than other geotechnical assets (National Cooperative Highway Research Program, 2019). Once the GAM is established, agencies can start exploring other physical assets including non-physical assets such as geotechnical data, user-impression information, and other geotechnical and laboratory information through digitalization of construction records. This staged approach also enables agencies to better evaluate internal review and data usage practices to ensure the highest possible return from implementing GAM. In all cases, a review of NCHRP 903 documents by involved agency staff is recommended to improve GAM acceptance and understanding.

Integration of GAM with Other TAM Systems

The integration of GAM with existing TAM systems is common across reviewed agencies. This integration serves to improve agency readiness to use and expand the GAM through familiarity with collection- and access-systems and with infrastructure technology (IT) integration. This integration can reduce the cost of GAM expansion. Integration may face limitations depending on the structure and use of existing databases and the methods of collection with limitations depending on the management system software flexibility. Several DOTs maintained the use of survey and management software across systems with ESRI ArcCollector and Survey123 typically used for field-collection and ArcGIS or an in-house GIS for data management (Fish, Trople, & Struthers, 2019) (Mines, Beckstrand, Bunn, & Landslide Technology, Inc., Development of a Geotechnical Asset Management Collection and Rating Program for Missouri Department of Transportation, 2022) (Waseem, Tappenden, St Michel, & Skirrow, 2022) (U.S. Department of the Interior, National Park Service).

GAM Implementation

Data Collection

During GAM initiation, data collection is a fundamental part of asset management and one of the first major challenges. Determining if asset data should be collected, which asset(s) to collect, to what extent, and at what frequency play an essential role in developing a useful management system. This decision is complicated by asset design, management, maintenance, and perceived ownership within an agency. Several key considerations prior to the start of data collection are provided in NCHRP Research Report 920, Management and Use of Data for Transportation Performance Management. These include determination if:

- “current agency data sources will not meet the requirements,
- there are no suitable commercial sources that meet the requirements,
- there is a business case for new data collection, and
- resources are available – both for initial collection and ongoing upkeep of the data.”

Guidelines for data collection should be individualized per agency and per asset, to collect information best suited for cost effective collection and practical use. The level of asset detail and total number of assets collected typically increases over time with the majority of GAMs and iterative review and discussion within an agency and agency external stakeholders. Electing to incorporate external utilities should also be considered. However, this incorporation may significantly increase the complexity in GAM implementation and development. When completed, incorporation of external agency assets may be limited to broad-risk level identification between the transportation agency and external asset stakeholders; sufficient for general risk assessment but limited in use to detailed network management or construction planning.

As there are several current well-developed guidelines available for transportation assets which cover data collection, the remainder of this section focuses on reiteration of key items and identified areas of concern for geotechnical assets.

Data Selection

Information collection should be limited to that which is impactful to the use, management, risk assessment, and other intended applications (detailed below) of an asset. Consideration should include all stages of the asset life cycle including planning, design, construction, operations and maintenance, and rehabilitation or reconstruction (NCHRP 2019a, 2019b). While not a comprehensive list these impact factors should typically include:

- Intent: the planned use or purpose of an asset which may be used to determine the impacts of a change in use if desired or required.

- Origin: background information including the basis of design, constraints, construction data, constructor, and information considered important based on agency and industry standard of practice.

- Owner / Steward: the agency, department, or individual responsible for management of the asset. This information may be expanded to include QA/QC personnel or groups responsible for changes to the asset.

- Stakeholders: the agency, department, group, or external organizations which may be impactful to decision-making for the asset.

- Type: the established asset order or broad classification based on agency developed classes. Many agencies include four primary physical types including embankments, slopes, retaining walls, and subgrades (NCHRP 2019a, 2019b).

- Location: the physical placement of an asset. This may also refer to a zone or region that an asset is within such as travel-, material- (soil type), or risk-corridor (landslide zone).

- Condition and/or Performance: the current physical state and service level provided by the asset.

- Condition Model: the recommended or selected condition-performance modeling methodology suitable for the asset. If no model or method has been established this should be noted to aid in quantifying the potential impacts of model development (i.e., the number of assets impacted and the potential benefits of this impact).

- Operations and Maintenance: a record of actions performed to or near the asset to maintain the condition and or performance.

- Criticality and/or Redundancy: an initial high-level risk assessment of an asset based on agency standards considering impacts of failure and level of asset redundancy. If no agency

standard determination method is established criticality and redundancy may be an outcome of GAM analysis.

Asset Delineation

The resolution and quantity of data collected is strongly dependent on delineation of an asset. This issue is typically more apparent for geotechnical and foundational assets than typical superstructure and surficial assets. Determination of what vertical and lateral extents should be considered as an asset should be determined by the managing agency based on which portion(s) of a structure may already be managed through another system, such as the National Bridge Inventory System (NBIS), and how maintenance or inspection are performed. General NCHRP guidelines provide guidance with includes delineating verticality of an asset by:

- Constructed vs. original ground,
- Foundation vs. superstructure, and
- Retaining wall vs. retained soil

While NCHRP guidelines have generally followed a restrictive asset definition, these delineations may still be used with a more inclusive definition by considering those comparative features (i.e., original ground, foundation, and retained soil) as separate assets. Lateral delineation is generally more direct than vertical delineation of an asset. Where present, a physical break such as the end of a retaining wall or the limits of a soil strata, readily serve to represent the change in an asset. While in the case of continuous or semi-continuous horizontal features, agency guidelines, terminology, or construction and maintenance practices may be used to determine breaks or subdivisions. An example of a guideline- or term-based break may be a transition of a wall asset from an abutment to a retaining wall at 25 feet from the edge of a bridge or the transition from a retaining wall to barrier wall at a height of 10 feet. In the case of non-physical assets consideration should be given to best practices, such as the frequency or recommended spacing of exploration points, to determine where data may no longer be acceptable per agency guidelines or no longer representative of site conditions.

Frequency and Methods of Collection

Frequency and methods of collection should be determined considering the ROI for the collected data. This determination may be difficult when the ROI has not yet been established; the case for many non-NCHRP 903 geotechnical assets. Under these conditions, consideration should be given to what data has an acknowledged use by the managing agency and which methods of collection may be performed as part of regular Operations and Maintenance (O&M) practice (see field-collection). Several methods of collection are recommended with frequency of collection, collection detail, and extent of collection to be determined by the agency. General guidelines are also provided in reference materials at the end of this section.

Record Digitalization

DOTs such as Utah DOT (UDOT) have used existing projects to improve overall asset management, such as record digitalization efforts, as a method to rapidly develop a GAM database (NCHRP 2019a, 2019b; Beckstrand and Mines, 2017b). While digitalization of existing records is a starting point, the ROI from asset digitalization specific to GAM is not well documented. Digitalization is instead considered a necessary starting point for quantification of assets and to provide a justification basis for additional efforts. Digitalization is also noted to improve communication, data access, and quality control of construction works (NCHRP 2019a, 2019b, 2019c), generating an overall better understanding of an agency's risk profile. Collectively, this digital information may also be considered an asset in itself.

Digitalization of existing records should consider inclusion of both engineering documents, such as structural, geotechnical, and environmental reports, and design documents such as construction and as-built plans. This information allows an agency to consider the site as an asset when performing regular O&M activities and at the end of an asset's service life.

Field-Collection

Recording of field-inspection data, verification of digital records, and recording of O&M activities are regularly used as a method of GAM data collection. Field-collection regardless of collection interval or inspection cause are generally well-reflected in lists of data recommended to be collected. As this data is also collected as part of O&M and under different inspection intervals (between reactive, interval, or condition-based), it is directly applicable to determination of asset performance and ultimately ROI for individual and overall treatments and O&M actions (American Association of State Highway and Transportation Officials, 2013). Maintaining O&M inspection and reporting intervals also reduces costs associated with GAM implementation. This reduction in additional costs is important as no reviewed studies provided quantified ROI results for field-collection.

As previously addressed, several tools are currently used by agencies to record data directly from the field. For common assets, individual agency practices and industry studies may provide the best available guidance on which asset details or elements are most impactful to asset operation. In general, the limited availability of these tools favor physical assets, either widespread or commoditized (e.g. culverts and pipelines (Najafi, Salem, Bhattachar, Salman, & Patil, 2008)), and assets with more highly engineered systems (e.g. retaining walls (Kulesza, Parsons, & Han, 2024)). Guidelines provided by these organizations however may be focused on determining the root-cause of failures and areas of concern, such a corrosion of metallic MSE reinforcement, without providing guidance on how pre-failure inspections of these assets may be completed in a cost-effective manner.

Alternative Collection Strategies

Transportation agencies have expanded GAM field-collection to include established and developing survey and monitoring technologies. These technologies are not always regionally-established but include ground penetrating radar (GPR) (Calhoon, Zegeye, Velasquez, & Calvert, 2022), light detection and ranging (LiDAR) (NCHRP 2019a, 2019b) (Maryland Department of Transportation, 2023) (Louisiana Transportation Research Center, 2023) (Oregon Department of Transportation, 2021),

interferometric synthetic aperture radar (InSAR) (Fergason, Panda, & Williamson, 2014) (Bruckno, Vaccari, Hoppe, Niemann, & Campbell, 2013), photogrammetry (Cerminaro, 2014), electric resistivity and electric resistivity imaging (ERI) (Nobahar, Salunke, ALzeghoul, Khan, & Amini, 2023) (Neely & Clark, 2013), falling weight deflectometer (FWD) (Calhoon, Zegeye, Velasquez, & Calvert, 2022), multichannel analysis of surface waves (MASW), geotechnical instrumentation (Minnesota Department of Transportation, n.d.), and other developing technologies (Thornley & Cannon, 2016) (Dye Management Group, Inc., 2014). In many cases, this information is complementary to visual inspections and may be considered as non-physical geotechnical assets or tied to existing physical assets. The use of these data types for assessment of risk for individual assets and along corridors has been established by MnDOT and CDOT. These technologies also aid in validation of wider environmental and engineering models which may serve resiliency planning within a network (Armstrong, Helm, Preston, & Loveridge, 2024). The potential of some of these collection strategies, their application, and strategy limitations are also part of an active Transportation Pooled Fund Program lead by Virginia DOT (Virginia Department of Transportation, 2023).

Additional resources on data collection and guidelines for collection are provided in:

- Practical Guide for Quality Management of Pavement Condition Data Collection (FHWA, 2013) https://www.fhwa.dot.gov/pavement/management/qm/data_qm_gu ide.pdf

- Guidelines for Development and Approval of State Data Quality Management Programs (FHWA, 2018) https://www.fhwa.dot.gov/pavement/management/pubs/dqmp.pdf

- Management and Use of Data for Transportation Performance Management: Guide for Practitioners (NCHRP, 2019c) https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/regulations-and-programs/safety/public-transportation-agency-safety-program/134691/management-and-use-data-transportation-performance-management-guide-practitioners.pdf

- Guidebook for Data and Information Systems for Transportation Asset Management (NCHRP, 2021) https://nap.nationalacademies.org/login.php?record_id=26126

GAM Application

A GAM program may serve several purposes for the managing agency and agency partners depending on how the system is implemented and the stage of implementation. GAM application most frequently begins as an inventory system before progressing as a tool for determination of performance gaps, ROI evaluations, and network or asset-specific risk assessment. A well-developed GAM program may also be suited for corridor-wide and network-wide risk and resiliency assessment, although no reviewed GAM programs were developed to the stage of network-wide or generalized corridor-wide risk and resiliency evaluation.

While described in a lateral, progressive manner, GAM application is more frequently cyclical with data development and application focused on a single asset or group of assets. After sufficient development of a limited number of assets the development restarts with a new asset group and further enrichment of the GAM program. This cyclical development and application are depicted in

the implementation workflow presented in NCHRP Report 903, and other GAM development guidelines. However, based on industry and agency publications, GAM has not received the level of use demonstrated by general DOT TAM systems which follow similar applications. These limitations in use are likely due in part to unclear asset definitions and extents, condition assessment focus on ultimate limit states, and unclear intermediate performance between service and ultimate limit states. Brief summaries of typical GAM application and observed limitations related to geotechnical assets are provided in the following subsections. Applications are structured in a progressive manner with subsequent uses reliant on preceding applications (e.g., condition assessment of an asset requires sufficient inventory records).

Asset Inventory

An inventory of an agency's assets is fundamentally the first step in asset management allowing qualitative and quantitative assessment of assets. Development of a geotechnical asset inventory faces additional challenges to those reported by other TAM systems as previously detailed due to unclear definitions, difficulties in asset delineation, and the ability to perform inspection of underground features. It is common for an agency to begin geotechnical asset inventory development using agency inspection segments to identity asset limits. These assets may be subsequently subdivided while maintaining data attributes. See *Frequency and Methods of Collection* for additional information.

Condition Assessment

Asset condition can be defined as the measure of the current health, serviceability, or state of an asset and is a common and practical use of a GAM program. Condition assessment may be performed using qualitative or quantitative guidelines developed by an agency, agency group (AASHTO), or industry group. While well-established for some assets, condition assessment of geotechnical assets remains a challenge for the same reasons as those provided under *asset inventory*.

Performance Modeling and Forecasting

Performance is a measurement of the intended purpose of the asset or assets and their functionality. Performance can be evaluated based on serviceability measures such as closure times, user and agency maintenance costs, detour lengths, service life, impacts of deformation. Some other practices define performance as the observed change in condition indices over a selected period to reflect the benefits of maintaining the asset at an acceptable condition level or state of repair. There are several analytical methods which may be applied to determine both current condition and asset performance, however not all assets have well developed modeling methods. Development of agency specific performance models may be suitable regionally based on uniformity of asset construction, age, and quality. However sufficient asset inventory and condition records must be available for evaluation (Virginia Department of Transportation, 2023). In general, guidelines which provide recommendations for asset data collection as presented in *Field-Collection* have higher availability of performance models. Caution should be used when applying performance models developed on an overly broad data set or under conditions atypical to the users' assets. Application of poorly fit performance models may lead to artificial reductions in risk and devaluation of individual condition assessments.

Life Cycle Analysis and Risk Management

With an understanding of asset conditions and performance, GAM may be used to improve the overall return on investment and capital costs of geotechnical and other geotechnical related assets. Development of life cycle analyses like performance modeling is generally restricted to a single asset type (e.g., retaining walls) instead of a corridor or network wide approach due to the lack of comprehensive LCA procedures for geotechnical assets.

LCA has found an increased use, specific to TAM and risk management, as part of budget justification and project prioritization for network planning. This approach, common with rockslides and other geohazards, broadly evaluates the reduced risk to an asset or group of assets through mitigation of geohazards. Determining the change in life cycle costs at a network level has been based on a preservation model or hypothetical scenarios by several users (Badger, Trople, Chaussee, Johnston, & Fish, 2023) (Post, Pihl, Oester Mapes, & Group, 2023). Application of this process was successful for Montana DOT (MDT) with a calculated reduction in life cycle costs of 19%; 115% of the preservation costs (Beckstrand et al., 2017c). However, the application of LCA to geotechnical risk mitigation is not widespread across DOTs. The application of LCA with risk management is frequently reliant on cost data related to the agency cost and subjective risk estimates which may not always be reflective of the actual conditions or the impacts on users. However, as GAM and geohazard risk assessment are areas of active development this is a reasonable application of existing GAM with the general understanding of an ROI of approximately 6 to 1 for natural hazard mitigation using FEMA analysis methodology (Federal Insurance and Mitigation Administration, 2018).

The use of a GAM program without LCA may still provide improvements in risk management by providing improved quantification of “known unknowns” and the reduction of corresponding unknown risks (NCHRP 2019a, 2019b). Allowing for improved predictive analysis of asset performance and pattern recognition of asset risk based on design, construction, materials, or other asset inventory data. Quantification of all assets by type or other data may also help better justify inspection priorities or require agency support to perform O&M operations; ultimately leading to improved network management.

Network Management and Resilience

Collectively GAM applications contribute to improved network management through optimization of effort and fund allocation. These applications also lead to improved network resilience levels through effective planning for adverse and extreme events. The need for improved resilience to climate and extreme events has been extensively researched and determined as one of the highest priorities by international-, federal-, state-, and outside- organizations, as well as by researchers related to both infrastructure and human costs. For example, FHWA has led several resilience pilot programs with state DOTs and issued FHWA Order 5520 which establishes a policy on preparedness and resilience (Parsons Brinckerhoff, 2023) (American Association of State Highway and Transportation Officials, 2017) (Bell, et al., 2018) (Urlainis, Ornai, Levy, Vilnay, & Shohet, 2022) (Markolf, Hoehne, Fraser, Chester, & Underwood, 2019) (Georgetown Climate Center, n.d.) (U.S. Department of Transportation, Federal Highway Administration, 2014). Like other infrastructure assets, geotechnical features associated with these studies are most related to visible superstructure assets and features with limited inclusion of subsurface assets.

Data Sharing, Interagency Collaboration, and Public Communication

The recognition of geotechnical assets and their impacts on internal - and external network resilience will largely be dependent on successful demonstration of GAM's ROI. Both pilot studies and early GAM programs which have incorporated geotechnical assets (geohazards) within other agency asset management programs have broadly demonstrated the benefits of GAM, but growth of these systems depends on the ability of agencies to share, collaborate, and communicate their experiences and results. Ultimately a fully developed GAM enables the benefits to be communicated both within and outside of an agency through well thought-out and documented standards of practice. Documentation of standards of practice including anecdotal experiences and troubleshooting may also aid in intra-agency resilience related to employee retention, retirement, or resource growth.

WORKSHOP

Introduction

The workshop was held in Hanley Building Conference Center (auditorium), Springfield, Illinois on January 3rd and 4th, 2024. The workshop included attendees from different districts and various offices from Illinois DOT, which provided the research team with a wide perspective of IDOT needs and engaged a wide audience from Illinois. The workshop was designed to aid Illinois DOT and the consultant research team in building a unique geotechnical asset management program for IDOT. The research team focused on providing the attendees with sufficient background information about the project and an overview of what a geotechnical asset management (GAM) program is. Then most of the workshop time was to solicit the attendees' feedback and vision based on carefully designed questions.

Workshop Findings

As described in the agenda, the workshop started with a plenary session to present project objectives, the purpose and structure of the workshop, anticipated outcomes, and an overview of the current state of the art and state of the practice in GAM. In that session, the attendees were divided into two breakout groups to discuss the different components of GAM and address the project needs in subsequent sessions. The discussions during the plenary and breakout sessions were guided by the questions shown in the agenda. The attendees were able to address most questions with some questions needing additional investigation in subsequent project tasks. The following subsections provide a summary of the discussions and findings from each session.

Below is the workshop schedule. The discussions in the following subsections will be structured to follow the program.

Day 1:

- 10am - noon Plenary Session 1-1: Introductions, overview and objectives
- Noon - 1pm lunch (on your own)
- 1pm - 1:30pm Plenary Session 1-2: first breakout room assignment

- 1:30pm - 3:30pm First Breakout Group Session (includes a break)
- 3:30pm - 3:45pm Break to prepare for Plenary Session
- 3:45pm - 4:30pm Breakout groups report out at Plenary Session 1-3
- Adjourn Day 1

Day 2:

- 8:30am - 9:00am Plenary Session 2-1 (Recap Day 1 and discuss second assignment)
- 9:00am - 11:50am Second Breakout Group session (includes a break)
- 11:50am - 1:15pm lunch (on your own)
- 1:15pm - 2:30pm Plenary Session 2-2 (summary of Workshop findings, challenges, gaps and needs)
- 2:30pm - 3:00pm Plenary Session 2-3 Next Steps and future communications with participants through ICT channels
- Adjourn Day 2

Plenary Session 1-1 (Day 1)

The plenary session started with a general introduction discussing several points as outlined below. It should be noted the points outlined below can be brief and scattered, and additional details will be discussed in subsequent project reports.

- GAM is not a requirement currently for state agencies. However, FHWA is moving in the direction of encouraging GAM. Moreover, GAM provides a cost-effective solution to be proactive in managing assets, improve the overall network condition and minimize the risk of failure and its consequences. A GAM program will also help Illinois build a robust and long-lasting TAM. It has been proven that GAM helped agencies be more cost effective in organizing their geotechnical asset data and become proactive in maintaining their assets.
- Discussed some general examples of other GAM programs and what other states are doing. This included a brief overview from the NCHRP report on GAM, Missouri DOT, NJDOT, NCDOT and Tennessee DOT.
- Failure needs to be redefined in this project. Ultimate limit state failure is clear; however, GAM programs are not only concerned about ultimate limit state failure, serviceability failure and reduced performance or progressive failure leading to ultimate limit state failure are major components of a proactive GAM program. The participants concluded that failure or reduced performance should be related to the risks associated with them and their possible economic and serviceability impacts on the network.

- There is a need for more specific review of the current practice that will be reported in the project literature review in Interim Report 1 (IR1).
- Discussed the definition of geotechnical assets. The general definition can be any asset constructed or modified from geomaterials or that is placed on or in geomaterials. This definition opens the door for a wide range of assets including, but not limited to:
    - Cut or fill slopes.
    - Embankments (including the side slopes).
    - Earth retaining systems (ERS).
    - Rock slopes below the road.
    - Rockfall above the road.
    - Ground improvement elements (including stone columns and piles supporting pavements [i.e., dryland bridges, unique to Illinois]).
    - Pavements foundations.
    - Borrow sites.
    - Earthen dams.
    - Masts and signs foundations.
    - Noise walls foundations.
    - Erosion control features
    - Culverts smaller than 6 ft in diameter (not included in bridge inventory and there are a significant number of 2-3 ft diameter culverts failing which are not evaluated regularly).
    - Shallow and deep foundations that are not part of the bridge program (including some of the previously identified assets)
    - Geotechnical data as a non-physical asset
- It was agreed that geotechnical assets included in an established program, such as the bridge management program, belong to that program. These can include bridge foundations, approach embankments and ERS supporting the bridge approach within 15 ft of the bridge, and major culverts larger than 6 ft in diameter.
- The group discussed the possible use of GAM to inform other asset programs which include geotechnical assets even if they are not included in the GAM. An example would be pavement

foundations, where a GAM program can support and assist pavement designers and managers.

- Discussed what assets need to be part of the GAM program. The discussion concluded it depends on the impact of the asset family on the network. For example, very short retaining walls far from the roadway may not have significant consequences and therefore should not be included. However, short retaining walls close to the roadway and extending a long distance can have significant consequences for highway users. In conclusion, the definition should depend on the risks associated with the feature and not a set size criterion.

- The group also discussed the procedure for segmenting and labeling the assets within the network. The procedures from NCHRP Report 903 Figure 49 was introduced and will be modified and adopted to meet IDOT needs.

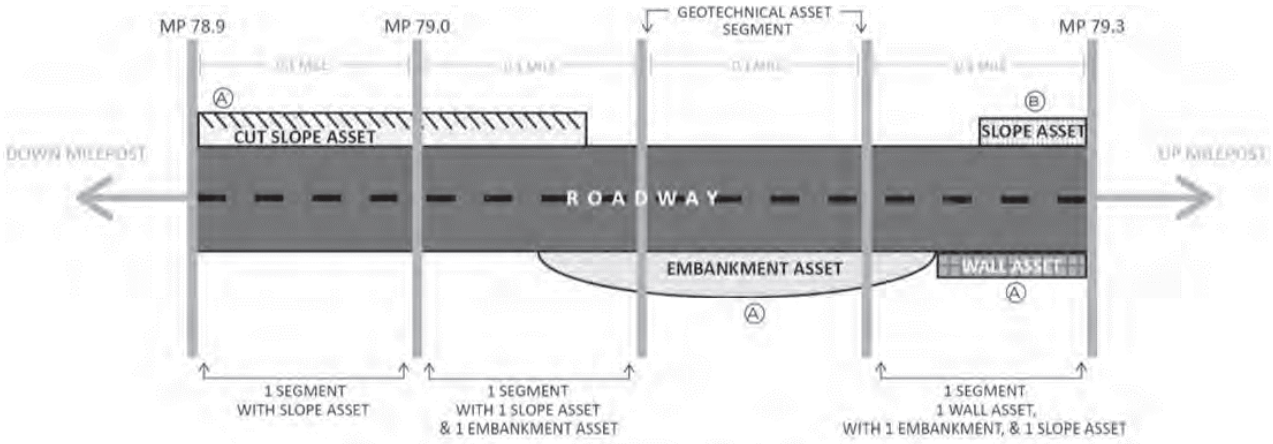
- An important item was the discussion on how IDOT will build the inventory and if the inventory should be an independent component of other IDOT TAM components, especially the bridge management system.

- The Bridge office has an inventory of some geotechnical assets (especially walls and embankments) which are considered as part of the bridge. These assets have a structural ID number assigned to them. A question to be addressed is whether these features should be separated or still be included within the bridge inventory.

- The group discussed the need to consider the labeling system used in IDOTs, Illinois Structure Inventory System (ISIS).

- This topic also initiated a discussion and introduced the need to integrate GAM with TAM. The GAM will eventually be part of the TAM and therefore the data inventory and developed tools should be ready to be integrated into dTIMS.

- The group discussed the development of a mobile application using ArcGIS Survey123 which will make it easy to collect data in the field and upload the data into IDOTs GIS.



GAM Inventory Example

ASSET ID	ASSET TYPE	TOTAL LENGTH IN SEGMENT
Highway MP 78.9	Cut Slope Ⓐ	400 feet
Highway MP 79.0	Cut Slope Ⓐ	400 feet
	Embankment Ⓐ	250 feet
Highway MP 79.1	Embankment Ⓐ	500 feet
Highway MP 79.2	Embankment Ⓐ	200 feet
	Wall Ⓐ	300 feet
	Slope Ⓑ	100 feet

Figure 49. Illustration. Geotechnical asset segmentation and labeling.

Source: Modified from NCHRP Report 903

- A brief discussion on potential data collection devices and techniques and for tiered data collection approach was introduced which included some possible technologies/ techniques; LiDAR, UAVs, InSAR, and visual inspection.

- It was mentioned that IDOT already has LiDAR data which will be reviewed in Tasks 3 and 4. Moreover, John Senger mentioned the availability of UAV devices that could be evaluated during the pilot program.

- Visual inspection could be a good starting point until technologies are mature enough for data collection. This is similar to pavement management, where agencies started with windshield visual data evaluation and now have moved to roughness evaluation and crack measurements using noncontact devices.

- The group also discussed availability of historical records and concluded that reviewing historical records extensively can be more expensive than starting a new data collection cycle. However, some desk study could still be useful if the data is easily accessible.

- It was noted that LiDAR will have a challenge in detecting the lower side of assets below the line of sight and steep assets at a high elevation above the line of sight. For example, the slope

on the sides of an embankment cannot be detected when LiDAR traverses the road segment above the embankment. However, LiDAR will be a good tool to explore for retaining structures, some cut slopes and other apparent assets within the line of sight.

- It is important to consider ways to define return on investment (ROI) for GAM and the potential benefits. An important aspect is to distinguish at this early stage between the estimated ROI, which will evolve over time, and the advantages which will help IDOT organize data and support other TAM components.

- Discussed the GAM process starting from establishing goals, then data collection and condition evaluation, performance modeling and projections, investment analysis and prioritization, communication, and process improvement.

- There was a significant discussion regarding the fundamental concepts on risk analysis and management. Risk management should be an integral part of GAM and used to evaluate the risks associated with performance and decision-making.

- The locations for the pilot were briefly introduced and given their geology and geohazards, Districts 8 and 9 are probably the most suitable for a pilot. D1 also has some interesting features and could be considered as part of the pilot, not necessarily to collect data but at a minimum to discuss the unique features in D1.

Plenary Session 1-2

After lunch the group reconvened to discuss the breakout groups assignments and the structure of the discussion, the intended goals, and the expected outcomes from the breakout sessions.

Breakout Groups (Day 1)

Group 1 (Facilitated by Ahmad Alhasan)

This group discussed the assets to be included in the GAM. These include (priority shown in square brackets):

- Retaining Walls [2]

- Cut slopes (consequences are big) [1]

- Rock slopes [5]

- Embankments, including earthen dams [3]

- Ground Improvements [4]

- Pavement foundations [6]. The GAM should at least inform the pavements office of recommended practices and sufficient information to be used in the design and the management of pavements.

- Typically, IDOT's geotechnical office interacts with the pavements group during construction. The two units also interact in situations when foundation related issues impact the pavement performance.

- Dryland bridges can be included as part of ground improvement assets.

- Culverts with a diameter greater than 6 ft are included in the bridge management program. Although smaller culverts can frequently fail, they could be a lower priority for early GAM implementation.

- Erosion control features (lower priority).

- Other ancillary assets can include high masts, overhead signs, and noise walls (these could be a lower priority for early-stage GAM implementation)

The group then discussed the deterioration mechanisms and sources of risk related to several aspects including performance, deterioration of condition, agency practices, technologies, and geohazards for the identified assets. Note that some of these risks overlap between assets and therefore should not be repeated.

- Deterioration and risks related to retaining walls include:

    - Impact loads (this is relatively low frequency and consequences).

    - Corrosion of reinforcement elements (this is relatively low frequency but could be a challenge because it is not easily observed or measured).

    - Drainage issues (middle level frequency but can have serious consequences, not very apparent, inspected every 5 to 10 years).

    - Concrete damage.

    - Railing damage due to impact loads.

    - MSE walls can be designed by wall system suppliers and there aren't well established requirements for some design elements.

    - Not accounting/ understanding the aging impacts through quantitative procedures and models.

    - Changing design practices and requirements.

    - Should define risk in terms of height relative to proximity to highway. For example, a 5 ft wall very close to the highway can pose a higher risk compared to the same wall if there is enough distance between the wall and the highway.

    - Risk should be related to the traffic levels.

- Risk will be affected if the wall supports a pavement versus adjacent walls.
- Traditionally, the bridge office includes walls with exposed heights of 8 ft or taller and assigns a structure number. Below that height the wall is considered as a geotechnical feature. There are no clear records of walls below 8 ft.
- One risk identified would be including too many walls at once and not being able to evaluate them leading to an incomplete attempt to establish the GAM program.
- Geohazards can include karst and underground abandoned mines. District 2 and the St. Louis area could be a district rich with interesting geotechnical assets and geohazards.
- Silt and loess soils.

- Deterioration and risks related to slopes include:
  - Water erosion and flooding (can be high risk especially for cut slopes).
  - Water can get channeled at the end of a curb and undermine the slope.
  - For steep fill slopes, the guard rails can tilt leading to serviceability risks.
- Deterioration and risks related to embankments include:
  - IDOT requires stability analysis for 15 ft heights toe to shoulder. Below that height embankments are not considered critical, which may impose a risk of ignoring problematic slopes.
  - The analysis may be required for embankment widening for heights less than 15 ft.
  - Settlement is one of the common performance issues related to embankments.
- Deterioration and risks related to rock slopes include:
  - Risks and deterioration can be related to joints and fractures.
  - Height and proximity of the slope is the main concern.
- The main risk associated with pavements at this stage is the note mentioned earlier that the geotechnical office is not always involved in the pavement projects.
- Deterioration and risks related to ground improvements include:
  - Can drill through utilities.
  - Lightweight materials can float, and fire can be a concern for geofoam.

- Deterioration and risks related to earthen dams include:
    - Rapid drawdown.
    - Trees and vegetation can be a concern leading to water infiltration.

Next, the group discussed the technologies needed to establish the GAM program and the challenges that can face IDOT.

- Start with historical records.
- Start with a desk study using the records or maybe LiDAR scans.
- Need to ask the geotechnical engineers about ground improvement projects (risk of losing knowledge from the DOT, knowledge management issues).
- Programming engineers can be inserting the data.
- Use the current bridge numbering and labeling system (can be modified by adding a fifth digit)
- One challenge in the future will relate to data ownership, who owns the data?
- Aerial LiDAR is interesting to explore, although have limitations.
- Non-physical assets can include the gINT to OpenGround database.

Group 2 (Facilitated by Darren Beckstrand)

- This group also discussed the assets to be included in the GAM. These include:
    - Walls
    - Soil fill slopes (Note: can have lower Factor of Safety, FOS, in practice; probably focus on higher risk slopes).
    - Slopes 15 ft in vertical height toe to shoulder or 1:1 slope are worth analyzing or being added to the inventory.
    - Soil cut slopes (Note: can have higher FOS in practice).
    - Rockfall above road.
    - Rock slope stability below the road.
    - Culverts with diameters 2 to 3 ft (smaller culverts can be overlooked however they fail frequently).

- The main challenge identified, and all present district representatives agreed on, was the availability of enough staff to inspect sites and creating the inventory.
- Dryland bridges were discussed and suggested to be included even though they may already be included in the bridge office inventory.
- Other ancillary assets that could be included in the GAM were:
    - Deep and shallow foundations not associated with bridges
    - Ground improvements
    - Soil nails
    - Micropiles
    - Subsurface drainage
    - Surface drainage control measures
    - Paved ditches
    - Structural landslide mitigation
    - Rockfall mesh
    - Rockfall fences
    - Concrete barriers for rockfall
    - Shotcrete (application for rock slope stability below the road)
    - Geotechnical instrumentation and exploration data (OpenGround Cloud)
- Next, the group discussed the technologies needed to establish the GAM program and the challenges that can face IDOT.
- The group discussed the historical plan database as an initial source of information (PDF plans).
- The GAM will need field laptops or tablets for data collection applications.
- The implementation stage could use photos from cell phones on demand.
- There could be some development issues for use of Android or iOS systems. Someone will need to check the requirements when developing Survey123 Application.

- Survey123 is an application in ESRI platform. We need to check if IDOT can provide the Research Team access and how many users IDOT can provide.

- A first step may need to use visual inspection (with some photos and condition evaluation uploaded using Survey123) and overlap it with LiDAR scans and use of the information from the pavement management system.

- Can use the Illinois Structure Inventory System (ISIS)

    - The system considers retaining walls 7 ft or higher.

    - It includes unique structure number for the assets. We may want to make sure the geotechnical assets can complement the database using a similar or connected numbering system.

    - All plans in the system are scanned for records beginning from 2005. Some plans prior to 2005 are scanned while some are still hardcopy.

- Geohazards mapping is still inconsistent throughout the state. Some resources include: 1984 USGS landslide map and the landslide records form the Illinois State Geological Survey (ISGS) from the University of Illinois Urbana-Champaign (UIUC).

- IDOT has UAVs which can be used to support the GAM and this study (the research team needs to follow-up on this for data collection and the pilot study).

- Should also consider LiDAR data including areal, terrestrial, and mobile LiDAR.

Plenary Session 2-1

The participants began the second day of the workshop with a brief recap of day 1 and introduced the topics to be discussed during breakout sessions. The plenary session was very brief to provide additional time for the breakout groups.

Breakout Groups (Day 2)

Group 1 (Facilitated by Ahmad Alhasan)

This group started with a discussion on the data inventory and the integration of the GAM data and program with TAM.

- The group noted that there is some data from the bridge office that can be migrated as a starting point.

- The Illinois Structure Inventory System (ISIS) is not necessarily the best place to start or host the GAM database. The GAM inventory could be independent at least at the start of the program but should consider using an existing system.

- Although it may be better to start outside the existing systems, IDOT should be aware of the future requirements if the GAM system may be merged with another system such as ISIS.
- IT needs to be heavily involved and informed of the process and updates to avoid future complications.
- The application to be developed in Survey123 can submit some data in between the data collection process before it is integrated into an existing system.
- IDOT will need to submit a project request and build a business case to obtain support for IT resources (may need to show ROI estimates and dollar amounts).
- IDOT is expecting that the GAM data will feed into IDOT's dTIMS.
- Deterioration models can be prepared outside dTIMS through a research project then be fed into it.
- Current process for other programs is to export shapefiles from the GIS system into dTIMS.
- For programming purposes, there is a need to identify and know the problematic areas and what are the issues associated with these locations.
- It is important to collect information that can help in understanding the impacts on safety (risk and cost).
- Need to build good records for preservation and maintenance practices.
- The GAM will help in finding the assets, measuring their condition and performance, and maintaining these assets.
- Geotechnical assets do fail but the failures are not currently well-captured.
- GAM can help with geohazards and resilience.
- There is a need to consider climate change and resilience. There are more rainfall events.
- GAM can be aligned with the All Hazards plan.
- Need to think of the impacts of GAM in freight and capacity if you have a geotechnical failure.
- GAM can align with the Rebuild Illinois (RBI) program.

The group took a short break from 10:00 to 10:15 AM

After the break, the group discussed the measures for the GAM program's progress and success:

- In TAM the goals are for network condition and relate to network performance targets.

- Need to start defining life cycle plans.
- Building an inventory is a great progress measure.
- Need high-level targets for GAM to relate to network performance. Need to define performance.
- Increased remaining service life will be a good measure of success.
- Reduced life cycle cost will be a good success measure.
- Using GAM to break the silos across TAM programs can be a great success by itself. All transportation infrastructure assets are supported by foundation elements/assets or are geotechnical assets.
- GAM can help in identifying problems before failure to increase proactive and preventive maintenance.
- An important communication tool could be white papers.

The group then discussed some of the current gaps that can impact GAM:

- There is no available database for geotechnical assets.
- Process to integrate new databases with existing databases/systems can be a challenge.
- Training and human resources will be a major challenge.
- Manpower is a challenge, and the group discussed the solution could be to use consultant or develop internal manpower.
- Condition evaluation procedures and deterioration models are ill-defined for geotechnical assets.
- Performance measures and models are ill-defined for geotechnical assets.
- Knowledge management can be a challenge.
- Defining roles and ownership and stewardship will be a challenge.
- Data management and who will maintain the program is a challenge.

Group 2 (Facilitated by Darren Beckstrand)

- The first topic discussed was the process to build the assets inventory. It is important to build in a method to enter the assets information into the new database (what are the protocols for data reporting)

- The protocol for data reporting and entry into a database will be developed in Task 3.
- For walls connected to bridges, there is a need to look into the policy on where walls stop and the abutment starts.
- In the discussion, the group discussed the challenge of low staffing to perform condition assessments. This challenge may lead to the need to outsource the condition assessment in the future.
- The next topic was who owns the GAM program?
    - The TAM group will not own the program.
    - Some districts do not have a geotechnical group.
    - Will likely need assistance from consultants.
- Some other needs discussed by the group are the development of deterioration models, performance measures, cost estimation models, budgets to achieve goals.

The group took a short break from 10:00 to 10:15 AM

- After the break, the group continued the discussion on who should provide feedback loops and improvement plans.
- D2 and D6 face maintenance issues.
- There is a need to have a module to record events and responses.
    - Scan the report and upload into a GIS application.
- The next topic discussed was the communication of GAM success with stakeholders.
- Should communicate with upper management and improve internal communication.
    - Maybe report success on a 1-year fact sheet
    - Some possible improvement measures can be reduced closure time or costs.
- Some communication tools are websites showing static reports or dynamic dashboards.
- The group then discussed some of the major gaps the GAM will face, these included:
    - Knowing where the assets are and having an inventory.
    - The staff is not familiar with the GAM concepts, need more training for a new and evolving concept.

- Gap in condition assessment process and what defines condition for the different assets.
- Enough resources and staff to implement a GAM program.
- Technology gaps can be resolved.
- NHI training course on GAM can be a good resource.

- The group concluded that the major challenges are:
  - Manpower
  - Resources
  - Policy

Plenary Session 2-2

Towards the end of the second day the attendees reconvened for a plenary session to discuss the findings and share concluding remarks with all attendees. Some of the topics discussed were:

- For the pilot program in this project and initial GAM implementation after the project, it is probably good to start with a desk study then start collecting data in the field.
- Pulling more detailed data (beyond a desk study) from existing plans can be actually more challenging and expensive compared to starting a new data collection program.
- It will be important to understand the level of work the GAM program will generate and to quantify the corresponding ROI.
- At an early stage the data collection may involve more human resources and at a later stage, with evolving technologies and a better understating of the program needs, human resources needed for data collection may reduce and will rely more on technology.
- The team will need to have a closer look at IDOTs manuals to help with developing the condition assessment procedures in Task 4.
- Some of the promising regions for pilot program are District 8 and 9 and maybe some desk studies for District 1.

WORKSHOP AGENDA

ICT Project No. R27-262

Developing a Framework for Establishing a Risk-Based Geotechnical Asset Management Program in Illinois

Background

This workshop is designed to aid Illinois DOT and the consultant research team in building a unique geotechnical asset management program for IDOT. Geotechnical assets represent the "foundational" platform for all other transportation infrastructure assets. Since the term "geotechnical assets" may be interpreted in several ways, a commonly accepted understanding and interpretation of that term is as follows. Geotechnical and foundational assets apply to all assets constructed directly on or in geomaterials (e.g., foundational assets supporting superstructures or buried assets) or of soil and rock. Depending on a specific application, a "geotechnical asset" may serve as a foundation of another asset, or the asset itself, or both. For example, an earth retaining structure may serve as both a foundation and an asset if it supports a pavement leading to a bridge or an abutment of a bridge. In that sense, geotechnical assets can fall under two major categories, stand-alone assets and support assets.

At this stage, IDOT's GAM can be viewed as a stand-alone program to manage geotechnical assets and be a service center to manage ancillary assets under other (TAM or resilience) programs. In addition, GAM will serve as a focal point for the information and data for all the geotechnical assets (stand-alone and ancillary) and projects. This data can help with managing the assets during their life cycle, evaluation for asset resiliency, and for designing new projects and evaluating alternatives.

In preparation of the workshop, we ask participants to send any good examples of major geotechnical assets, their deterioration mechanisms (if known), and practices for maintaining assets in good condition. We respectfully request that each participant provide at least one photo example of a typical geotechnical asset, identify effective preservation/maintenance activities, and topics of a particular IDOT need. Please send the examples before the new year to the IDOT workshop organizers. If the participants identify and share asset practices after the workshop these will be included in the appendices of the workshop report.

Workshop Objectives and Topics:

- Develop IDOT Team Building and Communication Channels for GAM
- Identify all pertinent units (Districts, Maintenance, Structures, Planning, Geotechnical, Pavements, Operations, Asset Management Specialists, Upper Management, etc.)
- Identify Gaps, Challenges, Risks and Required Resources
- Develop IDOT's Approach to Document and Demonstrate the Return on Investment (benefits from GAM could be qualitative or quantitative)

- Identify and Prioritize Asset Types
- Determine Asset Performance Requirements, and Inspection/Monitoring Protocols.
- Avoiding Big Data Overload
- Develop an Approach for Action Plans for Assets Experiencing Serviceability or Strength Distress.
- Approach and Process of How to Integrate GAM into the TAMP
- Identify Data Needs (sources of data, missing data, quality of data, etc.)

Workshop Schedule: January 3-4, 2024

January 3: DAY 1: 10:00am-4:30pm

January 4: DAY 2 8:00am-3-00pm

Logistics: the workshop will include Plenary sessions and Breakout Group sessions

- One ARA SME will be assigned as a facilitator, to each of the three breakout rooms to keep the group on track and on time related to the assigned session assignments.
- Each breakout group will identify a **recorder from their group participants** to keep notes and summarize the discussions.
- For the breakout sessions, each of the three groups will be assigned three to four topics/ questions to discuss, document the group's opinions and comments and provide feedback during the following plenary session. Each of the breakout groups will be assigned the same questions for each session.
- The ARA facilitator will identify the members ahead of the workshop and discuss the assignments again during the initial Plenary session. Although ARA will be provided a preliminary list of workshop participants, the actual participants may be somewhat different. The makeup of each breakout group will attempt to achieve a cross- section from IDOT units and offices. For example, each group may have representatives from planning, maintenance, geotechnical, structures, and the districts. It is understood that all group members may not contribute to each topic.
- Each group will be required to document their discussions and opinions and provide a 10-minute report summary at the next Plenary session. A written summary of each group activity will be provided to the Lead ARA SME at the end of each day.
- Plenary Sessions: Classroom style, two chairs per table. Set up for up to 35 participants with podium and table at front.

- Breakout Rooms: Theater style set up for about 10 participants with a table in the front. We will need 3 breakout rooms. We can use the plenary room for one of the breakouts.
- Large Screen, projector and two microphones for plenary room.
- ARA SMEs will keep workshop notes from plenary sessions and take notes at breakout sessions with assistance from the group recorder.
- Conclusions, and recommendations from the workshop will be documented by ARA in a Workshop Report.
- ARA will record the plenary sessions for the sole purpose of preparing the workshop report.
- ARA will take photos during the workshop and request that workshop participants sign a photo release form.

Moderators:

- Jerry DiMaggio, Ahmad Alhasan, Darren Beckstrand

Daily Agenda

Day 1:

- 10am - noon Plenary Session 1-1: Introductions, overview and objectives
- Noon - 1pm lunch (on your own)
- 1pm - 1:30pm Plenary Session 1-2: first breakout room assignment
- 1:30pm - 3:30pm First Breakout Group Session (includes a break)
    - Topics and expected outcomes are outlined in the table below.
- 3:30pm - 3:45pm Break to prepare for Plenary Session
- 3:45pm - 4:30pm Breakout groups report out at Plenary Session 1-3

ADJOURN Day 1

Day 2:

- 8:30am - 9:00am Plenary Session 2-1 (Recap Day 1 and discuss second assignment)
- 9:00am - 11:50am Second Breakout Group session (includes a break)
    - Topics and expected outcomes are outlined in the table below.
- 11:50am - 1:15pm lunch (on your own)
- 1:15pm - 2:30pm Plenary Session 2-2 (summary of Workshop findings, challenges, gaps and needs)

- 2:30pm - 3:00pm Plenary Session 2-3 Next Steps and future communications with participants through ICT channels

3:00pm-ADJOURN

Table 11 below provides a detailed agenda showing the expected outcomes or critical topics to be addressed in each session, with questions and tools that can guide the discussion to achieve the objectives from the sessions.

Table 11. Detailed Workshop Agenda with Expected Outcomes and Critical Topics

Session	Expected Outcomes/ Critical Topics	Questions	Discussion Tools and Strategies
Plenary Session 1-1 (Day 1: 10am -noon)	The overall purpose is to introduce the topics and concepts that can be used in breakout sessions		Present the current state of national practice. Present needs for GAM and anticipated ROI. Discuss current national GAPS in the Body of Knowledge.
	Define GAM	How should GAM operate? Is it a service center or another TAM program?	
	Introduce the question: what defines geotechnical assets?	Ask the question and discuss during breakout sessions	
	Discuss Assets Performance Evaluation	What defines performance and how to evaluate it	
	Discuss Assets Performance Requirements	What defines failure and limit states?	
	Data Needs (sources of data, missing data, quality of data, data management)	How would data collection programs look like and how can we include projects data?	
	Risk-based GAM Concepts of Return on Investment (ROI)	What does risk-based GAM mean? What is ROI mean in terms of success? Qualitative or quantitative? Funding consequences if preservation actions are not taken.	Discuss risk assessment and management and discuss the use of qualitative risk assessment as a tool in the workshop.
Noon – 1:00	Lunch Break (On your Own)		
Plenary Session 1-2 (Day 1pm -1:30pm)	Introduce breakout sessions, their structure, the questions and expected outcomes.		Provide milestones and major outcomes.

Session	Expected Outcomes/ Critical Topics	Questions	Discussion Tools and Strategies
First Breakout Group (Day 1, 1:30 pm - 2:30pm)	Define a list of critical geotechnical assets	• Which geotechnical assets are the most critical in Illinois? • What are the risks associated with these assets?	* Develop a risk register. * Perform qualitative risk assessment.
	Geotechnical assets as part of other TAM programs and ownership issues	• Should ancillary assets be separated from their respective programs? • What would be the challenges in managing geotechnical assets under other programs?	
2:30pm – 2:40pm	Break		
2:40pm – 3:30pm	Potential data collection practices	• What are the expected data collection technologies? (Visual versus objective measurements) • Resources for data collection? • Does IDOT have a good record of geotechnical projects? • What is the role of historical data? • In-house technology to leverage?	
3:30pm – 3:45pm	Break		
Plenary Session 1-3 (Day 1, 3:45pm - 4:30pm)	Each group reports out the breakout session summary (10 minutes per group)		
ADJOURN Day 1			

Session	Expected Outcomes/ Critical Topics	Questions	Discussion Tools and Strategies
Plenary Session 2-1 (Day 2, 8:30am – 9:00am)	Recap Day1 and discuss Breakout assignments.		
Second Breakout Group (Day 2, 9:00am – 10:00am)	Align the GAM process with IDOTs asset management processes	• What are the critical implementation steps? • How can the GAM process be incorporated in IDOTs TAM? • What are the appropriate Decision support tools?	Present the NCHRP process to the audience and start discussing what needs to move around
10:00am – 10:10 am	Break		
10:10 am– 11:00 am	Communication tools and documenting benefits	• How to measure program success? • How to document success and limitations? • Who should provide feedback loops and improvement plans? • How to communicate importance, success, and needs with different stakeholders?	
11:00am – 11:10am	Break		
11:10am – 11:50am	Identify Gaps (Knowledge and Data), Challenges, Risks and Required Resources	• What are the major knowledge gaps that IDOT has? • What do you think are the major challenges IDOT will face in implementing GAM?	

Session	Expected Outcomes/ Critical Topics	Questions	Discussion Tools and Strategies
		• What are the financial and human resources needed in the future?	
11:50am – 1:15pm	Lunch Break (On your Own)		
Plenary Session 2-2 (Day 2, 1:15pm – 2:30pm)	• Each group reports out the breakout sessions summary (10 minutes per group, 30 minutes total) • Summary of Workshop findings, challenges, gaps and needs (45 minutes)		
Plenary Session 2-3 (Day 2, 2:30pm – 3:00pm)	Next Steps and future communications with participants through ICT channels		
ADJOURN Day 2			

ADDITIONAL GAM PROGRAMS LITERATURE

This section provides more detailed reviews for some of the established GAM programs in 5 states and some of the procedures outlined in NCHRP. The review includes examples of risk assessment procedures, condition evaluation procedures, deterioration models, and some analytical tools and components of life cycle cost analysis.

Georgia

Georgia Department of Transportation (GDOT) has recently implemented a risk-based Geotechnical Asset Management (GAM) program (Macedo, et al., 2023). The GAM program considers the following assets: retaining walls, slopes, embankments, bridge foundations, and "other geo-assets", which include box culverts and high mast lighting foundations. GDOT's GAM is based on the method proposed in National Cooperative Highway Research Program report no. 903 (NCHRP-903) (Vessely, et al., 2019). Figure 50 presents the GAM framework adopted by GDOT. It has three parts: inventory, inspection, and development of GAM parameters.

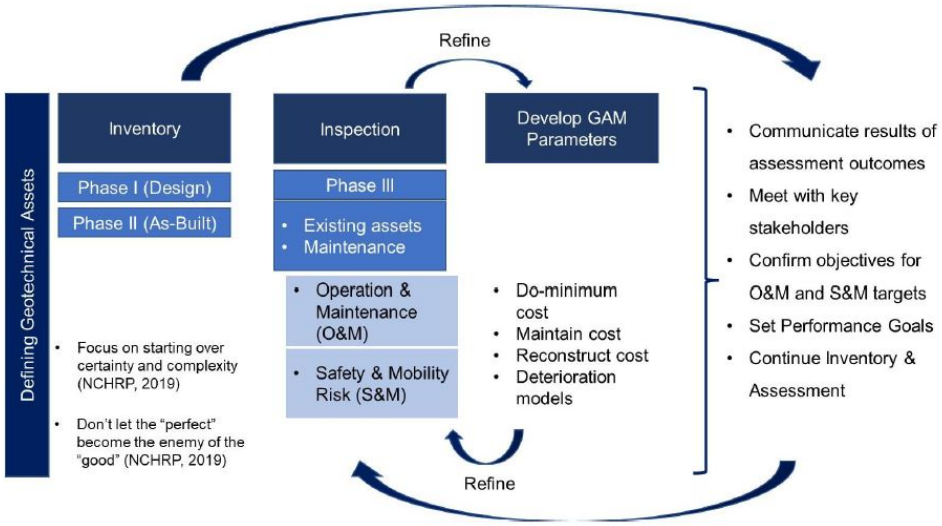


Figure 50. Illustration. GAM framework in Georgia.

Source: Macedo et al. (2023)

The first part of GDOT's GAM program is the creation of an inventory. It can be created either during the design phase of a new geotechnical asset or after the construction, which applies to existing structures. During the inventory creation process, the following features of the geotechnical assets were recorded to create a robust record, starting with attributes (identifying information), location, classification, geometry, inspection routine, and engineering details. In the inspection phase, the condition state of the assets is rated based on the observed distresses and deteriorations. It is a numerical scale ranging from 0-5, with 0 being the ideal or perfect condition and 5 being the worst. During the condition rating, the physical deterioration and the operation and maintenance (O&M) schedule to fix that deterioration are considered. For example, suppose a wall is showing medium to

high distress, compromised wall elements, exposed reinforcements, blocked drainage, and requires periodic maintenance. In that case, the wall is categorized to be in poor condition with a rating of 4. Like NCHRP-903, GDOT also considers the safety and mobility consequences of deteriorated or failed geotechnical assets through a rating scale ranging from 0 to 5, with a higher number representing severe consequences. The geotechnical asset's Level of Risk (LOR) is determined by multiplying and summing the safety and mobility consequences with the condition rating score, with a higher number signifying a higher risk.

GDOT uses three programs for the implementation of their GAM program. Field maps are used to gather geo-asset features to create an inventory. After that, Survey123 is used for the assessment of the assets. The information collected using these two platforms is fed into the ArcGIS platform for visualization.

GDOT has yet to adopt a data collection strategy using LiDAR, InSAR, or photogrammetry. Two concept studies showed promising results that intended to classify retaining wall images using machine learning. GDOT also does not have deterioration models specific to the conditions of Georgia at this initial stage of GAM.

Wisconsin

WisDOT performed a pilot study on GAM for slopes along Wisconsin State Highway 35 (WI-35) between milepost 60 and 90. The study corridor was divided into 25 ft segments. For each segment, several parameters were extracted using Geographic Information System (GIS) and LiDAR, which are shown in Figure 51 (Anderson, Vessely, Dowling, & Carter, 2022). Field inspections were also conducted to verify the geohazards present in the study corridor. Colluvial slides, rockfall from bedrock units, and rockfall sourced from colluvial erosion are geohazards associated with cut slope sides. Damage to the concrete wall barrier along the cut slope side was identified as a key indicator of adverse slope performance. Field observation data were also used to develop a conceptual geological model for the study corridor to identify the dominant hazard mechanism based on the materials.

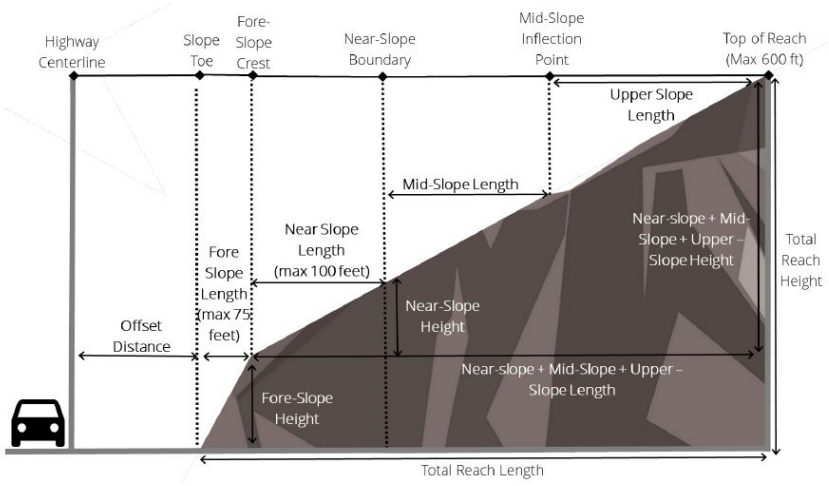


Figure 51. Illustration. GIS and LiDAR based Parameter Extraction for Slope Failure Model.

Source: Anderson et al. (2022)

Statistical analyses were performed to identify the parameters that can be used to predict the geohazards. Fore slope angle, near slope angle, fore slope height, and total slope angle were found to provide the best prediction of geohazards. These parameters were used to calculate the conditional probability of hazard, i.e., given a value of a parameter, calculate the probability of hazard. These conditional probabilities were converted to thematic weights, or hazard scores, which can take values from positive to negative. Positive weight represents a high susceptibility to failure, and negative weight represents a lower susceptibility to failure. The hazard scores were further categorized into high, medium, and low qualitative hazard susceptibility ratings for integration into the GAM.

The developed slope hazard GAM did not consider different upslope failure mechanisms. For example, the model was developed considering some parameters, such as fore slope angle, near slope angle, fore slope height, etc. It did not consider whether the slope failure occurs due to the rockfall or colluvial slide. Moreover, slope setback distance from the highway, condition of the slope, adjacent land use, etc., were also not considered in the developed model.

Missouri

Missouri Department of Transportation (MoDOT) developed a GAM program for six types of geotechnical assets: embankments, retaining walls, rock slopes, soil slopes, subgrade improvements, and subsidence. Subgrade improvements were not considered at this stage of the MoDOT GAM program. It is included as a placeholder to be implemented in future versions of GAM. MoDOT GAM program requires field surveys by expert geologists and geotechnical engineers. During the field survey, two types of data were processed through an application called Survey123. The first one is the general site information, and the second one is detailed rating categories. Much of the general information was common across different geotechnical assets, such as AADT, speed limit, and sight distance, while others were asset specific. This general site information is not directly used to determine the asset conditions; rather it may be used to determine a factor required in the detailed calculations. The primary use of the general site information is to group or filter the data. For example, general site information requires input on the repair work done on the asset. This information is not used in scoring but filters the data.

On the other hand, the speed limit is not directly scored, but is used in the calculation of the percent decision sight distance and average vehicle risk scores. The detailed rating categories are used to assess the condition of the geotechnical assets. There are a total of 37 detailed rating categories, but not all of them are shown in the Survey123 application during the survey. Based on the general information, detailed ratings corresponding only to the appropriate asset are shown. Depending on the categories, the detailed rating of asset conditions may follow a linear or nonlinear trend. For example, the score based on AADT follows a nonlinear trend, while the score based on average vehicle risk follows a linear trend. Moreover, no rationale was provided for selecting the maximum or minimum threshold values for a particular category; for instance, an AADT less than 1000 receives a maximum score of 100, while an AADT of 25000 or more receives a score of zero. The average of the detailed score is used to determine the condition state.

The condition scores of the asset were divided into five categories: good, satisfactory, fair, poor, and failed. These five categories were converted to good, fair, and poor ratings to be consistent with the MoDOT's TAM program.

The level of risk of a geotechnical asset is determined using the condition state score and probability of consequences, which is a function of AADT, roadway width, and percent decision sight distance score, as shown in Figure 52.

$$Level\ of\ Risk = \frac{Event\ Likelihood + Probability\ of\ Consequence}{2}$$

Figure 52. Equation. Level of risk of a geotechnical asset using condition state score and probability of consequence.

Here, probability of consequence, Figure 53, and event likelihood is the average of condition state. Due to the unviability of the event likelihood data within MoDOT, it was not possible to develop a quantitative relation to predict the event likelihood from the condition state. Thus, they were taken to be equivalent to each other. The risk matrix for MoDOT GAM program is shown in Figure 54.

$$Probability\ of\ Consequence = \frac{AADT\ Score + (\frac{Roadway\ width + \%decision\ sight\ distance\ score)}{2}}{2}$$

Figure 53. Equation. Probability of consequence based on AADT, roadway width, and decision sight distance score.

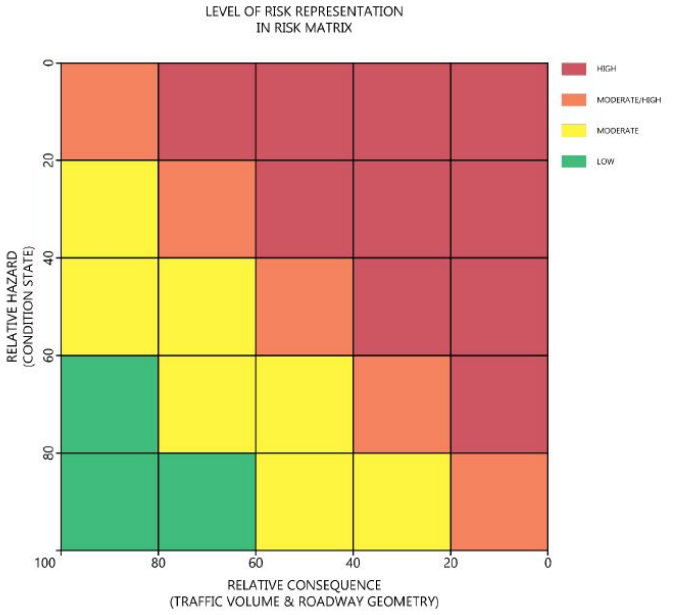


Figure 54. Graph. Risk Matrix for MoDOT GAM Program.

Source: Mines et al. (2022)

Alaska

Four types of geotechnical assets were considered in the GAM program adopted by the Alaska Department of Transportation and Public Facilities (Beckstrand, et al. 2017a). They are rock slopes, soil slopes and embankments, retaining walls, and material sites. During the field inventorying process, the rock and soil slopes were divided into three categories: class A, class B, and class C. Class A represents an asset that shows signs of instability and requires regular maintenance, and class B represents assets that show signs of minor instability and are unlikely to require maintenance, and class C represents assets with no signs of instability and will not affect roadways in the event of failure. Rock and soil slopes categorized as Class A and B received detailed ratings, while Class C did not. The preliminary rating for rock and soil slopes is done by Maintenance and Operations (M&O) supervisors, while the geotechnical engineers or geologists do the detailed ratings. The detailed ratings for rock and soil slopes are divided into two parts: hazard rating and risk rating. These two parts of detailed ratings have several categories, which can range from 0 to 100, with 100 being the worst scenario. In many instances, there are explicit equations to determine the hazard and risk rating for a particular category. In the event explicit equations are not available, the rating is done using the qualitative conditions according to the engineering judgment. For example, the hazard rating of a larger block of rockfall is determined using Figure 55.

$$Block\ size\ score = 3^x$$

Figure 55. Equation. Rockfall block size score.

Here, x is the block size in linear feet, and the maximum score is 100. On the contrary, ditch effectiveness, an important rating category for rock slope assessment, is based on the experience of the engineer, as shown in Table 12.

Table 12. Rock Slope Hazard Rating of Ditch Effectiveness

Ditch Effectiveness	Score
Good	3
Moderate	9
Limited	27
Not Effective	81

Source: Beckstrand et al. (2017a)

There were some categories that were common in both the hazard rating of soil and rock slopes. For example, the effect of precipitation and drainage was considered in the detailed hazard rating for both the rock and soil slopes as they can initiate the movement of the materials. Some hazard categories were asset-exclusive, such as the freeze-thaw effect on soil slopes and the erosion rate of rock slopes.

Unlike rock and soil slopes, the retaining walls were not categorized in Class A, B, or C prior to rating. They were assessed after meeting the following criteria:

a) Not within a bridge zone

b) Highway walls must be at least 4 ft tall at the maximum height location

c) Culvert walls must be at least 6 ft tall at the maximum height location

d) Regardless of the height or setback, any wall that showed signs of deterioration, which could impact the roadway, was assessed

Along with the hazard and risk rating categories, the Retaining Wall Management Program (RWMP) of AKDOT&PF also included the appearance rating category. Both non-technical general people and engineers can form opinions based on the physical appearance of the retaining walls. Thus, the appearance rating category has two subcategories: technical appearance and public perception.

Although the detailed hazard ratings are based on 8-9 categories depending on asset type, only a few of these categories are used to determine the Condition States (CS). Condition states have three categories, i.e., good, fair, and poor. As mentioned earlier, based on the field condition, the detailed rating category provides a rating from 0 to 100, with 100 being the worst condition. This field rating scale is based on the AKDOTP&F's Unstable Slope Management Program (USMP). The TAM program in Alaska is also based on a rating scale of 0 to 100, with 100 representing the best condition. Hazard ratings were converted to "Condition State Element Score (CSES)." This CSES score is used to determine the Condition Index (CI), which matches the TAM rating. The conversion of the detailed hazard rating of a retaining wall from the USMP scale to CI and CS, which is equivalent to the TAM rating, is shown in Figure 56 to Figure 59.

$$CSES = 100 - \left[25 \times \left(\frac{\ln\left(USMP\ SCore\right)}{\ln(3)} - 1\right)\right] \text{ if } 0 < \text{category score} \leq 81$$

Figure 56. Equation. Condition State Element Score for category scores greater than 0 and less than or equal to 81.

$$CSES = -1.3158 \times USMP\ Score + 131.58 \text{ if } 82 < \text{category score}$$

Figure 57. Equation. Condition State Element Score for category scores greater than 82.

$$Condition\ Index\ (CI) = \frac{Alignment\ CSES + Road\ Displacement\ CSES + Component\ Health\ CSES}{3}$$

Figure 58. Equation. Condition Index calculation.

$$Condition\ State\ (CS) = roundup\left[\frac{100 - CI}{20}\right]$$

Figure 59. Equation. Condition State calculation.

Consequence of Adverse Event

The objective of the GAM project is to minimize the life cycle cost of the assets for the agency and maximize safety and mobility. Due to the fixed budget of the agency, it may be difficult to allocate money to projects that require rehabilitation or maintenance based on either safety or preservation concerns. In this regard, it is beneficial to determine the safety and mobility costs.

Three scenarios were considered to determine the mobility disruption cost due to an adverse event. The first scenario is based on the disruption of less than an hour, and the detour is longer. If the road closure due to an adverse event of a geotechnical asset is less than an hour, then the user is likely to wait on the road unless the detour is shorter. In this scenario, the mobility cost is determined using Figure 60.

$$M\$ = \frac{ADT}{48} \times 0.25 \times TT\$ \times VO$$

Figure 60. Equation. Mobility cost calculation for disruptions less than an hour with an available detour.

Here, *ADT over 48* is the number of vehicles to arrive at the site in one-half hour, *TT$* is the value per hour of a vehicle occupant's time ($30.5 in 2015), and *VO* is the average vehicle occupancy rate.

The second scenario is based on the disruption of more than an hour with an alternate route. In this scenario, the mobility cost is determined using Figure 61.

$$M\$ = ADT \times DD \times (DL \times VOC\$ + \frac{DL}{DS} \times TT\$ \times VO)$$

Figure 61. Equation. Mobility cost calculation for disruptions more than an hour with an available detour.

Here, *ADT* is the number of vehicles per day that normally use the route, *DD* is the number of days the traffic is detoured, *DL* is the detour length in miles, *VOC$* is the average vehicle operating cost per mile ($0.207 in 2015), *DS* is detour speed in mph.

For disruption of more than an hour with no available detour, the mobility cost is determined using Figure 62.

$$M\$ = ADT \times DD \times VO \times AM\$$$

Figure 62. Equation. Mobility cost calculation for disruptions more than an hour with no available detour.

Here, *AM$* is the alternate mode cost.

Threat to safety is defined as the number of vehicular crashes that occur due to an adverse event. These vehicular crashes can be either a vehicle being struck by debris, a vehicle striking the debris already on the road, vehicular crashes due to the loss of control by trying to avoid the debris, or pavement damage. The safety disruption cost is estimated using Figure 63.

$$S\$ = AC \times ACC\$$$

Figure 63. Equation. General safety disruption calculation.

Here, *AC* is the accident count, *ACC$* is the average cost per crash ($43,525 in 2015)

After an adverse event, some costs are associated with restoring the service to normal condition. This is called recovery cost. The estimate of the potential cost of an adverse event is as follows:

- Acceptable: costs are less than $10,000
- Low: costs are between $10,000 to $50,000
- Minimal: costs are between $50,000 to $100,000
- Major: costs are between $100,000 to $250,000
- Catastrophic: costs are greater than $250,000

Based on the magnitude of the adverse event, the cost range is assessed in the field, and recovery cost is taken to be the midpoint of the applicable cost range as shown in Figure 64.

$$R\$ = midpoint\ of\ cost\ range$$

Figure 64. Equation. Adverse event cost calculation.

The total cost of service disruption due to an adverse event of a geotechnical asset is determined from the summation of mobility cost, safety cost, and recovery cost. as shown in Figure 65.

$$Consequence = M\$ + S\$ + R\$$$

Figure 65. Equation. Total cost of service disruption calculation.

The economic value of the risk associated with any geotechnical asset is determined using Figure 66.

$$Value\ of\ Risk = Likelihood \times Consequence$$

Figure 66. Equation. Economic value of risk calculation for any geotechnical asset.

Where, *Likelihood* = 365/ (*Return Period*).

Deterioration Model

Alaska's GAM project also includes a deterioration model. This deterioration model is based on Markov's model. The probability of a structure remaining in the same condition state j after one year is represented using Figure 67.

$$p_{jj} = 0.5^{1/t}$$

Figure 67. Equation. Alaska GAM asset deterioration model.

Here *t* is the median transition time required to migrate from condition *j* to the next worst state *k*. The probability of transitioning from state *j* to state *k* in one year is shown in Figure 68.

$$p_{jk} = 1 - p_{jj}$$

Figure 68. Equation. Alaska GAM asset deterioration transition model.

A historical database of the condition of the asset is typically required to predict the future condition of the asset using the Markov model. This historical database is used to generate the transition probability matrix. This matrix is multiplied by the vector of the current condition of the asset to determine the future condition state vector. In the event of unavailability of the historical condition data, expert opinion can be used to generate the transition probability matrix (Beckstrand, et al., 2017a).

Maintenance and Life Cycle Cost

AKDOTP&F GAM program used the condition states to estimate the geotechnical assets' high-level mitigation or improvement costs. These mitigation cost estimates were not suitable at the project level but appropriate for the network level. For rock slope and unstable soil slope, the estimate of mitigation cost by condition slope was developed using the data from MDT and the Washington Department of Transportation (WSDOT). The mitigation costs for the retaining walls were based on the bid data. Projected costs for the improvement of the material sites were obtained from the departmental records on permitting and developments, as well as input for the key personnel.

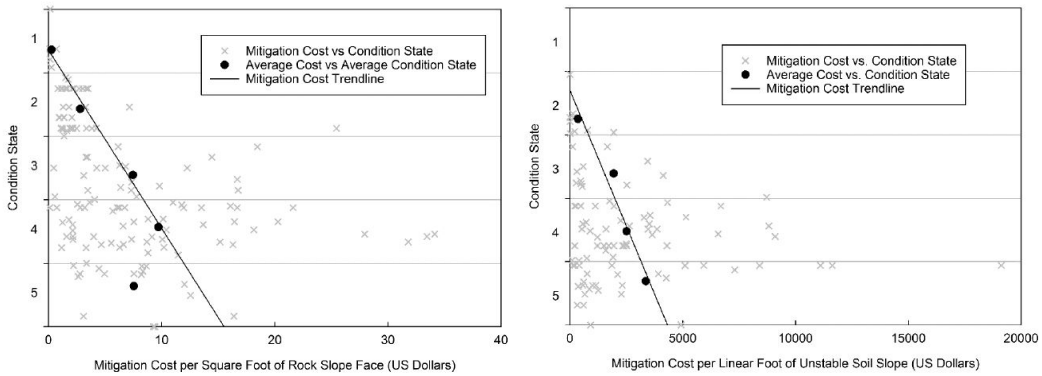
The mitigation or improvement of the rock slope was based on the square footage estimate of the average rock slope face. Initially, it was assumed that the rock slopes were vertical and that the area of a triangle could approximate the rock slope face area. Based on the detailed inspection of the photographs of the selected rock slope sites, a multiplier of 0.65 was used to determine the area, as shown in Figure 69.

$$Area = 0.65hl$$

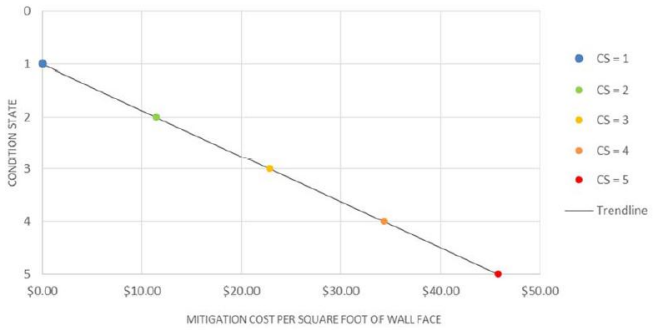
Figure 69. Equation. Area estimate of the average rock slope face.

Here, *h* is the height of the slope and *l* is the length of the rock slope along the roadway.

Figure 70 presents the mitigation cost for various geotechnical assets in Alaska by condition state. A linear relationship was developed for each asset type using the average condition state and associated mitigation costs. The coefficients of the condition state represent the base mitigation cost. It was increased by 105% to consider both the average mitigation cost and relevant overhead costs, such as mobilization, traffic controls, etc.



(a) Rock Slope (b) Unstable Soil Slope



(c) Retaining Wall

Figure 70. Graph. Mitigation cost for different types of geotechnical assets by condition state.

Source: Beckstrand et al. (2017a)

As an example, Table 13 presents the average condition state and cost for the top 100 rock slope sites obtained from the MDT data. The coefficient of 3.524 for the condition state was found by plotting mitigation cost vs average condition state. This coefficient was increased by 105% to include the overhead cost, which is around $3.7. Thus, the total mitigation cost per sq ft to improve the condition of a rock slope by a condition state of 1 was $7.224.

Table 13. Average Condition State and Average Mitigation Cost for Top 100 Rock Slope Sites

Condition State Category	Average Condition State	Average Mitigation cost per ft^2 without overhead in US Dollars
1-Good	0.64	0.26
2-Fair	1.57	2.79
3-Fair	2.61	7.46
4-Poor	3.43	9.72
5-Poor	4.36	7.54

Source: Beckstrand et al. (2017a)

The approximate total cost required to improve the condition of an asset by a certain condition state category, for example, improve the condition of a rock slope by two condition state categories, is determined based on the mitigation cost, which includes the overhead. Table 14 presents the approximate total cost required to improve the rock slope by a certain number of condition states.

Table 14. Approximate Total Cost for Improving a Rock Slope by a Certain Number of Condition States

Number of Condition States Improved by Mitigation Activities	Average Mitigation Cost per ft^2 without Overhead (US Dollars)	Average Mitigation Cost per ft^2 including Overhead (US Dollars)
1	3.56	7.3
2	7.12	14.6
3	10.68	21.9
4	14.24	29.2

Source: Beckstrand et al. (2017a)

Tables similar to Table 14 were generated for other geotechnical assets as well. These tables represent the unit costs associated with a single generic treatment plan. They were used to determine the life cycle cost analysis of the treatment plans. Table 15 presents the unit costs and application rates used in the life cycle cost analysis of rock slopes. The application rates were obtained from the expert opinion. A rate less than 1 indicates that a rock slope can remain in the same condition for more than a year before the application of the treatment, and a rate greater than 1 means that some sites may receive more than one application of treatment in a year.

The rightmost column in Table 15 is the total cost of the treatment plans for the rock slope assets for the present year based on their current condition if the stated unit cost and application rates are adopted.

Table 15. Treatment Unit Costs and Application Rates for the Rock Slopes

Treatment model	Percent acted upon each year, starting in each state					Unit cost	Total cost
	State 1	State 2	State 3	State 4	State 5	$/sq.	$k/year
Routine maintenance	0.00%	10.00%	100.00%	150.00%	1000.00%	0.26	4,415
Corrective action							
Improve by 1 state		0.11%	3.19%	1.54%	5.00%	7.30	2,529
Improve by 2 states			3.47%	0.84%	0.27%	14.60	4,487
Improve by 3 states				3.86%	0.25%	21.90	3,491
Improve by 4 states					0.98%	29.20	0
Total percent improved	0.00%	0.11%	6.66%	6.24%	6.50%		10,507
Reconstruct/relocate	$ 58.40/sq.ft						

The developed deterioration model could forecast the change of condition of the assets from one year to the other. These forecast conditions could be used to determine the associated treatment costs. Figure 71 was used to determine the life treatment cost.

$$LCSC = \sum_{y=0}^{N} df_y Q \sum_j x_{jy} \left(mc_j + \sum_a ce + ca_{jay} cc_a + ra_{jy} rc + lhd_j csq \right)$$

Figure 71. Equation. Life cycle associated treatment costs calculation.

$$df_y = {}^{1}/_{(1+d)^y}$$

Figure 72. Equation. Discount factor calculation for life cycle associated treatment costs.

Here, df_y, Figure 72, is the discount factor with discount rate *d* for year *y* computed from df_y ,*N* is the analysis period, 200 years, *Q* is the quantity of asset, x_{iy} is the fraction of inventory forecast to be in state *j* in year *y*, mc_j is the unit cost of routine maintenance in state *j*, *ce* is the corrective emphasis, ca_{jay} is the treatment application rate for state *j*, action *a*, and year *y*, cc_a is the unit cost of corrective action *a*, ra_{jy} is the application rate for reconstruction in state *j* and year *y*, *rc* is the unit cost of reconstruction, lhd_j is the likelihood of service disruption for condition state *j*, and *csq* is the consequence of the service disruption.

Montana

The Montana Department of Transportation (MDT) first adopted a Rockfall Hazard Rating System (RHRS) between 2003 and 2005. The initial RHRS program evaluated 2563 rockfall sites. Among these initially reviewed rockfall sites, 869 sites received a detailed rating. In 2015, MDT decided to update the RHRS to aid in project selection to mitigate rockfall hazards and incorporate the principles of TAM. As a part of the research project, field evaluations were conducted to evaluate the rock slopes

with newly adopted rating systems. Critical sites were identified from the field evaluations, and a benefit-cost ratio was performed to determine the appropriate hazard mitigation strategy.

MDT modified the initial RHRS and developed three new rating systems. These three new systems were used to evaluate the rockfall sites from the 2004 data. This was done to compare the old rating method with the new one. The hazard categories used in the new rating methods are very similar to the one adopted by AKDOTP&F.

Rating Method 1

Rating method 1 has four hazard categories, and each category can have a maximum value of 100. The rating method one, along with its hazard category, are shown in Figure 73.

$$Method\ 1 = Ditch\ Effectiveness + Traffic\ impacts + Failure\ Potential + Rockfall\ History$$

Figure 73. Equation. MDT Rating Method 1 for rockfall hazard.

Ditch effectiveness and rockfall history are obtained from the similar exponent-based rating obtained from AKDOTP&F. Traffic impact is determined from the Annual Average Daily Traffic (AADT) using Figure 74.

$$Traffic\ Impacts = 0.0082 \times AADT$$

Figure 74. Equation. MDT traffic impact calculation for rockfall hazards.

The potential for failure is a function of structural condition, rock friction and block size or volume.

Rating Method 2

Rating method two is based on the following hazard rating categories: ditch effectiveness, traffic impacts, immediate hazard, failure potential, the scale of the threat, and rockfall history. Similar to earlier methods, each hazard category has a maximum score of 100. Thus, the total score a rockfall site can have under rating method 2 is 600.

Rating Method 3

Rating method three is based on slope rating, vehicular risk, and impact on traffic. Slope rating is determined from the summation of ditch effectiveness, failure potential, and rockfall history. The maximum score of slope rating is 300. The second component of rating method 3 is vehicular risk, which is determined from the summation of roadway width and sight distance. This second component is based on a vehicle's ability to avoid a fallen rock on the road.

The exponent-based RHRS were converted to TAM-compatible scores, i.e., 0 being the worst condition and 100 being the best, using a methodology similar to Figure 56 to Figure 59. Similar to the Level of Service (LOS) in the transportation system, the Rockfall Asset Management Program (RAMP)

was also divided into six performance classes from A to F. The definition of RAMP performance classes is shown in Table 16.

Table 16. Performance Class and Level in RAMP Program

RAMP Performance Class	Performance Level
A	Very High
B	High
C	Minimum Acceptable
D	Unfavorable
F	Failing

This RAMP classification was used as a support tool to identify the possible candidates for mitigation, as shown in Table 17. For example, RAMP performance class A is associated with rockfall sites beside interstate highways. Thus, it has strict cutoff scores compared to other classes. For RAMP classification A, the rockfall sites that are in the worst 15th percentile in various rating categories are chosen for mitigation.

Table 17. Minimum Cutoff Scores Based on RAMP Performance Class

RAMP Class	Cutoff Scores	Mitigation Strategy
A	Condition Index/ Condition State: <35/ Poor (4/5)	Worst 15th Percentile
	Total RHRS Score: >450	
	Method 1: >175	
	Method 2: >280	
	Method 3 Slope Rating: >160	
B	Condition Index/ Condition State: <30/ Poor (4/5)	Worst 10th Percentile
	Total RHRS Score: >485	
	Method 1: >190	
	Method 2: >305	
	Method 3 Slope Rating: >175	
C	Condition Index/ Condition State: <25/ Poor (5)	Worst 5th Percentile
	Total RHRS Score: >550	
	Method 1: >215	
	Method 2: >345	
	Method 3 Slope Rating: >200	

Likelihood of Adverse Event

A likelihood of service disruption by the condition state of the rockfall hazard is determined for the MDT's GAM program. This table of the likelihood of adverse events was generated from the survey responses of the district geotechnical engineers. The survey asked the engineers to provide information about rockfall events that had affected the transportation system, particularly road

closure, work zone slowdown, vehicle property damage, and injury accidents. For a particular condition state, the likelihood risk of service disruption is determined from the summation of rock slope face areas that had exhibited adverse events in the past and total rock slope areas in that district. Table 18 presents the likelihood of service disruption and injury due to rockfall hazard in Montana.

Table 18. Likelihood of Service Disruption and Injury Accident due to Rockfall in Montana

Condition State (CS)	Annualized Risk of Service Disruption per sq ft of rock face (ARmob)	Annualized Risk of Injury Accident per sq ft of rock face (ARinj)
1	9.51E-09	9.51E-10
2	6.45E-08	6.45E-09
3	1.34E-07	1.34E-08
4	2.04E-07	2.04E-08
5	2.73E-07	2.73E-08

Source: Beckstrand et al. (2017c)

The probability of Likelihood Disruption (*LD*) of mobility or injury is determined using Figure 75.

$$LD = AR \times Area\ of\ Rockslope\ face$$

Figure 75. Equation. MDT likelihood of Disruption calculation for rockfall hazards.

Consequence of Adverse Event

The MDT GAM program uses equations similar to AKDOTP&F to determine the mobility, safety, and recovery cost due to a rockfall event. However, mobility and recovery costs were multiplied by the likelihood of service disruption, and safety costs were multiplied by the likelihood of injury to determine the respective annual consequences. For example, projected annual mobility consequences for rock slope 's' is determined using the Figure 76.

$$AM\$_s = AR_{mob} \times M\$_s$$

Figure 76. Equation. MDT projected annual mobility consequence costs calculation.

Here, $AM\$_s$ is the projected annual mobility consequences of slope *s*, AR_{mob} is the annual likelihood of service disruption at slope *s* determined from Table 18, and $M\$_s$ is the mobility cost of service disruption by slope *s*.

The total risk cost or annual cost for a rock slope hazard is calculated using Figure 77.

$$RC = AS\$ + AM\$ + AR\$$$

Figure 77. Equation. MDT total risk or annual cost calculation for rock slope hazards.

Here *AS$* is the projected annual safety cost of an individual disruption caused by the slope and AR$ is the projected annual recovery cost of an individual disruption caused by the slope. This annual cost or risk cost is applicable till the improvement or rehabilitation measures are performed on the rock slope. After the improvement measure, the risk cost will be reduced. This difference in risk cost is taken as a benefit. From this benefit and cost of improvement measure, a benefit-cost ratio can be determined to prioritize the projects requiring improvement in the event of funding constraints.

MDT GAM program uses Lifetime Risk Cost (LRC) to compare the rock slope condition improvement alternatives. It is shown in Figure 78.

$$LRC = RC \times \frac{1 - (1 + r)^{-T}}{r}$$

Figure 78. Equation. MDT Life Cycle Risk Cost calculation for rock slope hazards.

Here, *r* is the discount rate, and *T* is the lifespan of improvement.

NCHRP-903

NCHRP-903 (NCHRP 2019a, 2019b) proposes a risk-based GAM program for transportation agencies. It has six steps. The first step involves setting up the inventory. It recommends focusing on the development of a simplified risk-based GAM program at the early stages. This step includes obtaining preliminary information about the assets, such as identifier, age, type, location, and geometric properties. In the second step of the GAM program, a decision tree is used to obtain the condition of the asset. The condition of the structure is determined based on the visual inspection and the level of effort needed to maintain the assets in a good state. Figure 79 presents the Asset Condition (AC) determination decision tree based on the Operation & Maintenance (O&M) criteria.

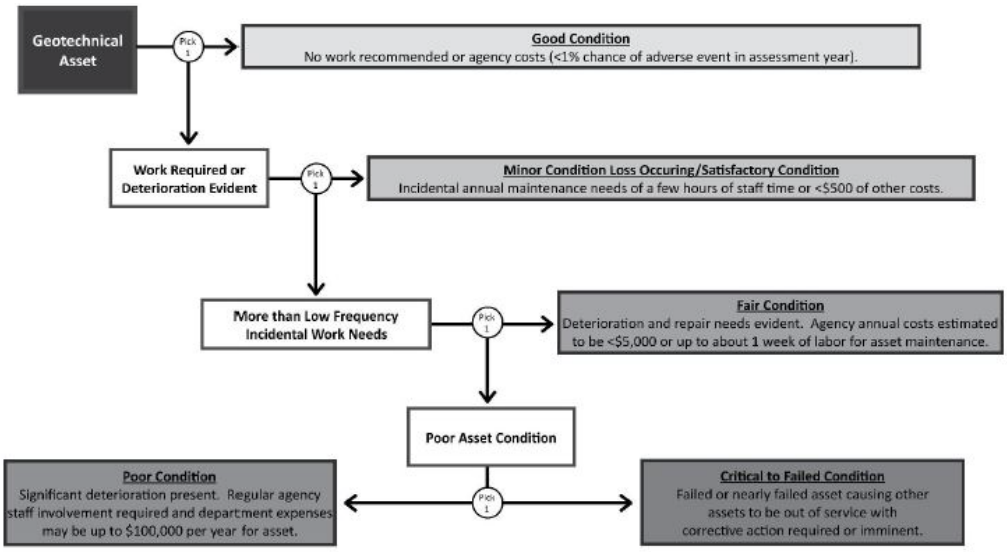


Figure 79. Flowchart. Condition of the geotechnical assets based on the O&M criteria.

Source: Vessely et al. (2019)

The third step evaluates the performance consequences. An important part of the risk-based asset management program is the evaluation of the performance consequences of asset deterioration or failure. There are two parts to performance consequences: Safety Consequences (SC) and Mobility Consequences (MC).

Mobility consequences consider the delays and closures arising from the failure of the geotechnical assets. Figure 80 presents the mobility consequences decision tree.

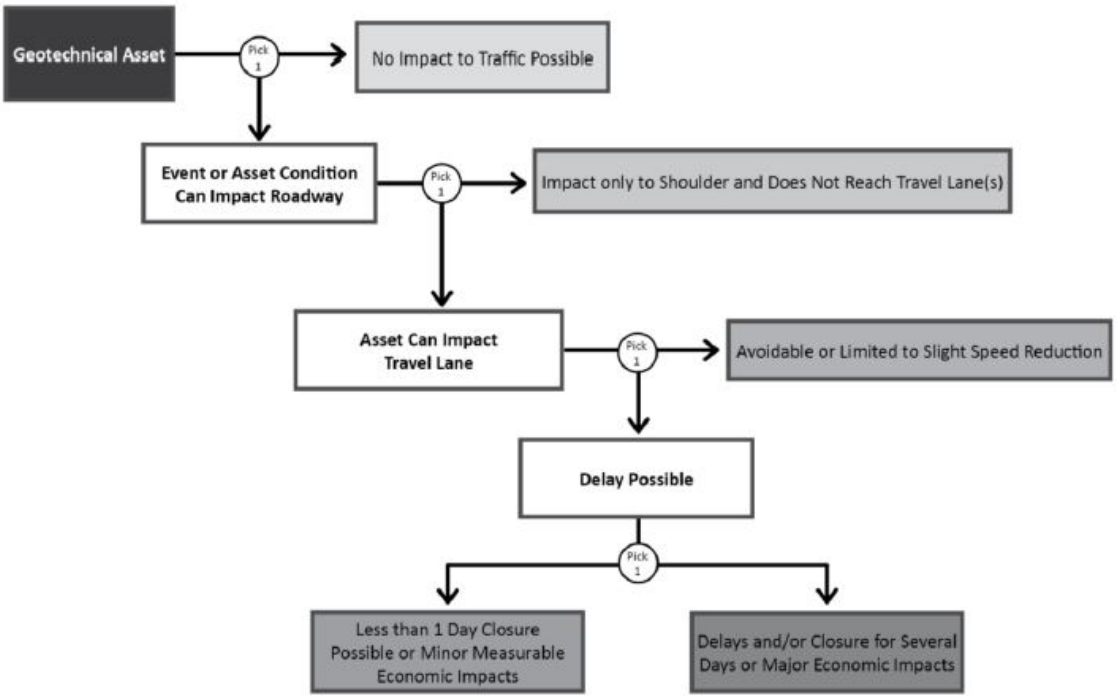


Figure 80. Flowchart. Mobility consequences decision tree.

Source: Vessely et al. (2019)

Regardless of the state of the GAM program, all transportation agencies strive to provide the highest safety for road users. The decision tree regarding the safety consequences of asset failure or deterioration is shown in Figure 81.

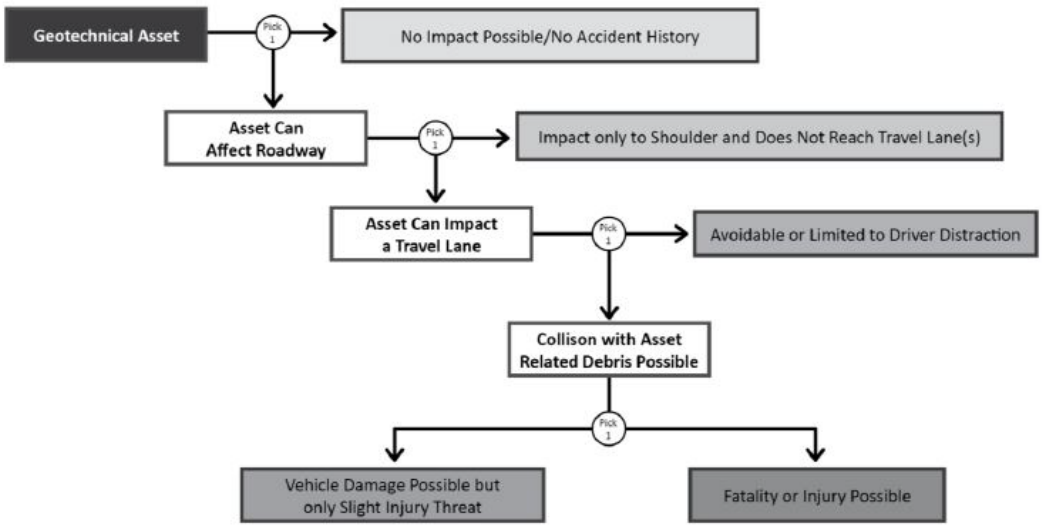


Figure 81. Flowchart. Safety consequences decision tree.

Source: Vessely et al. (2019)

Safety and mobility consequences, along with the condition of the asset, are used to determine the Level of Risk (LOR). Equation to determine LOR is shown in Figure 82.

$$LOR = AC \times SC + AC \times MC$$

Figure 82. Equation. Level of risk calculation for any geotechnical asset.

Here AC is the Asset Condition, SC is the safety consequences, and MC mobility consequences. The fourth step is the review of the treatment recommendations. The GAM program utilizes a Markov-based method to model the future deterioration or the condition state of the asset. An appropriate treatment strategy can be adopted once the future condition of the asset is known. These strategies can be do minimum, maintenance, rehabilitation, reconstruction, and restoration. With an optimum strategy, the Life Cycle Cost (LCC) for an asset in state x, given that treatment a is performed within the next period, can be determined using Figure 83.

$$LCC(x|a) = C_{x,a} + \frac{1}{1+i}\sum_{y} P_{x,y}^{a} LCC^{*}(y)$$

Figure 83. Equation. Life cycle cost calculation for any geotechnical asset in a given state.

Here, *LCC** is the minimum life cycle cost of the asset is state *x*, *a* is the optimum treatment to perform in state *x*, $C_{x,a}$ is the cost of taking treatment *a* in state *x*, *i* is the discount rate, $P^{a}_{x,y}$ is the probability of transitioning from state *x* to state *y* given that treatment *a* is applied.

The fifth and sixth steps involve the comparison of different investment strategies and communicating the results with decision-makers or the executives.

APPENDIX B: PILOT SUMMARY

INTRODUCTION

During the course of this project, the research team developed an inspection procedure for four types of geotechnical assets. These asset families are rock slopes, soil slopes/embankments, and retaining walls. Two inspection procedures were developed for retaining walls- one for generic retaining walls and another for MSE walls. In addition to the inspection procedures, the research team developed an ArcGIS-based survey123 web application to collect the asset condition field data. A pilot study was conducted between October 15-18, 2024, to test the developed inspection procedures and survey123 application, and perform any required adjustments based on feedback received from the team members. This report provides a summary of the pilot study.

PILOT STUDY 1

The pilot study was performed between October 15-18, 2024. Four members from the research team participated in the pilot study: Ahmad Alhasan, and Zafrul Khan from ARA, Darren Beckstrand from Landslide Technology, and David Jaromin from HNTB. Heather Shoup from Illinois Department of Transportation (IDOT) participated on October 15, 2024.

Prior to the field phase of the pilot study, the research team consulted with IDOT regarding the locations of assets. Initially, the IDOT technical panel provided two corridors with multiple assets for inclusion in the pilot study. The first location was on IL-3, and the second was on IL-2. The corridor in IL-3 had multiple assets, including retaining walls, rock slopes, and soil slopes/embankments. IL-2 corridor mostly consists of retaining walls. IDOT also provided three specific locations for inspection as part of the pilot. These sites were located in Macomb, Marion, and Farmersville. The site in Macomb had several soil slopes, while the Marion site had an MSE wall. The site near Farmersville on I-55 had a soil subsidence issue.

The research team also identified 31 other potential geotechnical assets (GAs) throughout Illinois. The primary criterion in selecting the pilot locations was to identify a corridor that contains a variety of assets. The team identified several assets between Alton, IL and Grafton, IL. Note: red: wall; yellow: rock slope; green: soil slope; cyan: IDOT provided locations. Figure 84 presents the locations of geotechnical assets throughout Illinois initially considered for the pilot.

The initial tentative schedule for the pilot study is presented in this appendix. Although 31 assets were initially identified throughout Illinois, not all shown in Figure 84 were included. The research team identified several new interesting assets during the pilot and also skipped some sites due to time and distance constraints. In total, the research team surveyed a total of 42 assets. A breakdown of the asset types inspected is shown in Figure 85. The following report provides a summary of the inspected assets. Field inspection sheets for the inspected assets are provided in Data Records .



Note: red: wall; yellow: rock slope; green: soil slope; cyan: IDOT provided locations

Figure 84. Map. Locations of geotechnical assets initially considered for the pilot study.

Courtesy: Google Maps

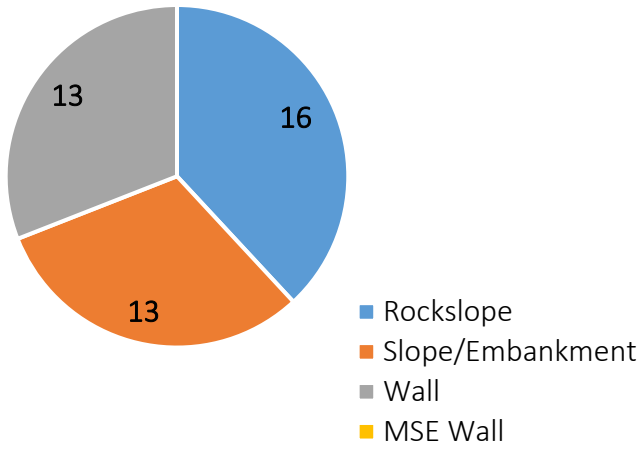


Figure 85. Chart. Breakdown of assets inspected during pilot study.

Day 01

During the first day of the pilot, the research team, along with IDOT, inspected seven geotechnical assets. The primary objective of day one was to inspect the different types of assets by the entire research team. The team included a mix of engineers-from very experienced field inspectors to relatively new inspectors. Some team members are experts in retaining walls, while others are more experienced in rock slopes and pavements. The idea behind conducting the field inspection by the entire research team on the first day was to agree on the different aspects of the rating procedure and identify potential limitations and future refinements. For instance, there may be only two rating categories, i.e., good or bad, for a condition rating of a particular asset component or aspect of a geotechnical asset. The addition of an intermediate category appeared to be more appropriate. Inspection of assets as a group on day one enabled discussions to improve the developed rating systems for different asset families.

Rock Slope 1

The first geotechnical asset the research group inspected was a rock slope on IL-100 near Alton, IL. The rock slope had a height of @150 ft. There is a bikeway between the rock slope and the roadway. Along with the condition of the asset, preliminary information regarding the asset location is required to assess the condition rating, such as speed limit, sight distance, AADT, etc. Sight distance is the maximum distance beyond which a driver cannot identify any object (fallen rock) with a minimum size of six inches on the roadway. During the pilot study, sight distance and length of the rock slope were measured using a measuring wheel, and height was measured using a laser range finder. Figure 86 presents the condition of the rock slope on IL-100 near Alton, IL.

Figure 86-a presents the condition of the rock slope crest. The difference in color or appearance between the layers of rocks at the crest, highlighted in red in Figure 86-a, suggests the presence of moisture at the top of slope. Block size and volume are important categories in hazard rating. The length of the largest fallen rock is generally used for the size measurement, and the combined volume of the fallen rocks accumulated at a particular location is used for the volume measurement. The maximum observed fallen rock had a length of around 6 ft, and the volume of smaller fallen rocks was estimated to be 20 yd^3. A few rockfalls were also observed, as evidenced from Figure 86-b and Figure 86-c. However, the large rockfall event occurs infrequently as nearby large fallen rocks were observed to be covered by vegetation (highlighted in yellow in Figure 86-d). The ditch was also observed to be effective in retaining and preventing the fallen rocks from entering the roadway. Trees at the slope base also prevented the fallen rocks from reaching the roadway, as evidenced by the impacted tree at the base of the rock slope, highlighted in red in Figure 86-d.



(a) Condition at crest

(b) Condition at base

(c) Bikeway at the base

(d) Vegetation and fallen rocks

Figure 86. Photo. Rock slope condition on IL-100 near Alton.

Wall 1

The second inspected asset was a retaining wall. The wall is situated on IL-100 near Alton, IL as shown in Figure 87. The wall had evidence of weathering and drainage issues, and surface distress was also visible.



Figure 87. Photo. Wall inspected on IL-100 near Alton, IL.

Rock Slope 2

The second rock slope is also located on IL-100 near Alton, IL. The height of the asset was measured to be @ 75 ft. Figure 88 also shows images of the rock slope and the surrounding conditions. Similar to the first rock slope, the ditch was found to be effective in preventing rocks from entering the roadway. Although there were some fallen rocks on the bikeway, the activity appeared to be infrequent. The largest fallen rock had a dimension of around 7.5 ft. A moderate differential erosion rate was observed between the top and the bottom portion of the slope. No presence of moisture suggested a well-drained condition within the rock slope.



(a) Rock slope crest (b) Fallen rocks (c) Condition at base

Figure 88. Photo. Second rock slope condition on IL-100 near Alton.

Wall 2

The second retaining wall inspected was located on IL-100 near Grafton, IL, which is shown in Figure 89. The wall had a height of 11.25 ft, and did not appear to have foundation or settlement issues. In addition, no issues with drainage, erosion of backfill, or vegetation growth were observed. However, the wall exhibited surface distresses, including horizontal movement and cracking in the wooden facing in several locations. There was also evidence of corrosion in the H-piles, as shown in Figure 89-c. Overall, the condition of the wall was found to be in good condition.



(a) Wall (b) horizontal movement (c) corrosion in piles

Figure 89. Photo. Inspected wall near Grafton, IL.

Rock Slope 3

The fifth asset inspected on the first day was a rock slope on IL-100 near Grafton, IL. Figure 90 presents the condition of the rock slope. The amount of rocks present in the ditch, implies rockfall activity is minimal or infrequent throughout the year. The height of the rock slope was measured to be @15 feet, and the maximum dimension of the fallen rock was observed to be 5 feet. The joint patterns of the rock slope were observed to be in an adverse orientation, with lengths exceeding 10 feet. For rock friction, a planar condition was observed as the friction derives from the roughness between the surfaces. These two conditions are evident in Figure 90-a. The red highlighted circles in Figure 90-b presents some recent evidence of rockfall activity. However, the ditch was observed to be effective in restricting the fallen rocks entering the roadway. Poor drainage condition of the rock slope was observed due to the presence of moisture, which is highlighted in yellow in Figure 90-c.



(a) Joint pattern and ditch (b) rockfall evidence (c) Moisture

Figure 90. Photo. Second rock slope condition on IL-100 near Grafton, IL.

Wall 3

A modular block retaining wall in Grafton, IL, was also inspected during the first day. Several issues were observed with the wall components. First, there was a distortion of the wall facing at many locations along the wall alignment. Second, significant horizontal movement of the wall was observed, as shown in Figure 91. Although not as severe as horizontal movement, the wall also had signs of vertical movement. Third, the drainage pipes were also found to be clogged, as shown in Figure 91-c. The average rating of the wall components was determined to be poor, while the average rating for drainage was determined to be between good and marginal.



(a) Bulging of wall facing (b) Horizontal movement (c) Clogged drainage pipe

Figure 91. Photo. Second inspected wall near Grafton, IL.

Slope/Embankment

Figure 92 presents the slope/embankment located near Hardin, IL, inspected during the first day. The asset was observed to have moderate erosion of the foundation material. The electric pole was observed to be tilted due to the movement. Despite the tilting, the pole appeared to be stable. Thus, it was recommended to add a new category of "M" between the good and poor conditions for "utilities" in the slope embankment components of the inspection sheet. Localized horizontal and vertical movement within the asset is shown in Figure 92-a and Figure 92-b. Due to the localized movement within the asset, distress was observed in the pavement as shown in Figure 92-c. The overall condition of the asset components was found to be between marginal and poor, while the drainage components were rated between good and marginal condition.



(a) Horizontal Movement (b) Vertical movement (c) Distress in pavement

Figure 92. Photo. Inspected slope/embankment near Hardin, IL.

Day 02

During the second day of the pilot study, the team was divided into two groups: the south group and the north group. Darren and Zafrul from the south group inspected the sites on IL-3 near Chester, IL, while Dave from the north group inspected the sites near Macomb, IL.

South Group

Wall 1

The first retaining wall inspected by the south group was at 340 feet in length. The wall did not exhibit any issues related to settlement of foundation, or erosion, but it had moderate distress at the wall surface and localized horizontal movement. The localized horizontal movement of the wall and the gap between the backfill and the wall are highlighted in Figure 93-b and Figure 93-c. Separation between the wing wall and the main wall was also observed, as shown in Figure 93-d. Overall, the wall had a rating of 'Marginal" for both the wall and drainage components.



(a) Measuring wall length



(b) Horizontal movement



(c) Gap between wall and the backfill



(d) Separation between the wall and the wing wall

Figure 93. Photo. First wall inspected on IL-3 near Chester, IL.

Wall 2

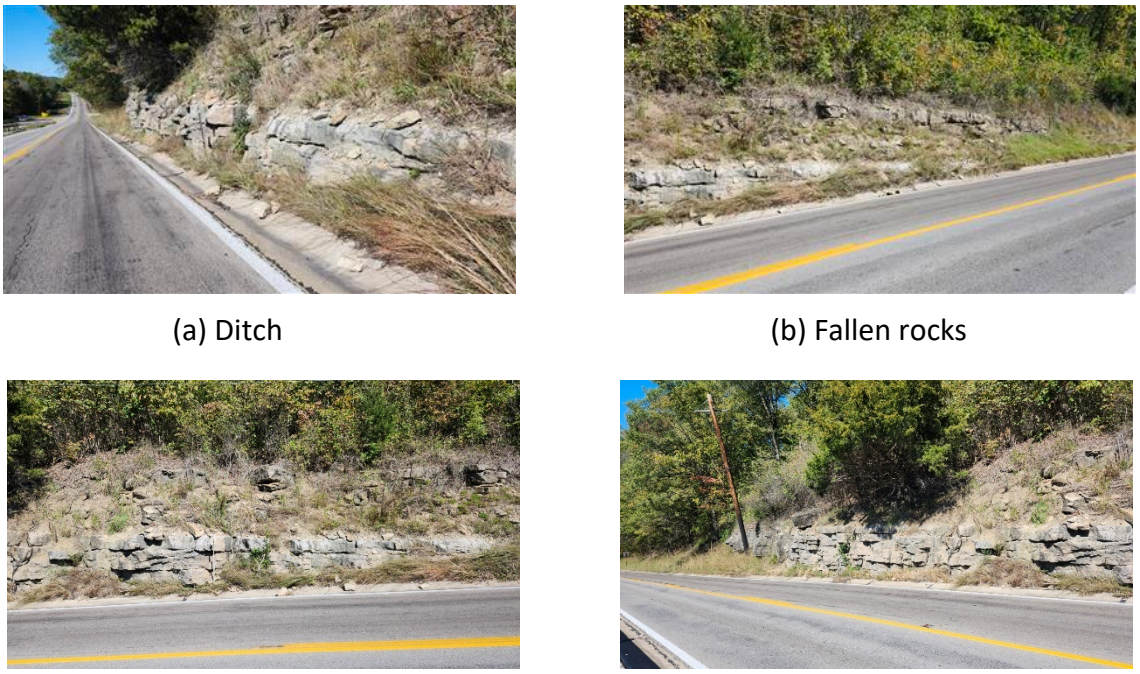
The second retaining wall inspected by the south group is at 650 feet in length, shown in Figure 94. The wall did not exhibit any issues with the foundation settlement; however, erosion was observed at the wall base. In addition, cracks were also observed at the wall face and in the concrete gutter on the south end of the pile wall section. The last 150 feet on the south end is an old bin wall. The concrete-faced pile wall may have encased the existing bin wall as a repair. Occasional depressions are also observed at the top of the wall; however, no localized movements were observed. Sand and gravel accumulation was observed at an drainage pipe outlet located at the south end of the wall near a manhole. Piping of wall backfill material into drainage system is suspected. It is recommended that the drain be inspected and repaired to prevent backfill material ingress. Overall, the wall had a rating of 'Marginal" for both the wall and drainage components.



Figure 94. Photo. Second wall inspected on IL-3 near Chester, IL.

Rock Slope

Figure 95 presents the rock slope inspected on IL-3. Although the rock slope has a ditch, it is not sufficient to prevent the rocks from reaching the roadway, particularly larger ones. Occasional rockfall activity is expected based on the fallen rocks in the ditch, which is shown in Figure 95-a and Figure 95-b. Case 2 is selected for the geologic character of the rock slope due to the differential erosional features between the top and bottom, as shown in Figure 95-c and Figure 95-d. The failure type observed is raveling as talus slopes are controlled by differential erosion. Overall, the condition of the rock slope is rated to be poor.



(a) Ditch (b) Fallen rocks

(c) Erosional Feature (d) Bent utility pole

Figure 95. Photo. Rock slope inspected on IL-3 near Chester, IL.

Slope/Embankment 1

The first soil/embankment inspected on IL-3 is shown in Figure 96. The soil slope had soil nails embedded, as shown in Figure 96-a. No foundation or erosional issues were observed within the asset. However, evidence of pavement distress as shown in Figure 96-b and Figure 96-c suggests localized movements in both horizontal and vertical directions. Along with the slope/embankment material loss, moderate bulging and cracking of the slope face were also observed. It is recommended that the drainage issue be repaired to resolve the issues with material loss. The overall condition of the asset is rated to be “Marginal”.



(a) Soil Nails



(b) Material loss



(c) Distress on shoulder



(d) Distress on pavement

Figure 96. Photo. First soil slope/embankment inspected on IL-3.

Soil Slope/Embankment 2

The second soil slope inspected on IL-3 also had features similar to the first slope. However, compared to the first soil slope, pavement distress is much more pronounced as shown in Figure 97-a. Figure 97-b presents evidence of soil erosion. The overall condition rating of the asset is "Marginal."



(a) Pavement Deformation (b) Erosion of soil

Figure 97. Photo. Second soil slope/embankment inspected on IL-3.

Soil Slope/Embankment 3

Figure 98 presents the third soil slope inspected on IL-3. The material appeared to be moist, and there was slight bulging along the slope face. There is evidence of soil erosion at the beginning of the soil slope (north end). The average rating for both the slope components and drainage is "Marginal".



Figure 98. Photo. Third soil slope/embankment inspected on IL-3.

Soil Slope/Embankment 4

The fourth soil slope also had soil nails. The rutting of the pavement suggests an underlying foundation settlement issue. There was also evidence of material loss. The condition of the soil slope/embankment is shown in Figure 99. Additional drainage control is required to control the erosion of sand and gravel at the road's edge. The overall condition rating of the asset is "Marginal".



(a) Soil nails



(b) Material loss



(c) Rutting

Figure 99. Photo. Fourth soil slope/embankment inspected on IL-3.

Soil Slope/Embankment 5

The condition of fifth soil slope inspected on IL-3 is shown in Figure 100. The fourth soil slope and the fifth soil slope are adjacent to each other. The decision to split the soil slope into two assets was made based on the steepness of the slope and the presence of soil nails. Unlike the previous soil slope, this slope was much steeper and had no soil nails. However, there was evidence of slight rutting and material loss. The overall rating of the asset is “Marginal.”



(a) Material loss



(b) Steep slope

Figure 100. Photo. Fifth soil slope/embankment inspected on IL-3.

North Group

As mentioned previously, the north group inspected several assets in the Macomb diversion on IL-110. Both assets were soil slopes/embankments. The first asset inspected was a riprap slope, which is shown in Figure 101. The slope components were rated good. However, there was some evidence of erosion and inconsistent vegetation growth. Thus, the drainage components were rated “Marginal”.



Figure 101. Photo. Rip-rap slope on IL-110.

The second soil slope/embankment was concerning. It showed evidence of embankment movement and had recently been repaired, within the last year. There is evidence of foundation erosion and surface distress on the slope face, which was worsened by the movement of the grass mower. There is also evidence of erosion at the toe of the drainage, however the entire slope is vegetated, and extent of erosion is difficult to assess.



Figure 102. Photo. Rip-rap slope/embankment with depression on the IL-100.

Day 03

South Group

The south group started day 03 by inspecting the soil subsidence site near Farmersville, Illinois and then several sites not visited the previous day were inspected.

Soil Subsidence

On October 17, 2024, the research team visited the mine subsidence site on I-55 between milepost (MP) 69 to 71 near Farmersville, IL. The primary concern at this location was identified to be the undulation in both the northbound and southbound pavements. The observations from the site visit are summarized below:

Summary of Observations

Presence of the following features are typically evidence of mine related surface deformations (ODOT, 2017).

- Unusual cracks or dips in the roadway
- Distress in the adjacent structures
- Dips in guardrail and ditches
- Unusual vegetation, drainage, seepage or disappearance of surface water
- Ponding of water
- Topographical anomalies at the surface level

During the initial inspection, several dips were observed on the pavement. The wavelength of the dips in the northbound direction appeared to be longer than the southbound direction. However, the number of dips were larger in the southbound direction. In addition to the dips in the pavement and shoulder, slight dips were also observed in the unpaved area adjacent to the shoulder. Figure 103 presents the extent of dips in the north and southbound direction of I-55 between MP 70-71.



(a) Northbound direction (b) Southbound direction

Figure 103. Photo. Unusual dips in the pavement in I-55.

The team estimated the amplitude and wavelength of the waves in the pavement without any tool. During the amplitude measurement, one team member stood at the trough of the wave or dip while the other team member positioned himself close to the pavement surface level, as shown in Figure 104.



Figure 104. Photo. Measuring dip characteristics in the field.

Several measurements of the dips were taken to determine the wavelengths and amplitude are presented in Table 19.

Table 19. Approximate Characteristics and Locations of Dips in the Pavement on I-55

Location	Direction	Wavelength (ft)	Amplitude (in)
Near MP 70	Northbound	500	2-3
Near MP 71	Northbound	1100	2-3
Near MP 71	Southbound	400	6
Near MP 69	Northbound	300	8

Apart from dips or waves in the pavement and unpaved area near the shoulder, no other distresses were observed on the pavement or adjacent structures. The pavement appeared to be paved recently. The only distresses observed in the pavement were the presence of reflective joint cracks between the lanes and transverse thermal cracks on the shoulder, as shown in Figure 105.

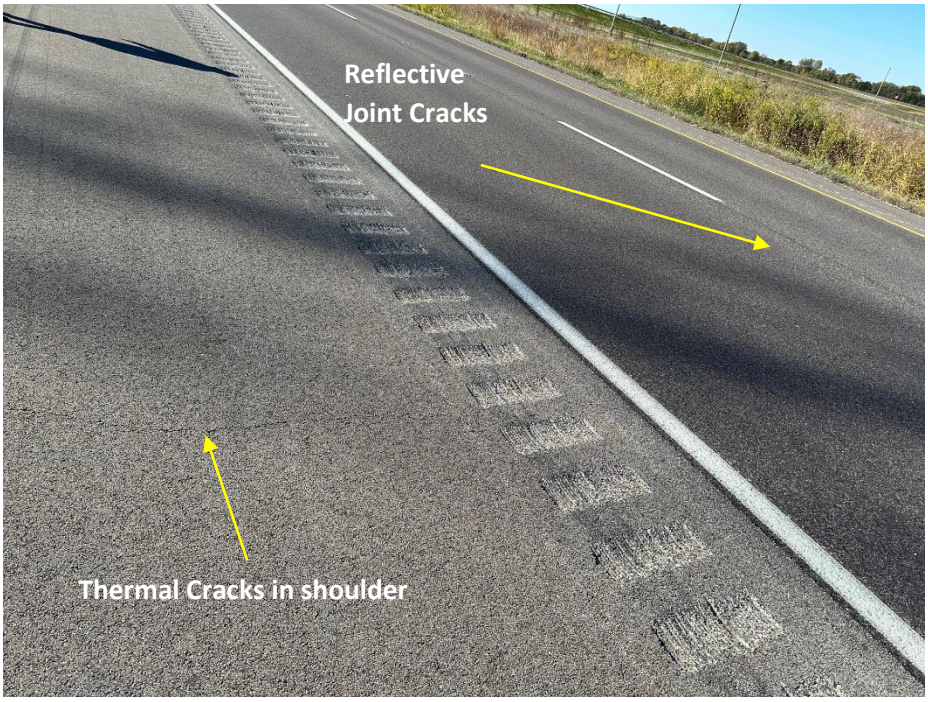


Figure 105. Photo. Reflective and thermal cracks on the pavement.

There are no guardrails adjacent to the dips. The vegetation in the surrounding area close to the dips also did not show any unusual pattern. No evidence of unusual drainage or seepage was observed. The drainage lines were found to be intact. The research team also did not observe any formation of voids or depressions in the surrounding area. Figure 106 presents the features observed in the surrounding area near the dips in the pavement.



(a) Consistent vegetation growth



(b) Intact drainage

Figure 106. Photo. Features of the surrounding area near the dips.

Recommendations

IDOT may adopt the following recommendations for determining the extent of soil subsidence progression:

- Consider measuring the amplitude and lengths of dips in the pavement at a regular interval to observe their progression over time.
- Instead of the manual or eye estimation method the research team adopted in the field, consider using two personnel with staff rod and theodolite or total station for accurate measurement of the location and dip characteristics.

Soil Slope/Embankment

Figure 107 presents the soil slope/embankment inspected on Bluff Road in Monroe County. All components of the soil slope appeared to be in good condition. The slope material appeared to be in moist condition. Thus, the slope component rating was good. For drainage components, it appeared that water may accumulate at the slope bottom after heavy rain. In addition, there was also evidence of soil erosion at several locations along the slope face. The average rating of the drainage components of the asset is “Marginal”.



Figure 107. Photo. Inspected soil slope/embankment on Bluff Road in Monroe County.

Rock Slope 01

Figure 108 presents the inspected rock slope on IL-155. The largest rock in the ditch was measured to be around two feet. The ditch did not appear to be effective in catching fallen rocks. It appeared that the larger rocks would certainly reach the roadway. There was a launch feature that further deteriorated the situation. Based on the available rocks in the ditch, it appears rockfall occurs several times a year, typically after a severe storm. The geology of the rock slope was characterized as Case 2 due to the differential erosional feature between different parts of the rock slope.



Figure 108. Photo. Rock slope on IL155.

Rock Slope 02

Figure 109 presents the condition of the inspected rock slope in Randolph County. The largest dimension of the fallen rock was measured to be eight feet, and the volume was more than 20 feet. The wide ditch was observed to be very effective in preventing the fallen rocks from reaching the roadway. There has been minor to no activity for a long time, as mature vegetation cover was observed at the fallen rock locations. In addition, vegetation was observed on the rock face and opening. Most likely, the asset was used as an aggregate quarry site. Geologic characteristics were chosen to be Case 2 due to the differential erosional features between different portions of the asset. Failure type was observed to be raveling. Overall, the rock slope was rated to be in 'Good' condition.



Figure 109. Photo. Rock slope on Bluff Road on Randolph County.

Rock Slope 03

Figure 110 presents the inspected rock slope on IL-156. The geologic feature of the rock slope was characterized as Case 2 due to the differential erosional shown in Figure 110-a. The largest rock in the ditch was measured to be around two feet. Ditch effectiveness appeared to be moderate due to the presence of the fence, particularly for larger rocks, as shown in Figure 110-b. However, smaller rocks still reached the roadway as evidenced by Figure 110-c. Figure 110-d presents a location of the pavement where ready-mix asphalt was applied. This pothole or damage in the pavement may have been caused by the moisture and tire load. However, the location of the distress was between the

wheel path, which suggests the damage might have occurred from the fallen rocks. The fence to protect the fallen rocks was damaged in several locations.



(a) Rock slope geologic feature (b) Accumulated rocks (c) Rocks on road



(d) Impact on Pavement (e) Bent fence post

Figure 110. Photo. Rock slope on IL-156.

North Group

On day 03, the north group inspected the geotechnical assets along IL-2.

Rock Slope 01

Figure 111 presents the inspected rock slope on IL-2. The largest rock on the ditch was measured to be around one foot. The ditch was moderately effective in catching the fallen rocks. Based on the available rocks in the ditch, it can be said that rockfall occurs several times a year, typically after a severe storm. The geology of the rock slope was characterized as Case 2 due to the differential erosional features, which would take many years to develop. Failure type is observed to be raveling as talus slopes are controlled by differential erosion. The overall condition of the rock slope was rated to be “Fair”.



Figure 111. Photo. First rock slope inspected on IL-2.

Rock Slope 02

Figure 112 presents the second inspected rock slope on IL-2. The largest rock on the ditch was measured to be around one foot. The ditch was wide enough to prevent the fallen rocks from entering the roadway. Rockfall occurs several times a year, generally after a severe storm. The geology of the rock slope was characterized as Case 2, with raveling as failure type. Moreover, it was observed that the rock cut is transitioning to a steep rock/soil slope. Talus is redirecting the features; however, the ditch is wide enough to prevent any adverse conditions. The overall condition of the rock slope was rated to be "Good".



Figure 112. Photo. Second rock slope inspected on IL-2.

Rock Slope 03

Figure 113 presents the third inspected rock slope on IL-2. The largest rock on the ditch was measured to be around one and a half feet. The ditch did not appear to be effective in preventing fallen rocks from entering the roadway. Based on the rocks available on the ditch and the geometry of the asset, it appeared that rockfall occurs frequently during certain seasons, such as the wet period or the winter freeze/thaw. The geology of the rock slope was characterized as Case 2 due to the differential erosional features. Failure type is observed to be raveling as talus slopes are controlled by differential erosion. The overall condition of the rock slope was rated to be "Poor."



Figure 113. Photo. Third rock slope inspected on IL-2.

Wall 01

The first inspected retaining wall on IL-2 is shown in Figure 114. The wall was built in 2011; thus, the condition of various wall and drainage components appeared to be in good condition, except for the saturation of the backfill material. Despite no bulging of the wall facing, 0-1° deviation was observed.



Figure 114. Photo. First wall inspected on IL-2.

Wall 02

The second inspected retaining wall along IL-2 is shown in Figure 115. Although there were no signs of when the wall was built, similar to the first wall, the condition of various wall and drainage components appeared to be in good condition, except for the saturation of the backfill material. Despite no bulging of the wall facing, 0-1° deviation was observed from the vertical plane. There is good drainage and no signs of erosion. The inspector recommended adding a feature indicating the vegetation growth through the wall face. Overall, the wall was in great condition. However, the wall received a rating of ”Marginal” due to the presence of moist backfill soil.



Figure 115. Photo. Second wall inspected on IL-2.

Wall 03

Figure 116 presents the third wall retaining inspected on IL-2. Similar to the other walls along IL-2, the wall did not show any visible distress or movement except for moist soil. The drainage also appeared to be in good condition without any issues. The overall rating of the wall components is “Marginal”. For drainage, the rating is “Good”.



Figure 116. Photo. Third wall inspected on IL-2.

Day 04

Zafrul from the south group inspected the soil slope/embankment site on Illinois Route 110 - Chicago-Kansas City Expressway near Macomb, IL, on Friday, October 18, 2024. Figure 117 presents the condition of the soil slope/embankment. The primary issue at this location was the dip in the pavement, which was recently repaired, as seen in Figure 117-a. Dip in the pavement suggests issues

with the foundation. Localized horizontal movement might have caused the bulging of the slope face shown in Figure 117-b. There was also evidence of localized vertical movement on the unpaved shoulder due to the presence of depressions at several locations. Surface distresses, such as cracks shown in Figure 117-c were also present on the slope face. The water inlet and outlet are located on the opposite side of the patched pavement location, as shown in Figure 117-e and Figure 117-f.

Localized vertical movement appears to be load-related and are inconsistent along the slope, which suggests the presence of underlying issues needing further investigation. Cracks on the slope are wider and more frequent near the patched area in the pavement. The probable reason for the dip in the pavement appears to be because of seepage and drainage. A detailed investigation is recommended.



(a) Patched pavement (b) Bulging of slope face (c) Crack on slope



(d) Crack on shoulder (e) Inlet (f) Soil slope opposite of inlet

Figure 117. Photo. Macomb soil slope/embankment site on Illinois Route 110 - Chicago-Kansas City Expressway inspected by south team.

TENTATIVE SCHEDULE FOR IDOT GAM PILOT STUDY

Groups

The inspection team will be sub-divided into the following two teams for Thursday (10/17), and Friday (10/18):

- South Group
- North Group

Monday, October 14, 2024

Team: All members

- *Location:* Meet in the evening at the hotel lobby in O'Fallon, IL.

Tuesday, October 15, 2024

Team: All members

8:00 AM- 35 miles drive to Alton, IL from O'Fallon, IL (41 minutes).

Table 20. List of Potential Sites to Consider during Pilot Study 1

Asset Type	Location (Latitude, Longitude)	Route	Driving Distance from previous Asset (miles)	Driving Time from earlier Asset (minutes)	Parking	Roadside space	Priority
Rock Slope	Alton (38.8923429,-90.1938053)	IL100	0	0	Park and walk (1 min)	Narrow	Low
Retaining Wall	Godfrey (38.931399, -90.2653115)	IL100	4.8	5	Park and walk (12 min)	Bike lane	Low
Rock Slope	Godfrey (38.9358147, -90.2777783)	IL100	1	2	Park and walk (5 min)	Bike lane	Low
Rock Slope	Elsah (38.9545687, -90.37042)	IL100	5.5	5	Shoulder	Narrow	Med
Rock Slope	Grafton 38.9632139, -90.3921241)	IL100	1.3	1	Shoulder	Narrow	Med
Retaining Wall	Grafton (38.968514, -90.4925029)	IL100	6.2	9	Ferry Dock (1 min)	Narrow	Med
Rock Slope	Grafton (38.9683537, -90.5031304)	IL100	0.6	1	Opposite Lane	Medium	Med
Retaining Wall	Grafton (38.9679444, -90.5189566)	IL100	0.8	1	Opposite Lane unpaved shoulder (3 min)	Bike lane	Low
Soil Slope/ Embankment	Hardin (39.1630499, -90.6155326)	IL100	17.1	19	Opposite Lane	Medium	Med
Soil Slope/ Embankment	Hardin (39.1972594, -90.6108952)	IL100	2.5	3	Park and Walk (3 min)	Medium	Med
Rock Slope	Mozier (39.3004044, -90.7542155)	IL96	16	18	Opposite Lane unpaved shoulder (0 min)	Narrow	Low
Rock Slope	Quincy (39.9055176, -91.4086688)	IL57	58	65	Opposite Lane Shoulder (0 min)	Medium	Low

Wednesday, October 16, 2024

Team: All members

- 7:30 AM
- 68 miles drive to Macomb, IL from Quincy, IL (70 minutes).
- 9:00 AM to 1:00 PM
- Inspect the sites in Macomb diversion (40.4639437,-90.741657) between US 136 and US 67.
- 1:00 PM to 2:00 PM
- Lunch Break
- 2:00 PM
- South team will leave for hotel in East St. Louis, IL or O'Fallon, IL area (approx. 162 miles, 3 hrs)
- 2:00 PM to 3:00 PM
- North team will rate any rest of the geotechnical assets in the Macomb diversion area.

Thursday, October 17, 2024

South Group: Darren and Zafrul

- 8:00 AM
- Start from hotel in East St. Louis, IL to first inspection site in Columbia, IL (15 miles, 21 minutes)

Table 21. List of Potential Sites to Consider during Pilot Study 1 (Continued)

Asset Type	Location (Latitude, Longitude)	Route	Driving Distance from previous Asset (miles)	Driving Time from earlier Asset (minutes)	Parking	Roadside space	Priority
Rock Slope	Columbia 938.4307342, -90.1817558)	IL3	0	0	Shoulder	Sufficient	Medium
Rock Slope	Valmeyer (38.3019318, -90.2861459)	IL156	15.2	19	Opposite lane unpaved shoulder	Medium	Medium
Soil Slope/ Embankment	Valmeyer (38.2997445, -90.2928081)	IL156	0.4	1	Opposite lane unpaved shoulder	Narrow, Opposite-sufficient	Medium
Rock Slope	Prairie du Rocher (38.0946042, -90.1059892)	Co Rd 7	18.9	24	Unpaved Shoulder	Sufficient	Low
Rock Slope	Prairie du Rocher (38.0882756, -90.0911268)	IL155	0.7	1	Opposite lane unpaved shoulder	Narrow, Opposite-sufficient	Medium
Retaining Wall	Menard (37.9107899, -89.8435215)		21	26	Correctional facility parking	Sufficient	Medium
Retaining Wall	Chester (37.9014033, -89.8306962)	Water St	1	2	Opposite	Sidewalk	Low
Rock Slope	Chester 937.8759697, -89.7696779)	IL3	4.1	6	Park and Walk (10 min)	Narrow	Medium (IDOT)
Rock slope	Gorham (37.7614851, -89.4455146)	IL149	19.9	23	Opposite unpaved shoulder	Medium	Low

North Group: Ahmad and Dave

Table 22. List of Potential Sites to Consider During Pilot Study 1 (Continued)

Asset Type	Location (Latitude, Longitude)	Route	Driving Distance from previous Asset (miles)	Driving Time from earlier Asset (minutes)	Parking	Roadside space	Priority
Retaining Wall	Dixon (41.8870733, -89.4251927)	IL2	0	0	Shoulder	Medium	Medium
Retaining Wall	Oregon (42.0414953, -89.3413933)	IL2	12.9	17	Shoulder	Sufficient	Low
Retaining Wall	Oregon (42.0502247, -89.3471891)	IL2	0.6	1	Shoulder	Sufficient	Low
Retaining Wall	Oregon (42.0562095, -89.3464304)	Il2	0.6	1	Shoulder	Sufficient	Low
Retaining Wall	Oregon (42.0875121, -89.3290895)	IL2	2.6	3	Shoulder	Sufficient	Low
Soil Slope/ Embankment	Oregon (42.1111419, -89.2990597)	IL2	2.3	2	Shoulder	Sufficient	Low
Retaining Wall	Byron (42.1203352, -89.2883298)	IL2	0.6	1	Shoulder	Sufficient	Low
Soil Slope/ Embankment	Byron (42.1647083, -89.2300681)	IL2	5.1	8	Park and Walk (6 min)	Narrow	Medium
Retaining Wall	Byron (42.1717087, -89.2006884)	IL2	1.8	2	Park and Walk (2 min)	Medium	Low
Soil Slope/ Embankment	Byron (42.1772884, -89.1937442)	IL2	0.5	1	Shoulder	Narrow	Low

Friday, October 18, 2024

Any additional location inspection by North (Dave) and south (Zafrul) team, if required.

DATA RECORDS

Day 01

Rock Slope

Table 23. Data Records for Rock Slopes Evaluated on Day 01 of Pilot Study 1

Inspector:	Darren Beckstrand	Ahmad Alhasan	David Jaromin	Ahmad Alhasan	Darren Beckstrand	Darren Beckstrand	Ahmad Alhasan
Asset Type:	Rockslope	Rockslope	Rockslope	Rockslope	Rockslope	Rockslope	Rockslope
lat	-90.2636	-90.2637	-90.2644	-90.2769	-90.278	-90.5019	-90.5029
lon	38.93066578791081	38.93095089549042	38.931122148728065	38.93559513950469	38.93594156225821	38.968130951406664	38.968211934749064
Roadway Width (ft)	27		27	32	32	25	25
County Name	MADISON	MADISON	MADISON	JERSEY	JERSEY	JERSEY	JERSEY
Road Name	MACADAM PKY	MACADAM PKY	MACADAM PKY		IL100	IL100	
Route ID	IL100		IL100				
Route Type	Primary	Primary					
Travel Direction	Northbound	Northbound	Northbound	Northbound	Northbound	Northbound	Northbound
Speed Limit (mph)	55	55	55		55	55	55
Slope Length (miles)	0.8		0.9		0.1	0.06	
AADT	4900	4900	4900	5450	5450	1100	1100
1. Block Size or Event Volume	Both	Size	Volume	Size	Size	Size	Size
Size (ft)	6	6		7.5	8	5	5
Volume (yd3)	20		20				
g1_h_1_score	100	100	100	100	100	100	100
Score:							
2. Slope Height Score (ft)	150	145	140	75	75	15	15
g1_h_2_score	100	100	100	27	27	1.933	1.933
Score:							
3. Ditch Effectiveness Score	3	3	3	3	3	3	3
4. Geologic Character Score	Case 2	Case 2	Case 2	Case 2	Case 2	Case 1	Case 1
Case 1: Structural Condition						81	81
Case 1: Rock Friction						27	27
Case 2: Differential Erosion Rate	9	9	9	9	9		
5. Rockfall Activity Score	3	3	3	3	3	3	3
6. Water on Slope	9	9	9	3	3	27	27
rsh_summary	224	224	224	145	145	242.933	242.933

Inspector:	Darren Beckstrand	Ahmad Alhasan	David Jaromin	Ahmad Alhasan	Darren Beckstrand	Darren Beckstrand	Ahmad Alhasan
sum_hazard2	224	224	224	145	145	242.933	242.933
Comment	Walkway is occasionally impacted by rocks but generally serves as a good fallout fit the road. Activity at the path is on the order of 1 to 2 times per 1 or 2 years.	A wall is nearby and the pavement below the wall shows edge cracks could be weak foundation under the wall. The pavement in the trail has some scars indicating rockfall.					
AADT_score	11.38	11.38	11.38	12.997	12.997	3.165	3.165
1. AADT Score	11.38	11.38	11.38	12.997	12.997	3.165	3.165
vehicle_value	11.879		13.364		1.652	0.2	
vehicle_score	100	100	100	100	6.141	1.246	100
2. Average Vehicle Risk Score	100	100	100	100	6.141	1.246	100
sight_value	875	875	875		875	875	875
3. Decision Sight Score	1000	1000	1000	410	405	610	610
sight_score	1.369	1.369	1.369	100	57.35	15.835	15.835
width_value	2.125		2.125	1.5	1.5	2.375	2.375
width_score	10.325	100	10.325	5.196	5.196	13.588	13.588
4. Roadway Width Score	27	100	10.325	5.196	5.196	13.599	13.588
5. Rockfall Related Maintenance Frequency Score	3	3	3	3	3	3	3
sumrisk2	126.074	215.749	126.074	221.193	84.684	36.834	135.588
sumrisk	126.074	215.749	126.074	221.193	84.684	36.834	135.588
Rockslope Class	B	B	B	B	B		B
Failure Type	Raveling	Raveling	Raveling		Multiple Movement		Planar
sum_risk_score	350.074	439.749	350.074	366.193	229.684	279.767	378.52099999999996
ditch_cs	76	76	76	76	76	76	76
rockfall_cs	100	100	100	100	100	100	100
avg_cs	88	88	88	88	88	88	88
avg_fieldrating	3	3	3	3	3	3	3
rockfall_condition	Good	Good	Good	Good	Good	Good	Good
rockfall_score	1	1	1	1	1	1	1

Table 24. Data Records for Walls Evaluated on Day 01 of Pilot Study 1

Inspector:	Ahmad Alhasan	Darren Beckstrand	Darren Beckstrand	Ahmad Alhasan	Ahmad	Darren Beckstrand
Asset Type:	Wall	Wall	Wall	Wall	Wall	Wall
Lat	-90.264926	-90.265061	-90.491443	-90.491441	-90.51939	-90.518201
Lon	38.93134712849739	38.931365199999334	38.96868289999934	38.968800616640955	38.967979566136385	38.96805879999935
Roadway Width (ft)	27	27	25	25	25	25
County Name	MADISON	MADISON	JERSEY	JERSEY	JERSEY	JERSEY
Road Name	MACADAM PKY	MACADAM PKY	IL100			IL100
Travel Direction	Northbound	Northbound	Northbound	Northbound	Northbound	Northbound
Speed Limit (mph)	55	55	45	40	50	55
Slope Length (miles)	6.9	0.03	0.02	75		0.13
AADT	4900	4900	2050	2050	1100	1100
1. Foundations	2	2	1		2	2
2. Foundation Erosion and Scour	1	1	1		1	1
3. Utilities	1	1	1	1	3	1
4. Surface Distress	2	2	2	2	3	3
5. Barrier and Guard Rail	1	1	2	1	3	3
6. Material Saturation	2	2	1	1	2	3
7. Localized Horizontal Movement (cracks in wall/pavement) Parallel to the Wall	1	1	1	1	3	3
8. Localized Vertical Movement (cracks in wall/pavement)	1	1	1	1	2	2
9. Shallow Surface Failure/Depressions near Top of Wall	2	2	1	1	2	2
g4_w_mode	1	1	1	1	2,3	3
g4_w_avg	1.44	1.44	1.22	0.89	2.33	2.22
g4_w_avg_cond	Marginal	Marginal	Marginal	Good	Poor	Poor
g4_w_mode_cond	Good	Good	Good	Good	Unknown	Poor
Comment	The wall facing has weathered elements				Modular wall	
1. Soil Erosion	1	1	1	1	1	1

Inspector:	Ahmad Alhasan	Darren Beckstrand	Darren Beckstrand	Ahmad Alhasan	Ahmad	Darren Beckstrand
2. Vegetation	2	2	1	1	2	2
3. Drainage Systems (Surface and Subsurface)	1	1	1	1	2	3
4. Water Accumulation (top of wall)	1	1	1	1	2	1
5. Water Accumulation (bottom)	1	1	1	1	2	1
g4_d_mode	1	1	1	1	2	1
g4_d_avg	1.2	1.2	1	1	1.8	1.6
g4_d_avg_cond	Marginal	Marginal	Good	Good	Marginal	Marginal
g4_d_mode_cond	Good	Good	Good	Good	Marginal	Good
Comment		Few apparent drainage issues.				

Soil Slope/Embankment

Table 25. Data Records for Soil Slopes and Embankments Evaluated on Day 01 of Pilot Study 1

Inspector:	Darren Beckstrand	Ahmad
Asset Type:	Slope/Embankment	Slope/Embankment
Lat	-90.6156	-90.6152
Lon	39.162884999999335	39.16464314547302
Roadway Width (ft)	26	
County Name	CALHOUN	CALHOUN
Road Name	PARK ST	PARK ST
Route ID	IL100	
Travel Direction	Northbound	Southbound
Speed Limit (mph)	35	35
Slope Length (miles)	0.05	
AADT	2450	2450
1. Foundations	1	1
2. Foundation Erosion and Scour	2	2
3. Utilities	3	3
4. Surface Distress	2	2
5. Barrier and Guard Rail	1	2
6. Slope or Embankment Material Loss	1	3
7. Apparent Material Saturation	3	2
8. Localized Horizontal Movement (cracks in slope-embankment/pavement) Parallel to the Slope/Embankment	3	3
9. Localized Vertical Movement (cracks in slope-embankment/pavement)	2	2
10. Shallow Surface Failure/Depressions near Top of Slope or Embankment	2	2
g2_s_mode	2	2
g2_s_avg	2	2.2
g2_s_avg_cond	Marginal	Poor
g2_s_mode_cond	Marginal	Marginal

Inspector:	Darren Beckstrand	Ahmad
Comment		Light poles are leaning significantly. Utilities should be M. Number 6 will be M. The slope under the road is a separate asset because and seems to have shallow failures.
1. Soil Erosion	3	1
2. Vegetation	2	2
3. Drainage Systems (Surface and Subsurface)	1	
4. Water Accumulation (top of slope)	1	1
5. Water Accumulation (bottom)	1	1
g2_d_all	3,2,1,1,1	1,2,,1,1
g2_d_mode	1	1
g2_d_avg	1.6	1
g2_d_avg_cond	Marginal	Good
g2_d_mode_cond	Good	Good
Comment		Soil erosion will be M.

Day 02

South Group

Rock Slope

Table 26. Data Records for Rock Slopes Evaluated on Day 02 of Pilot Study 1

Inspector:	Darren Beckstrand	Zafrul H Khan
Asset Type:	Rockslope	Rockslope
Lat	-89.7699	-89.7698
Lon	37.87605099999936	37.87607
Roadway Width (ft)	26	25
County Name	RANDOLPH	RANDOLPH
Road Name	(GRR)	(GRR)
Route ID	IL3	
Travel Direction	Northbound	Northbound
Speed Limit (mph)	55	55
Slope Length (miles)	0.015	0.05
AADT	3550	3550
1. Block Size or Event Volume	Size	Size
Size (ft)	2	2
g1_h_1_score	9	9
2. Slope Height Score (ft)	11	11
g1_h_2_score	1.622	1.622
3. Ditch Effectiveness Score	81	81
4. Geologic Character Score	Case 2	Case 2
Case 2: Differential Erosion Rate	27	
5. Rockfall Activity Score		9
6. Water on Slope		3
sum_hazard	118.622	139.622
sum_hazard2	118.622	139.622
Comment	Occasional differential erosion features. 9pts.	
aadt_score	7.924	7.924

Inspector:	Darren Beckstrand	Zafrul H Khan
1. AADT Score	7.924	7.924
vehicle_value	0.161	0.538
vehicle_score	1.193	1.806
2. Average Vehicle Risk Score	1.193	1.806
sight_value	875	875
3. Decision Sight Score	470	470
sight_score	38.134	38.134
width_value	2.25	2.375
width_score	11.845	13.588
4. Roadway Width Score	11.845	13.588
5. Rockfall Related Maintenance Frequency Score	9	9
sum_risk2	68.096	70.452
rsr_summary	68.096	70.452
Rockslope Class	A	A
Failure Type	Raveling	Raveling
sum_risk_score	186.71800000000002	210.074
rockfall_condition	Poor	Poor

Wall

Table 27. Data Records for Walls Evaluated on Day 02 of Pilot Study 1

Inspector:	Darren Beckstrand	Zafrul H Khan	Zafrul H Khan
Asset Type:	Wall	Wall	Wall
Lat	-89.7624	-89.7701	-89.7619
Lon	37.870525699999355	37.87624	37.8701
Roadway Width (ft)	24	26	24
County Name	RANDOLPH	RANDOLPH	RANDOLPH
Road Name	(GRR)	(GRR)	(GRR)
Route ID	IL3	IL3	IL3
Travel Direction	Southbound	Southbound	Southbound
Speed Limit (mph)	55	55	55
Slope Length (miles)	0.123	0.064	0.123
AADT	3550	3550	3550
1. Foundations	1	1	1
2. Foundation Erosion and Scour	2	1	2
3. Utilities	1	1	1
4. Surface Distress	2	2	2
5. Barrier and Guard Rail	1	1	1
6. Material Saturation	2	2	2
7. Localized Horizontal Movement (cracks in wall/pavement) Parallel to the Wall	1	2	1
8. Localized Vertical Movement (cracks in wall/pavement)	1	1	1
9. Shallow Surface Failure/Depressions near Top of Wall	2	2	2
g4_w_mode	1	1	1
g4_w_avg	1.44	1.44	1.44

Inspector:	Darren Beckstrand	Zafrul H Khan	Zafrul H Khan
g4_w_avg_cond	Marginal	Marginal	Marginal
g4_w_mode_cond	Good	Good	Good
Comment	Cracks in concrete gutter on south end of pile wall section. Last 150 feet on south end is an old bin wall. The concrete faced pile wall may have encased the existing bin wall as a repair. Occasional depressions at top.	Tilting of wall was observed. Wing wall was totally separated from the main wall.	Material loss at the back of the wall near top was observed. There are also distress or signs of material loss on the pavement.
1. Soil Erosion	3	1	3
2. Vegetation	1	2	1
3. Drainage Systems (Surface and Subsurface)	2	2	2
4. Water Accumulation (top of wall)	1	1	1
5. Water Accumulation (bottom)	1	1	1
g4_d_mode	1	1	1
g4_d_avg	1.6	1.4	1.6
g4_d_avg_cond	Marginal	Marginal	Marginal
g4_d_mode_cond	Good	Good	Good
Comment	Manhole at south end leads to a drain pipe with sand and gravel accumulation at outlet. Piping of wall backfill material into drainage feature is suspected. Inspect drain and repair to prevent fill ingress as needed.	Void in the back of the wall near the top was observed	

Soil Slope/Embankment

Table 28. Data Records for Soil Slopes and Embankments Evaluated on Day 02 of Pilot Study 1

Inspector:	Darren Beckstrand	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan
Asset Type:	Slope/Embankment	Slope/Embankment	Slope/Embankment	Slope/Embankment	Slope/Embankment	Slope/Embankment
Lat	-89.7648	-89.7679	-89.7652	-89.7654	-89.76451	-89.7638
Lon	37.87228799999936	37.8747	37.87264	37.87283	37.87213	37.87155
Roadway Width (ft)	24	24	25	26	25	25
County Name	RANDOLPH		RANDOLPH	RANDOLPH	RANDOLPH	RANDOLPH
Road Name	(GRR)	IL3	(GRR)	(GRR)	(GRR)	(GRR)
Route ID	IL3		IL3			IL3
Travel Direction	Southbound	Southbound	Southbound	Northbound	Southbound	Southbound
Speed Limit (mph)	55	55	55	55	55	55
Slope Length (miles)	0.03	0.125	0.061	0.03		0.07
AADT	3550	3550	3550	3550	3550	3550
1. Foundations	2	1	1	1	2	1
2. Foundation Erosion and Scour	1	1	1	1	2	1
3. Utilities	1	1	1	1	1	1
4. Surface Distress	2	2	2	2	2	1
5. Barrier and Guard Rail	1	2	1	1	1	1
6. Slope or Embankment Material Loss	3	3	1	1	3	3
7. Apparent Material Saturation	2	2	2	2	2	2
8. Localized Horizontal Movement (cracks in slope-embankment/pavement) Parallel to the Slope/Embankment	1	2	2	1	1	1
9. Localized Vertical Movement (cracks in slope-embankment/pavement)	1	2	2	1	1	2
10. Shallow Surface Failure/Depressions near Top of Slope or Embankment	1	2	2	1	1	2
g2_s_mode	1	2	1,2	1	1	1
g2_s_avg	1.5	1.8	1.5	1.2	1.6	1.5

Inspector:	Darren Beckstrand	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan
g2_s_avg_cond	Marginal	Marginal	Marginal	Marginal	Marginal	Marginal
g2_s_mode_cond	Good	Marginal	Unknown	Good	Good	Good
Comment	Pavement	Cracks in the pavement were observed. There was slight difference in crack elevation. Soil nails were present to retain soil	Elevation difference and large separation at the middle of the pavement suggesting both horizontal and vertical movement.	Slight and insignificant bulging pf slope was observed	Significant rutting and material loss was present	Rutting is present on the pavement
1. Soil Erosion	1	1	3	3	1	1
2. Vegetation	1	2	1	1	1	1
3. Drainage Systems (Surface and Subsurface)	2	2	1	1	2	2
4. Water Accumulation (top of slope)	1	1	1	1	1	1
5. Water Accumulation (bottom)	1	1	1	1	1	1
g2_d_mode	1	1	1	1	1	1
g2_d_avg	1.2	1.4	1.4	1.4	1.2	1.2
g2_d_avg_cond	Marginal	Marginal	Marginal	Marginal	Marginal	Marginal
g2_d_mode_cond	Good	Good	Good	Good	Good	Good
Comment	Some additional surface drainage control would help with the erosion of sand and gravel at the road’s edge.				Slope is steep compared to other locations	Steep slope with no soil nails.

Day 03

South Group

Rock Slope

Table 29. Data Records for Rock Slopes Evaluated by the South Group on Day 03 of Pilot Study 1

Inspector:	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan
Asset Type:	Rockslope 01	Rockslope 02	Rockslope 03
Lat	-90.09119	-90.106091	-90.286844
Lon	38.08819	38.09474112177732	38.30175909578412
Roadway Width (ft)	24	24	26
County Name	RANDOLPH	RANDOLPH	MONROE
Route ID	IL155		IL156
Travel Direction	Southbound		Southbound
Speed Limit (mph)	55	55	55
Slope Length (miles)	0.03	1	0.06
AADT	1100	750	900
1. Block Size or Event Volume	Size	Both	Size
Size (ft)	2	8	2
Volume (yd3)		20	
g1_h_1_score	9	100	9
2. Slope Height Score (ft)	18	120	30
g1_h_2_score	2.206	100	3.737
3. Ditch Effectiveness Score	81	3	9
4. Geologic Character Score	Case 2	Case 2	Case 2
5. Rockfall Activity Score	3	3	9
6. Water on Slope	3	3	3
sum_hazard	116.206	215	45.737
sum_hazard2	116.206	215	45.737
Comment	Big rocks will certainly reach the roadway. There is a launch feature which further deteriorates the situation.	Minor to no activity for a long time. Lots of vegetation at the fallen rock locations. Vegetation on the rockface and opening as well. Quarry site most likely.	Fence to protect rockfall entering to roadway is damaged. In many places, fence posts are heavily bent or replaced. A pavement patch can be seen, indicating probable damage due to rockfall. Presence of small rocks outside fence.
aadt_score	3.165	2.589	2.836
1. AADT Score	3.165	2.589	2.836

Inspector:	Zafrul H Khan	Zafrul H Khan	Zafrul H Khan
vehicle_value	0.1	2.273	0.164
vehicle_score	1.116	12.148	1.197
2. Average Vehicle Risk Score	1.116	12.148	1.197
sight_value	875	875	875
3. Decision Sight Score	225	1320	1100
sight_score	100	0.184	0.731
width_value	2.5	2.5	2.25
width_score	15.588	15.588	11.845
4. Roadway Width Score	15.588	15.588	11.845
5. Rockfall Related Maintenance Frequency Score	9	3	3
sum_risk2	128.869	33.509	19.609
sum_risk	128.869	33.509	19.609
Comment			
Rockslope Class	B	C	B
Failure Type	Raveling	Raveling	Raveling
sum_risk_score	245.075	248.50900000000001	65.346
Combined Risk Score:			
ditch_cs	1	76	51
rockfall_cs	100	100	75
avg_cs	50.5	88	63
avg_fieldrating	42	3	9
rockfall_condition	Fair	Good	Fair
rockfall_score	3	1	2

Soil Slope/Embankment

Table 30. Data Records for Soil Slopes and Embankments Evaluated by the South Group on Day 03 of Pilot Study 1

Inspector:	Zafrul H Khan
Asset Type:	Slope/Embankment
lat	-90.142143
lon	38.128277
Roadway Width (ft)	24
County Name	MONROE
Road Name	BLUFF RD
Slope Length (miles)	5
AADT	325
1. Foundations	1
2. Foundation Erosion and Scour	1
3. Utilities	1
4. Surface Distress	1
5. Barrier and Guard Rail	1
6. Slope or Embankment Material Loss	1
7. Apparent Material Saturation	2
8. Localized Horizontal Movement (cracks in slope-embankment/pavement) Parallel to the Slope/Embankment	1
9. Localized Vertical Movement (cracks in slope-embankment/pavement)	1
10. Shallow Surface Failure/Depressions near Top of Slope or Embankment	1
g2_s_mode	1
g2_s_avg	1.1
g2_s_avg_cond	Good
g2_s_mode_cond	Good
Comment	Moderately steep slope but no distress observed on the slope face nor on the pavement.
1. Soil Erosion	3
2. Vegetation	1
3. Drainage Systems (Surface and Subsurface)	1

Inspector:	Zafrul H Khan
4. Water Accumulation (top of slope)	1
5. Water Accumulation (bottom)	2
g2_d_all	3,1,1,1,2
g2_d_mode	1
g2_d_avg	1.6
g2_d_avg_cond	Marginal
g2_d_mode_cond	Good
Comment	Water may accumulate at the ditch after heavy rain

North Group

Rock Slope

Table 31. Data Records for Rock Slopes Evaluated by the North Group on Day 03 of Pilot Study 1

Inspector:	David Jaromin	David Jaromin	David Jaromin
Asset Type:	Rockslope 01	Rockslope 02	Rockslope 03
Lat	-89.193611	-89.296538	-89.385188
Lon	42.17744573954645	42.11379040634648	41.96315052049561
Roadway Width (ft)	32	40	25
County Name	OGLE	OGLE	OGLE
Road Name	IL2	IL-2	IL-2
Travel Direction	Southbound	Southbound	Southbound
Speed Limit (mph)		55	55
Slope Length (miles)	500	0.325	315
AADT	7050	5900	4100
1. Block Size or Event Volume	Size	Size	Size
Size (ft)	1	1	1.5
Volume (yd3)			
g1_h_1_score	3	3	5.196
2. Slope Height Score (ft)	34	35	32
g1_h_2_score	4.455	4.656	4.081
3. Ditch Effectiveness Score	9	3	81
4. Geologic Character Score	Case 2	Case 2	Case 2
Case 2: Differential Erosion Rate	3	9	27
5. Rockfall Activity Score	3	3	27
6. Water on Slope	3	9	9
sum_hazard	25.455	31.656	153.277
sum_hazard2	25.455	31.656	153.277
Comment		Rock cut transitioning to a steep rock/soil slope. Tallus redirect features however wide ditch.	
aadt_score	18.486	14.419	9.249
1. AADT Score	18.486	14.419	9.249

Inspector:	David Jaromin	David Jaromin	David Jaromin
vehicle_value		5.811	3913.636
vehicle_score	100	100	100
2. Average Vehicle Risk Score	100	100	100
sight_value		875	875
3. Decision Sight Score	675	750	400
sight_score	100	6.575	59.179
width_value	1.5	0.5	2.375
width_score	5.196	1.732	13.588
4. Roadway Width Score	5.196	1.732	13.588
5. Rockfall Related Maintenance Frequency Score	3	3	27
sum_risk2	226.682	125.726	209.016
sum_risk	226.682	125.726	209.016
Comment			Have Darren review rating.
Rockslope Class	B	C	C
Failure Type	Raveling	Raveling	Raveling
sum_risk_score	252.137	157.382	362.293
ditch_cs	51	76	1
rockfall_cs	100	100	50
avg_cs	75.5	88	25.5
avg_fieldrating	6	3	54
rockfall_condition	Fair	Good	Poor
rockfall_score	2	1	4

Wall

Table 32. Data Records for Walls Evaluated by the North Group on Day 03 of Pilot Study 1

Inspector:	David Jaromin	David Jaromin	David Jaromin
Asset Type:	Wall 01	Wall 02	Wall 03
lat	-89.347427	-89.341496	-89.425781
lon	42.05054243004017	42.040966	41.88676928315434
Roadway Width (ft)	45	65	55
County Name	OGLE	OGLE	LEE
Road Name	IL-2		IL-2
Slope ID	071-7003	No plate	
Travel Direction	Southbound	Southbound	Southbound
Speed Limit (mph)	55	55	55
Slope Length (miles)	675	245	275
AADT	4900	4900	5500
1. Foundations	1	1	1
2. Foundation Erosion and Scour	1	1	1
3. Utilities	1	1	1
4. Surface Distress	1	1	1
5. Barrier and Guard Rail	1	1	1
6. Material Saturation	2	2	2
7. Localized Horizontal Movement (cracks in wall/pavement) Parallel to the Wall	1	1	1
8. Localized Vertical Movement (cracks in wall/pavement)	1	1	1
9. Shallow Surface Failure/Depressions near Top of Wall	1	1	1
g4_w_all	1,1,1,1,1,2,1,1,1	1,1,1,1,1,2,1,1,1	1,1,1,1,1,2,1,1,1
g4_w_mode	1	1	1
g4_w_avg	1.11	1.11	1.11
g4_w_avg_cond	Marginal	Marginal	Marginal
g4_w_mode_cond	Good	Good	Good

Inspector:	David Jaromin	David Jaromin	David Jaromin
Comment	No bulging, 0-1deg deviation, 709+10 to 715+65	No bulging signs, 0-1 deg deviation from verticle Add notes/comment feature to first page, wall height: 12.5 ft, cut wall, cantilever, soldier pile and lagging.	
1. Soil Erosion	1	1	1
2. Vegetation	1	1	1
3. Drainage Systems (Surface and Subsurface)	1	1	1
4. Water Accumulation (top of wall)	1	1	1
5. Water Accumulation (bottom)	1	1	1
g4_d_all	1,1,1,1,1	1,1,1,1,1	1,1,1,1,1
g4_d_mode	1	1	1
g4_d_avg	1	1	1
g4_d_avg_cond	Good	Good	Good
g4_d_mode_cond	Good	Good	Good
Comment		Good drainage all around, no signs of erosion. Add feature to indicate veg growth through structure face? Wall in great shape but marginal rating, is moist soil only cause of this rating. Should be rated good in my opinion	

Day 04

Table 33. Data Record for the Asset Evaluated on Day 04 of Pilot Study 1

Inspector:	Zafrul H Khan
Asset Type:	Slope/Embankment
lat	-90.74025204
lon	40.475961697661496
Roadway Width (ft)	24
Road Name	Macomb Diversion
Route ID	IL336
Travel Direction	Northbound
Speed Limit (mph)	55
Slope Length (miles)	0.012
1. Foundations	2
2. Foundation Erosion and Scour	2
3. Utilities	1
4. Surface Distress	2
5. Barrier and Guard Rail	1
6. Slope or Embankment Material Loss	3
7. Apparent Material Saturation	2
8. Localized Horizontal Movement (cracks in slope-embankment/pavement) Parallel to the Slope/Embankment	2
9. Localized Vertical Movement (cracks in slope-embankment/pavement)	2
10. Shallow Surface Failure/Depressions near Top of Slope or Embankment	1
g2_s_all	2,2,1,2,1,3,2,2,2,1
g2_s_mode	2
g2_s_avg	1.8
g2_s_avg_cond	Marginal
g2_s_mode_cond	Marginal

Inspector:	Zafrul H Khan
Comment	Localized vertical movement appears to be load related. They are inconsistent along the slope, which suggests presence of underlying issues needing further investigation. Cracks on the slope are wider and frequent near the patched area in the pavement.
1. Soil Erosion	1
2. Vegetation	1
3. Drainage Systems (Surface and Subsurface)	2
4. Water Accumulation (top of slope)	1
5. Water Accumulation (bottom)	1
g2_d_all	1,1,2,1,1
g2_d_mode	1
g2_d_avg	1.2
g2_d_avg_cond	Marginal
g2_d_mode_cond	Good
Comment	Probable reason appears to be seepage and drainage. Big manhole near the patched pavement section. Detailed investigation suggested.

PILOT 2 INTRODUCTION

A second pilot study (Pilot 2) was conducted as part of ICT Project R27-262 to evaluate revisions to the field inspection process, forms, and Survey123 application that were developed following the first pilot study (Pilot 1) performed in October 2024. Pilot 2 had three primary objectives: (1) re-evaluate the revised inspection process and forms for rock slopes and soil slopes/embankments, (2) revisit selected Pilot 1 locations to evaluate the impact of revisions on rating outcomes, and (3) conduct the first field assessment of mechanically stabilized earth (MSE) walls. This report summarizes the comments, feedback, and recommended revisions identified during Pilot 2.

PILOT 2 OVERVIEW

Pilot 2 was performed from October 27 through October 29, 2025. The team inspected seven sites across Illinois comprising ten individual geotechnical assets, including two rock slopes, seven MSE walls, and one soil slope/embankment. Field inspections were conducted by two members of the research team, Ahmad Alhasan and Michael Prohaska, with participation by IDOT personnel, including TRP co-chairs, Heather Shoup and Laura Heckel, who accompanied the team at several sites and provided direct feedback on the inspection process.

The feedback received during Pilot 2 was compiled and is summarized in the following sections. The following subsection identifies the inspected sites and reconciles the MSE wall visits against the pre-pilot site selection list. The following two sections addresses revisions identified for the inspection forms and process, organized by asset type and presents general commentary applicable to the overall inspection program.

Inspection Sites

The seven sites inspected during Pilot 2, grouped by geographic location, are listed below. Site names, approximate coordinates, and route references are based on the Survey123 field records, paper inspection records completed in the field where Survey123 was not used, georeferenced field photographs, and the pre-pilot MSE wall site selection documentation.

- Rock slope on Bluff Road, Randolph County, northbound (approx. 38.0972, −90.1080).
- Rock slope on IL 156, Monroe County, southbound (approx. 38.3018, −90.2867).
- Two MSE walls at the MLK Bridge / Packers Avenue ramp to I-55/64 and I-70, St. Clair County (approx. 38.629, −90.165) — corresponds to planned Site 8.
- MSE wall at Route 40 over SW Washington Street, Peoria (approx. 40.6876, −89.5943) — corresponds to planned Site 7.
- Two MSE walls at I-74 over W Jefferson Street, Morton (Tazewell County; approx. 40.621, −89.477) — corresponds to planned Site 6.
- Soil slope/embankment on I-55 southbound, Sangamon County (approx. 39.8771, −89.5969).

- MSE walls at the Chicago metropolitan area, including one wall on the I-55 eastbound ramp to Ashland Avenue, Cook County (approx. 41.836, −87.682; not on the planned site list), and one wall at I-290 / N Wolf Road, Hillside (approx. 41.872, −87.902) — the latter corresponds to planned Site 2.

MSE Wall Site Selection

Prior to Pilot 2 field operations, the research team prepared an MSE wall site selection package identifying nine candidate locations across Illinois and the St. Louis metropolitan area. Inspection data for Pilot 2 was captured using a combination of the Survey123 field application and paper inspection forms, with paper forms used in the field where the Survey123 application was not practical (e.g., due to limited internet connectivity). Five of the nine planned sites were inspected during Pilot 2:

- Site 2 (I-290 / N Wolf Road, Hillside),
- Site 5 (Archer Avenue over I-294, Justice),
- Site 6 (I-74 over W Jefferson Street, Morton),
- Site 7 (Route 40 over SW Washington Street, Peoria), and
- Site 8 (MLK Bridge / Packers Avenue ramp to I-55, St. Louis).

Site 5 was inspected on October 28, 2025, using a paper inspection form rather than Survey123. Four planned sites were not visited:

- Site 1 (I-294 over E North Avenue, Northlake),
- Site 3 (I-88 over Warrenville Road, Lisle),
- Site 4 (I-88 over S River Street, Aurora), and
- Site 9 (I-70 over Industrial Avenue, St. Louis).

In addition to the planned sites, two MSE walls not on the pre-pilot site selection list were inspected as sites of opportunity: one wall in the East St. Louis area near the MLK Bridge complex, and one wall on the I-55 eastbound ramp to Ashland Avenue in Cook County. These additions expanded the range of MSE wall conditions represented in the Pilot 2 dataset.

INSPECTION FORM AND PROCESS REVISIONS

General (All Asset Types)

Feedback applicable across all asset families focused on improving the completeness of site documentation, the usability of the data entry interface, and the clarity of rating categories. The following revisions were identified:

- The General Information form should function more closely as a daily field report and capture surface condition (wet, dry, puddling), weather (raining, clear, cloudy), and temperature. This information supports interpretation of observations that are weather-dependent, such as drainage performance and ponding.

- A general comment field should be available to document accessibility or inspection limitations (e.g., portions of a wall not inspected due to limited access or excess vegetation).

- Asset location and offsets should be integrated with centerline offsets for database integration. Offsets from centerline support database integration, while distance from the pavement edge is needed for risk calculations; both measures may need to be collected. Data available through IROADS should be leveraged where possible.

- The speed limit field should include 70 mph to accommodate interstate inspections.

- Asset length may be more usable in feet rather than miles; a unit toggle should be considered.

- The Excel inspection forms allow comments per observation category (e.g., barrier and guard rail, utilities), while Survey123 only offers comments per component group. Survey123 should incorporate a “+” button or similar control to add category-level comments and match the level of detail supported by the Excel version.

- Toggle buttons for “Requires Maintenance,” “Requires Detailed Inspection,” and similar key actions should be incorporated so that basic required actions can be flagged without being inferred from ratings.

- Visual aids, including scaled photos or sketches depicting typical damage and percent affected, should be developed to illustrate severity levels for each component.

- Response options should include “Not Visible” and “Unknown” in addition to “N/A” to distinguish between conditions that cannot be observed and conditions that are not applicable.

- “Saturation” fields are difficult to rate meaningfully as part of a standard visual inspection. Revisions should clarify observable indicators (e.g., free moisture draining from the slope face) or relocate these fields.

Rock Slopes

No additional revisions specific to rock slopes were identified during Pilot 2. The revised inspection form and process performed as intended at both rock slope sites.

Soil Slopes / Embankments

Feedback for soil slopes/embankments focused on clarifying component definitions and improving the drainage assessment categories:

- Slope inclination (steepness) should be added as a required geometric input.
- Under Component Distress:
    - The “Foundations” category should be better defined and should specifically reference the slope toe.
    - “Apparent Material Saturation” requires revision to provide clear indicators of each rating state (e.g., free moisture draining from the slope face), as saturation is not readily rated from visual inspection alone.
- “Shallow Surface Failure/Depression…” should be revised to better indicate the area of interest.
- Under Drainage:
    - The “Erosion” category would benefit from the addition of a Marginal rating.
    - The “Vegetation” descriptions should be revised to indicate percent of vegetation loss or otherwise better capture severity. A longer-term approach may assign weighted categories (e.g., Good 75%, Marginal 20%, Poor 5%, N/A 0%).
    - A “Gutter/Ditch” category should be added, as these features are common along slopes and may fill in with material loss from the slope, providing an indicator of slope performance.

Retaining Walls

Feedback for generic retaining walls emphasized the inclusion of basic build information and improved clarity in rating fields:

- Limited geometric and build data should be incorporated into the wall inspection form.
- Under Wall Components:
    - “Shallow Surface Failure/Depressions” should be better defined.

- "Material Saturation" requires revision as it is not readily rated visually; alternatively, an "Unknown/Unable to be Rated" option should be offered so that blank entries are not misinterpreted as skipped inspections. Note that the evaluation procedures are based on surficial observations and are not designed for intrusive testing.

- Under Drainage:

  - The "Erosion" category would benefit from a Marginal rating.

MSE Walls

Pilot 2 represented the first field deployment of the MSE wall inspection form. Feedback was substantial and is grouped below by form section:

- Limited geometric and build data should be captured, including maximum exposed height, typical exposed height, panel/facing unit type or style, and reinforcement type. "Unknown" and "N/A" options should be available for build data fields.

- Under Component Distress:

  - "Geotextile Joint Material" ratings depend on knowledge of the original build or design. "Not Visible" and "Visible" options should be offered, and a Marginal rating should be available where wear is observed but joint material remains in place.

  - "Shallow Surface Failure/Depressions near the Toe" should clearly state in the user guide that erosion-related depressions are excluded.

  - Fences and non-traffic barriers are common non-structural elements that may pose safety hazards; these should be incorporated into an appropriate rating group.

  - "Backfill Saturation" may be better located within the Drainage group unless clear visual indicators are provided.

  - A "General Erosion/Scour" field should be added to capture material loss at locations other than the foundation. This condition was observed at several MSE sites and can impact safety features, result in loss of reinforced fill or reinforcement cover, and contribute to general site wear.

- Under Metallic Component Distress:

  - Visual aids illustrating the distinction between alignment and displacement should be developed during future revision of the user guide and training material.

  - "Reinforcement or Connection Corrosion" is difficult to assess from an external inspection and, in practice, defaults to observations of facing displacement (bulging and bowing). Good and Poor ratings appear to require different inspection types (external only versus

reinforcement exposure). The inspection procedure should be unified or the expected inspection type clearly stated.

- General Statement: It should be clearly emphasized in the user guide that these ratings are based on EXTERNAL inspection and do not necessarily reflect the condition of internal structural components. For example, a rating of "G: No facing connection rupture or reinforcement pullout" may not represent the actual condition of the reinforcements. The team should determine whether the MSE inspection sheet (and others) should be limited to visual indicators that infer condition, or whether a mix of invasive and visual inspection points is appropriate.

GENERAL COMMENTARY

In addition to the form-specific feedback, Pilot 2 identified several broader considerations relevant to the overall inspection and rating program:

- Inspection activities were regularly hindered by lack of internet connectivity at field sites. During Pilot 2, paper inspection forms were used at several locations as the practical workaround when Survey123 could not be used in the field. For future inspection programs, the Survey123 field application supports cached (offline) data collection, and this capability should be enabled and used routinely to reduce reliance on paper forms and to keep digital and paper inspection records consistent.

- Natural "break points" for segmenting assets should be developed to prevent over-smoothing of condition and risk ratings. Anticipated break points include:

- General: maximum asset length and asset exposed height.

  - Rock slopes: to be determined.

  - Slopes/embankments: inclination (2:1 breakpoint) and height (greater than 15 ft triggers slope stability analysis).

  - Walls: height (greater than 8 ft triggers a structure/geotechnical report).

  - MSE walls: to be determined.

- The final report should indicate that individual observation categories may require distinct weights based on asset performance monitoring outcomes and changes in relative importance over time. Recent work by Kulesza (2024) on rating individual distresses by importance should be considered.

- Group and element weights may require revision to better reflect real-world hazards observed during Pilot 2.

SUMMARY

Pilot 2 successfully tested the revised inspection process and forms for rock slopes and soil slopes/embankments, revisited Pilot 1 locations to evaluate the impact of revisions, and provided the first field trial of the MSE wall inspection form. No substantive revisions to the rock slope form were identified, while additional refinements were recommended for soil slopes/embankments, retaining walls, and particularly MSE walls. General program-level recommendations addressed offline data collection, natural asset break points, weighting of observation categories, and clarification that external inspections do not fully characterize internal structural condition. The team will incorporate many of the revisions identified in this report into the final versions of the inspection forms, the Survey123 application, and the user guide as part of the project final report.

APPENDIX C: ROCK SLOPE INSPECTION AND CONDITION ASSESSMENT FOR ILLINOIS DOT

INTRODUCTION

The Illinois Department of Transportation (IDOT) is advancing research for developing a framework for a Geotechnical Asset Management (GAM) Program. Assets considered for inclusion into the framework include soil and rock slopes, embankments, and retaining walls. This document proposes an inspection and condition assessment framework for rock cut slopes, including inventorying, inspection, and condition assessment.

Asset management generally seeks to assess condition separate from the risk posed by the deterioration or failure of the subject asset. An asset's condition can inform the probability of failure, but the consequences posed by that failure should be assessed independently from probability. Risk-based rock slope assessments have been developed within GAM programs since the Alaska Department of Transportation and Public Facilities (AKDOT) further developed the initial Unstable Slope Management Program (USMP) between 2011 and 2017. The approach, since further developed, tested, and implemented in several additional states, also included collection of Rockfall Hazard Rating System (RHRS) data and other supporting information. Collection of RHRS data helps with several facets of rock slope management, including using the RHRS score as a common communication tool amongst geotechnical personnel, collection of size and extent information, and relative risk factors (sight distance, road width, AADT, etc.) that others within IDOT may find useful. Utilizing this proven approach is recommended for Illinois and is described below.

INVENTORYING AND INITIAL INSPECTION

Rock slopes are typically inherently unstable and most produce rockfalls in differing amounts and at various times, though event frequency can vary from rarely to almost constantly. These events represent safety concerns that can cause accidents and disrupt mobility and local economies. They can also put inordinate demands on maintenance operations and budgets and create safety concerns for maintenance staff. All rock slopes that could potentially generate rockfall requiring maintenance attention, even on an infrequent basis, are initially categorized into two of three categories. Slopes meeting the third classification may be entered into the database to achieve a complete inventory, but DOT's may opt to exclude them due to their very small size, setback from the road, relative stability, and the negligible hazard and risk posed to public safety and the DOT.

Rock slopes will be divided into three classifications: A, B, and C based on the potential and/or history of rockfall reaching the roadway. An initial inspection process will subdivide and assign a classification to each rock slope. Slopes in Class A have the highest likelihood of producing rockfall that impacts the road and will receive a detailed field assessment by an experienced geotechnical engineer or engineering geologist. Slopes in Class B will be entered in the inventory and will receive a detailed assessment when on a high-volume or otherwise critical route (for instance, above 4,000 AADT). Slopes in Class C will be included in the inventory but not receive a detailed assessment. All the slopes are typically excavated above road grade for the highway, however an adjacent natural rockfall-prone

slope that poses a hazard to the right-of-way, the public and/or requires maintenance action should also be entered into the database. These three slope classifications are defined below while Table 34 summarizes the screening-level determination of Rock Slope Classification based on a combination of rockfall potential and catchment.

The field data collection platform should allow the collection of beginning and ending mileposts, geographic coordinates, comments, approximate length and height, site photos, and the determination of the A, B, or C classification.

Class A – Rockfall from these slopes have a moderate to high likelihood of reaching the road. There is either limited catchment or a record of regular and active rockfall activity. A mitigated rock slope may also be included in this category if the mitigation was completed in response to a history of required maintenance and rockfall activity.

Class B – Rockfall from these slopes have a low likelihood of reaching the roadway but may occur based on reasonable inspector judgment. These sites typically have moderate rockfall potential, low rockfall history, and good catchment. There may be records of occasional maintenance attention in the past. Traffic volume is straightforward metric to serve as the basis of when a Class B slope receives a detailed assessment versus simply entered into the database. Risk factors, such as sight distance, detour length, and commercial truck traffic, could be the subject of additional research regarding these potential moderate risk slopes.

Class C – Rockfall from these slopes is unlikely to reach the road. The general classification of a C slope is one where the slope is shorter than 15 feet and shorter than the roadside ditch's width. Rockfall from a C slope would have no reasonable way to reach the road or require maintenance.

Table 34. Initial Inspection Determination of Rock Slope Classification Based on Combination of Rockfall Potential and Ditch Effectiveness

		Historic Failure Frequency or Potential		
		High	Moderate	Low
Likelihood of Rockfall Affecting the Road	High	Class A	A	A
	Moderate	A	A	B
	Low	A	B	C

DETAILED INSPECTION

The proposed detailed rock slope inspection procedure uses a combination of data collected in the field and data obtained from IDOT or other in-office sources. Data collected in the field includes categories like slope height, slope drainage, site distance, etc. Data obtained from existing sources includes information that cannot be measured in a site visit, but is important when assessing risk. Inventoried and assessed rock slopes will be evaluated in 12 categories. These evaluation categories are divided between hazard and risk categories, consistent with prior research results developed and proven in several other rock slope-based GAM systems. Hazard describes the presence, potential, and severity of rockfall activity at a site and its impact of reaching the roadway. The risk categories

capture the relative consequences of damage, injury, or roadway impedance due to a rockfall event. Both the hazard and risk categories are described in detail in the following subsections.

The field evaluation work is summarized using different methods, as shown in Table 35. The goal of the summary methods is to help the field personnel conducting the rating and inventory work communicate site conditions, site risk, and potential impacts to an audience of varying geotechnical expertise. Each of the evaluation criteria will factor into the following evaluation approaches to serve the needs of geotechnical, planning, asset managers, and executive leadership.

Table 35. Slope Evaluation Results Summary and Their Intended Audience

Summary Method	Intended Audience	Notes
Rockfall Hazard Rating System (RHRS)-style total score.	Primary: Geotechnical personnel, Operations Secondary: Planners	A high score equates to a higher hazard and/or higher risk slope
Condition State	Primary: Asset Managers, Executive, Operations Secondary: Geotechnical personnel	Integers 1 through 5 with Good, Fair, Poor terminology
Condition Index	Primary: Asset Managers, Operations Secondary: Geotechnical personnel	0 (poor, failed) to 100 (good, high performance)

The field evaluation categories, condition, and risk approaches were developed as part of other states' GAM programs. The evaluation categories are described in the following section and the derivation of the slope's RHRS Score, Condition State and Index, and the risk assessments described in detail within the sections thereafter. The evaluation categories and how each is used in evaluating slope and developing condition and risk are summarized in Table 36.

Table 36. Condition Evaluation Categories

	RHRS Score	Condition State/Index
Hazard Categories		
Block Size / Event Volume	✓	
Ditch Effectiveness	✓	✓
Geologic Character	✓	
Rockfall Activity	✓	✓
Slope Height	✓	
Annual Precipitation	✓	
Slope Drainage	✓	
Risk Categories		
Annual Average Daily Traffic (AADT)	✓	
Average Vehicle Risk & Slope Length	✓	
Decision Sight Distance	✓	
Roadway Width	✓	
Rockfall Related Maintenance Frequency	✓	

Integration of External Data Sources

Site evaluations are based both on available data and on-site observations, making the assessments as independent and robust as possible. A complete assessment should not depend on information entered later in the office, as that step could be neglected, unavailable, or inconsistently evaluated statewide. However, some information, such as average daily traffic or average annual rainfall is not observable during a site visit but is ideally collected before field assessments and is used on-site to generate a completed assessment while still in the field. This external data required for rock slope ratings typically includes:

- Route geodatabase with linear referencing codes and route IDs.
- Geodatabase with all mile post locations of the route systems to be evaluated (i.e. National Highway System).
- A geodatabase of maintenance station management responsibility for each roadway segment.
- AADT for all department roadways.
- Average annual rainfall, in inches, presented as a geospatially referenced polygon file.

Geodatabases containing these data can be automatically referenced in GIS-based field data collection platforms, such as ESRI's Survey123. The field data is easily added to interactive ArcGIS Online maps and dashboards. Additional information, such as maintenance frequency and insights on rockfall history, is obtained by interviewing Maintenance and Operations personnel.

Interviews with maintenance station supervisors may be conducted before or after the majority of field assessment work is completed in a maintenance section. These interviews help gauge rockfall activity at various locations and provide the opportunity to identify those sites that require the most frequent or extensive maintenance attention. Although informal and anecdotal, these interviews provide important external data, thus improving the quality of the data collected during inventory fieldwork.

Incorporating Reference Data Layers

The external datasets listed above are most useful when read automatically at the point of inspection rather than transcribed by field staff. In the Survey123 form developed for this study, three reference attributes, County Name, Road Name, and AADT, are already populated automatically from a hosted reference layer using a spatial lookup against the inspector's recorded location. The same mechanism can be extended to the remaining reference data, and IDOT is encouraged to adopt the following approach as the program scales beyond the pilot.

Reference layers should be hosted within IDOT's own ArcGIS organization. Each reference dataset (e.g., route and linear-referencing systems, milepost locations, maintenance-station responsibility, AADT, and average annual rainfall) should be published as a hosted feature layer inside the Department's ArcGIS Online or Enterprise organization rather than referenced from an external

endpoint. Internal hosting gives IDOT control over schema, update cycle, and availability, and avoids a production inspection form depending on a third-party service that may change or be withdrawn.

Site attributes can be populated by spatial lookup. Once a reference layer is hosted, the corresponding survey field is populated by a location-based query returning the attribute value for the polygon or segment beneath the inspection point. County, road, and AADT already use this pattern; route identifier, milepost, maintenance station, and average annual rainfall can be added the same way. This removes manual entry, eliminates transcription error, and ensures every record carries a consistent, source-traceable value.

As precipitation is a function of location and does not change between inspections, average annual rainfall should be supplied as a static polygon layer of rainfall contours in inches and read by the same spatial lookup, not computed from a live weather service at inspection time. A statewide layer clipped from a recognized climate normal (for example, the PRISM 1991–2020 annual-precipitation normals) and hosted within IDOT's organization provides a stable, defensible source. A read-only rainfall field has been added to the inspection form for this purpose; it requires only that the hosted rainfall layer and its attribute field be identified before deployment.

As the asset management program matures, further reference layers, for example geologic mapping, historical rockfall or maintenance records, drainage infrastructure, and prior inspection history, can be incorporated through the same hosted-layer and spatial-lookup pattern. IDOT can successfully plan for additional GAM data layers by establishing a consistent convention now (e.g., internal hosting, documented attribute names, and location-based population of survey fields). Allowing new data sources to be added without redesigning the form and keeps the inspection record aligned with the Department's broader GIS data holdings.

RHRS Scoring

The experienced field engineer/geologist collects additional site information, photographs, and evaluation criteria as appropriate after determining if a rock slope is Class A or a Class B slope on a high-value route. Slopes classified as C slopes do not receive a detailed inspection. This information is entered into the field data collection platform or an equivalent paper copy. This subsection outlines the various elements used in generating detailed rock slope assessments.

The detailed categories developed for rock slopes use an exponential scoring system similar to what was developed as part of the RHRS in the early 1990s (Pierson & Van Vickle, 1993). Each category includes four subcategories that represent mathematical or logical breaks. Adaptations of the RHRS rating categories to meet the needs of IDOT are detailed in the following subsections.

Determination of Failure Type

The geotechnical personnel should evaluate the primary failure mechanism generating rockfall at the site. Simple schematics of these failure types are shown in Figure 118. The rockfall movement types include both classic failure mechanisms such as planar, wedge, and toppling failures, along with raveling/undermining rock slopes (i.e. talus slopes or slopes controlled by differential erosion) and block failure. Block failure is for sites where the rockfall mechanism is a complex interaction between

multiple joints, and where the straightforward planar, wedge, or toppling models are insufficient to describe the failure. Field personnel are encouraged to mark all failure types that are prominent at a rock slope, even if this called for the selection of multiple movement types.

RHRS Rating Categories

In the detailed rating, each rock slope is scored in seven Hazard Rating categories and five Risk Rating categories. Collectively, the hazard ratings seek to quantify the likelihood that a rockfall event will occur at a site and affect the roadway, requiring some level of maintenance response. The risk ratings assess the consequences and inconvenience which an event will pose to the traveling public and the potential costs of this event, resulting from maintenance involvement, slope or roadway repairs, or right of way purchase should the failure extend beyond current ROW boundaries.

Each category is scored to a maximum of 100 points. Each category score is summed to calculate the total RHRS score for a site. For those rating categories which are not directly scored through equations, the field rater estimates the most reasonable score based on professional judgement, input from maintenance personnel, and past performance history. The following subsections describe the various rating categories in detail.

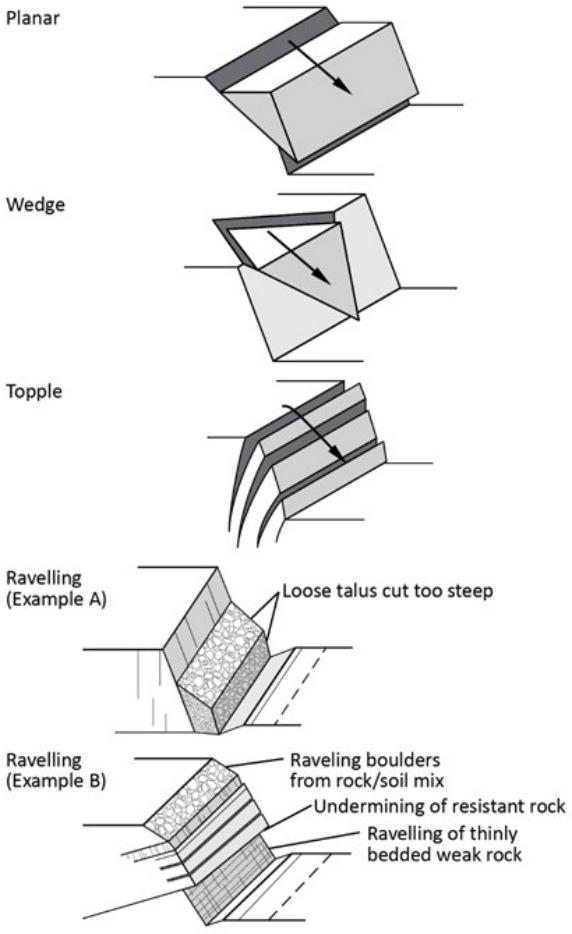


Figure 118. Illustration. Sample rockfall failure types.

Hazard Categories

Block Size or Event Volume Score

Larger blocks or greater quantities of falling rock produce more total kinetic energy and greater impact force than smaller events. In addition, the larger events obstruct more of the roadway, reducing the possibility of safely avoiding the rock(s) and resulting in higher response costs for the managing agency. In essence, the larger the blocks or event volume; the greater the hazard created and the higher the site scores in this category.

This measurement should be representative of the type of rockfall event most likely to occur. If maintenance input is not readily available, debris currently contained in a roadside ditch can help generate a reasonable estimate of block size or event volume. If individual blocks on the slope are typical of the rockfall observed in the ditch at a site, then block size should be used for scoring. If a mass of blocks tends to be the dominant type of rockfall, volume per event should be used. The field rater can also use both block size and event volume for scoring and keep the highest score. Figure 119 presents a slope where either measurement will lead to a maximum score in this category. A decision on which to use can be determined from the maintenance history or estimated from observed conditions when no history is available. This measurement will assist in determining risk reduction measures.



Figure 119. Photo. Example of a slope producing large individual blocks and high-volume events.

The category score is calculated using either block size or volume size, as shown in the two equations presented in Figure 120 and in Table 37. If it is unclear on which equation to use, rate the site using both equations and record the higher of the two scores. Sample calculated category scores are shown in Figure 120.

$$Block\ Size\ Score = 3^x\ (\max 100)\ ;\ x = block\ size\ (ft)$$

$$Volume\ Size\ Score = 3^x\ (\max 100)\ ;\ x = \left(\frac{yds^3}{3}\right)$$

Figure 120. Equation. Category score calculated by block size or volume size.

Table 37. Block Size and Volume Size Sample Calculated Scores

Category Score	Block Size	Volume Size
3 points	1 foot	3 cubic yards
9 points	2 feet	6 cubic yards
27 points	3 feet	9 cubic yards
81 points	4 feet	12 cubic yards

Ditch Effectiveness Score

Ditch effectiveness describes the ability of the existing roadside ditch and associated improvements (concrete barrier, guardrail, etc.) to prevent falling rock from reaching the paved roadway, including any paved shoulder. When all or almost all rockfall from the slope does not reach the roadway, then no matter how frequently rockfall occurs, ditch effectiveness is high, the danger to the public is low, and the category score is also reduced. Conversely, if rockfall events are rare, but catchment is nonexistent and all falling rock can be reasonably expected to reach the pavement, then ditch effectiveness is low, danger to the public is increased, and the category score is also high.

This is a subjective category that relies heavily on the rater's experience to evaluate the multiple factors contributing to overall ditch effectiveness. A wide fallout area does not necessarily guarantee that rockfall will be prevented from reaching the highway. In estimating the ditch effectiveness, the rater should consider several factors: (1) slope height and angle; (2) ditch width, depth, and shape; (3) anticipated rockfall event volume or rock size; and (4) impact of slope irregularities (launch features) on falling rocks. Evaluating the effect of slope irregularities is especially important because they can completely negate the benefits expected from a fallout area. Valuable information on past ditch performance can be obtained from maintenance personnel.

Figure 121 presents a graphic diagram of ditch effectiveness for guidance but does not replace professional experience. As shown in the diagrams, slope angle and presence of launch features contribute to the effectiveness of the ditch constructed at the site. Figure 122 contains a photo example of a launch feature reducing ditch effectiveness. Narratives describing the scoring categories are presented in Table 38.

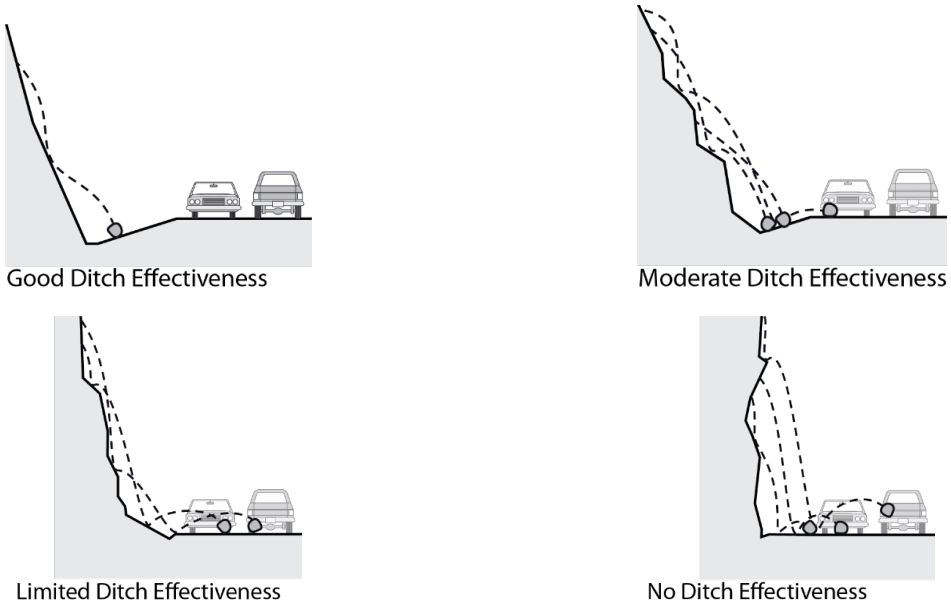


Figure 121. Illustration. Ditch effectiveness explanatory diagram.

Note the negative effect that launch features and cut slope irregularities have on ditch effectiveness.

Table 38. Ditch Effectiveness Category Narratives

Score	Description
3 points	Good Catchment. All or nearly all falling rocks are retained in the catch ditch. Consider mitigation elements (on-slope and/or roadside improvements) in all categories.
9 points	Moderate Catchment. Falling rocks are expected to occasionally reach the roadway.
27 points	Limited Catchment. Falling rocks are expected to frequently reach the roadway.
81 points	No Catchment. No ditch, or ditch is totally ineffective. All or nearly all falling rocks reach or would reach the road.



Figure 122. Photo. Rock slope with a launch feature creating a less effective ditch.

Geologic Character Score

The geologic conditions of a rock slope typically fit into one of two categories: Case 1 or Case 2. Case 1 describes slopes where joints, bedding planes, or other discontinuities control rockfall. Case 2 describes slopes where differential erosion is the dominant rockfall contributor. Erosion features include over steepened slopes, unsupported rock units (overhangs), or exposed resistant rocks on a slope, which may eventually lead to a rockfall event. These cases were first developed in the original RHRS manual and have been maintained in subsequent rating programs. Representative examples of each case are shown in Figure 123.



Figure 123. Photo. Representative examples of case 1 (left) and case 2 (right) geologic character slopes.

The experienced field inspector should determine which case best fits the slope and rate accordingly. If both structural and differential erosion conditions are contributing to rockfall, and it is unclear which condition is dominating, scores for both cases may be collected and the worst case (highest score) is used in the final RHRS score for the rock slope.

Definitions for the terms used in this category are provided below.

- Adverse: Describes a joint's spatial relationship to the slope where the joint daylights in the face of the slope and the dip of the joint is oriented towards the roadway; as well as rock friction angle, joint infilling, and the effects of water on slope stability, if present.
- Favorable: Describes a joint's spatial relationship to the slope where the joint(s) may or may not daylight in the face of the slope and the dip of the joint or joint intersections are oriented away from the roadway.
- Continuous: Joints that are greater than 10 feet in length.
- Discontinuous: Joints that are less than 10 feet in length.
- Joint: All possible discontinuity types contributing to rockfall, including bedding planes, foliations, fractures, and faults.

Case 1 – Structural Condition

Jointed rock is more prone to rockfall than massive rock because movement occurs along discontinuities where the resistance to movement is significantly less than in intact rock. When the joints are orientated adversely to the slope, the potential for rockfall is greater. Adverse joints are those that singularly, or in combination with other joints, make planar, circular, block, wedge or toppling failures kinematically possible. Continuous adverse joints increase the likelihood of larger failures. Case 1 structural condition category scores are provided in Table 39.

Table 39. Case 1 Structural Condition Category Narratives

Score	Description
3 points	Joints with favorable orientations. Slope contains jointed rock with no or very few adversely oriented joints.
9 points	Random (both favorable and unfavorable) orientations. Slope contains randomly oriented joints creating a variable pattern. The slope is likely to have some scattered blocks with adversely oriented joints, but no dominant adverse pattern is present.
27 points	Discontinuous joints with adverse orientations. Rock slope exhibits a prominent joint pattern with an adverse orientation. These features have less than 10 feet of continuous length.
81 points	Continuous joints with adverse orientations. Rock slope exhibits a dominant joint pattern with an adverse orientation and a length greater than 10 feet.

Case 1 – Rock Friction

In addition to joint orientation, joint condition, or rock friction, contributes to rockfall potential by impacting how easily blocks on the slope can move relative to each other. Joint condition is described in terms of micro and macro roughness. Macro roughness is the degree of undulation of the joint relative to the direction of possible movement. Micro roughness is the texture of the surface. The scoring category descriptions for rock friction are presented in Table 40.

Table 40. Case 1 Rock Friction Category Narratives

Score	Description
3 points	Rough. Irregular. The surfaces of the joints are rough, and the joint planes are irregular enough to cause interlocking.
9 points	Undulating. Rough but without the interlocking ability, judged on the macro scale. Common with cooling joints in basalt formations and deformed argillite.
27 points	Planar. Macro smooth and micro rough joint surfaces. Friction is derived strictly from the roughness of the rock surface.
81 points	Clay Infilling, Open, or Slickensides. Low friction materials separate the rock surfaces, negating any micro or macro roughness of the joint surfaces. Slicken-sided joints also have a lower friction angle and belong in this category.

The Joint Roughness Coefficient (Barton & Choubey, 1977) can be used as a guide for approximating roughness in joints that are not infilled with low-friction materials, as shown in Figure 124.

Slopes where the joints are filled with hydrothermally altered or weathered material, where slickensides or fault gouge are present, or where joints are open or filled with water should all receive a score of 81 or higher in this category.

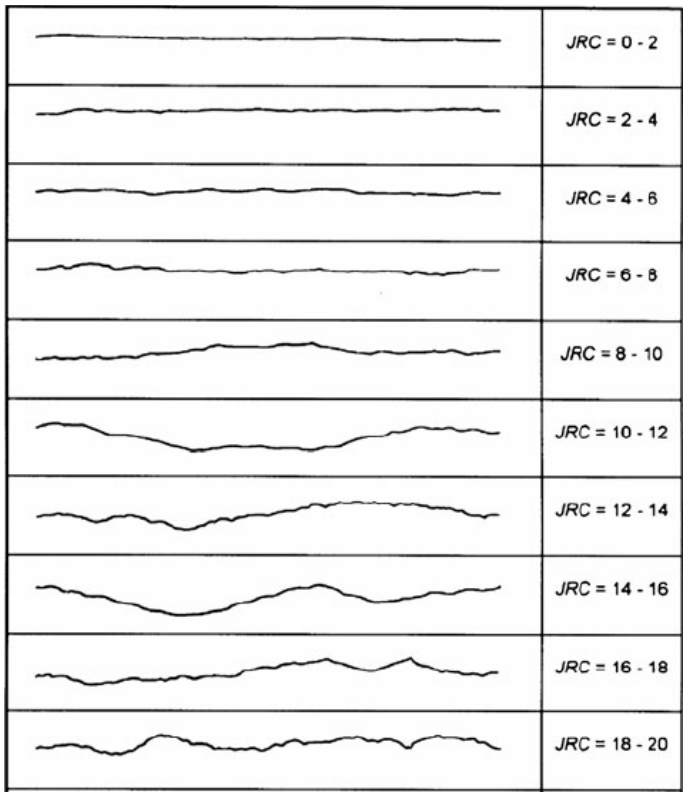


Figure 124. Illustration. Joint Roughness Coefficient (JRC) guide, modified here as dimensionless. Low JRC values for macro roughness (large planar joints) joints would equate to a higher score. Rough, irregular joints (high JRC), both in macro and micro scale, score low.

Case 2 – Structural Condition

The Structural Condition for Case 2 describes the severity and extent of differential erosion features, as opposed to the orientation and extent of joints in Structural Condition for Case 1. Adverse structural conditions in this category describe differential erosion that leads to a loss of support, either locally or throughout a slope. The types of slopes most susceptible to this condition are:

- layered geologic units containing beds with different erosion rates;
- talus slopes;
- highly variable geologic units such as conglomerates and mudflows where resistant rocks and blocks can weather out of the weaker matrix; and
- combination rock/soil slopes where rocks fall as the soil matrix material is eroded

Scoring narratives for this category are presented in Table 41.

Table 41. Case 2 Structural Category Narratives

Score	Description
3 points	Few Differential Erosion Features. Minor differential erosion features that are not distributed throughout the slope.
9 points	Occasional Differential Erosion Features. Minor differential erosion features that are widely distributed throughout the slope.
27 points	Many Differential Erosion Features. Differential erosion features that are large and numerous throughout the slope.
81 points	Major Differential Erosion Features. Severe cases such as dangerous erosion-created overhangs, or significantly over-steepened soil/rock slopes or talus slopes.

Case 2 – Differential Erosion Rate

The rate of differential erosion on a Case 2 slope describes the rate at which unsupported or over steepened slope conditions develop. It also contributes to the potential for a future rockfall event. The scores given in this category should reflect the rate at which erosion is occurring, the size of rock blocks or units being exposed, the frequency of rockfall events caused by this erosion, and the amount of material released during an event. The approximate age of the rock slope should also be considered when estimating rates. The impact of the common physical and chemical erosion processes, as well as the effects of human actions, should all be considered. Category narratives for differential erosion rates are provided in Table 42.

Table 42. Case 2 Differential Erosion Rate Category Narratives

Score	Description
3 points	Small Difference. Erosion features take many years to develop. Slopes that are near equilibrium with their environment are covered by this category.
9 points	Moderate Difference. The difference in erosion rates allows erosion features to develop over a period of a few years.
27 points	Large Difference. The difference in erosion rates allows noticeable changes in the slope to develop annually.
81 points	Extreme Difference. The difference in erosion rates allows rapid and continuous development of erosion features.

Rockfall Activity Score

This category describes rockfall activity at the site. This category is an important descriptor for future rockfall potential since past performance indicates future risk in the absence of mitigation measures. Scoring in this category is most effective when the rater incorporates information from the maintenance personnel responsible for the slope. If this information is not readily available, quantity of rock in the ditch, the presence of fresh surfaces on the rock slope face, and evidence of damage to pavement or guardrail can all contribute to an assessment of rockfall frequency at a site. The rater should visually verify the maintenance-reported history with the physical evidence of rockfall activity

at the site as not all maintenance personnel report activity identically. Rockfall activity category narratives are provided in Table 43.

Table 43. Rockfall Activity Category Narratives

Score	Description
3 points	Few Falls. Rockfalls occur only a few times a year (or less), or only during severe storms. This category is also used if no rockfall history data is available and evidence of rockfall is absent.
9 points	Occasional Falls. Rockfall occurs regularly. Rockfall can be expected several times per year and during most storms.
27 points	Many Falls. Typically, rockfall occurs frequently during a certain season, such as the winter or spring wet period, or the winter freeze/thaw, etc. This category is for sites where frequent rockfalls occur during a certain season but not during the rest of the year.
81 points	Constant Falls. Rockfalls occur frequently throughout the year. Seasonal increases in activity may be present, but measurable rockfall activity also occurs year-round.

Slope Height Score

This category evaluates the hazard associated with the height of a rock slope. The slope height measurement is the greater of 1) the highest point from which rockfall is reasonably expected, or 2) to the top of the cut, as shown in Figure 125. If rockfall is generated from the natural slope above the cut slope, the slope height measurement should include both the cut height and the additional vertical height on the natural slope to the rockfall source.

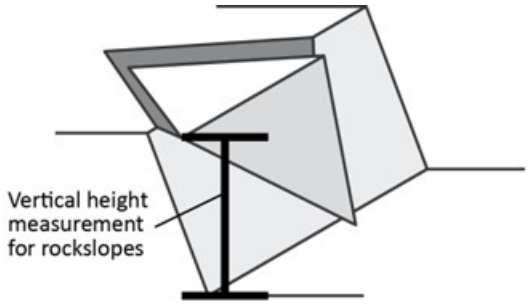


Figure 125. Schematic. Measuring vertical slope height.

This category is directly measured and scored using the equation in Figure 126. Scores range from 0 to 100. All slopes 105 feet in height or greater receive a score of 100. Sample calculated category scores are presented in Table 44.

$$Score = 3^{x}\ (\max 100)\ ;\ x = \frac{slope\ height}{25}$$

Figure 126. Equation. Slope Height Score.

Table 44. Slope Height Sample Calculated Scores

Score	Slope Height
3 points	25 feet
9 points	50 feet
27 points	75 feet
81 points	100 feet

Water on Slope

Both total annual precipitation and the nature of drainage on the rock slope contribute to the weathering and displacement of rock materials. Although related, many GAM programs divide precipitation and drainage into separate rating categories. While slope drainage can potentially be improved through mitigation, total annual precipitation is solely a function of asset location and anecdotally results in more frequent failures. Ranges can be extreme in mountainous states, for example, Idaho's average ranges from 8 to greater than 80 inches annually. In Illinois, precipitation ranges much less, between 35 and 50-inches statewide (Dahal, 2018). Evaluation categories typically seek to achieve a meaningful separation of scores and the range experienced in Illinois is less than other states, reducing the impact of precipitation variation in the evaluation. Thus, IDOT's rock slope evaluations will evaluate slope drainage only.

Drainage characteristics of a rock slope contribute to likelihood of rockfall. Slopes with seeps and springs, for example, are more vulnerable to rockfall due to erosion and freeze-thaw processes. This category is rated based on professional judgment, but rating a slope at different times of year may still produce variable results if seepage points dry up seasonally. Typically, the most accurate time of year to assess seepage is after a sustained wet period (at least 1 week), colder seasons during freeze-thaw cycles, or in spring before plants leaf out. However, these may not be periods where personnel are available for field assessment work. In that case, a combination of professional judgment and maintenance input is used to rate this category. For guidance in field evaluations, Figure 127 is provided below, and rating category narratives are provided in Table 45.

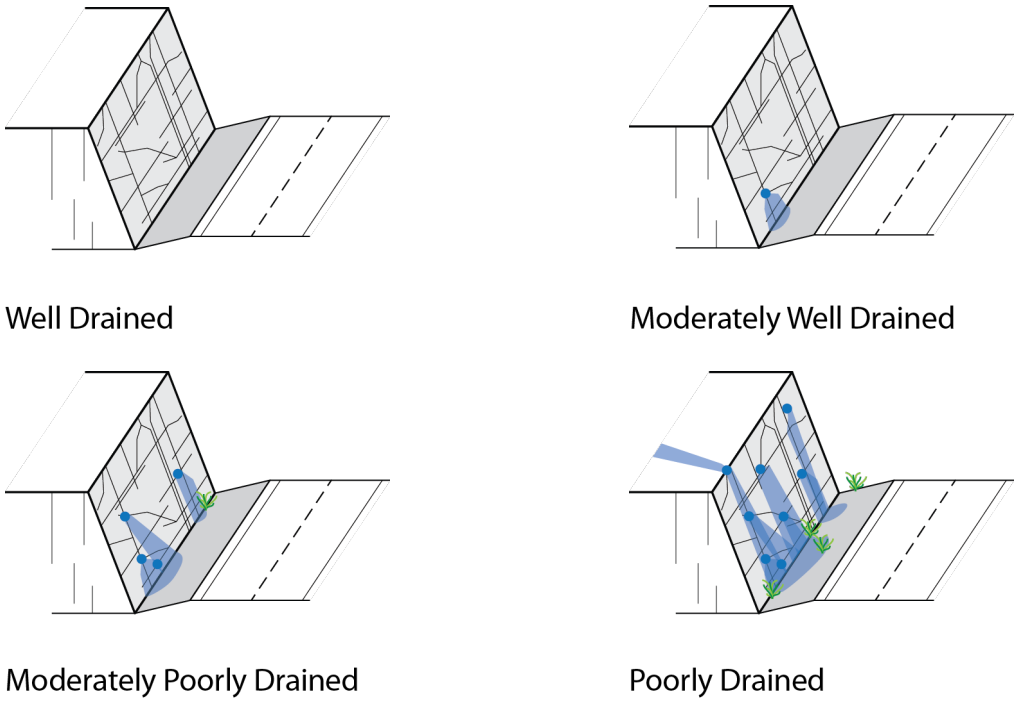


Figure 127. Illustration. Guidance figure for evaluating slope drainage.

Table 45. Slope Drainage Category Narratives

Score	Description
3 points	Well Drained. Slope appears dry or well drained; surface runoff is well controlled; slope is dry hours after rain events; or a functioning drainage system has been installed.
9 points	Moderately Well Drained. Water is intermittently on slope; moderately well drained; surface runoff is moderately controlled; slope is dry days after rain events.
27 points	Moderately Poorly Drained. Water usually on slope; poorly drained; surface runoff poorly controlled; slope is still wet a week or two following rain events but may dry during prolonged dry spells.
81 points	Poorly Drained. Water always on slope; very poorly drained; or surface water runoff control not present.

Risk Categories

Risk categories capture roadway geometry and usage information to assess the relative likelihood of disruption, damage, or injury after a rockfall event. The categories capture risks for both roadway users and maintenance personnel. Each unstable rock slope is evaluated in five Risk rating categories. Each category is worth a maximum of 100 points, so the maximum possible Risk Rating score for a rock slope is 500 points. Scores from the Risk Rating categories are combined with those from the Hazard Rating categories to calculate the final RHRS score for a site.

AADT Score

The AADT of a roadway provides an approximate quantitative indicator of its impact on the regional economy and mobility of people, goods, and services. Failures in high-traffic corridors pose a larger consequence and likewise should receive a higher risk score. The denominator in the AADT equation should be adjusted for different states to reflect typical traffic volumes along the roadways where rock slopes are concentrated. Figure 128 presents the 2019 AADT of the National Highway System (NHS) in Illinois.

To determine the best denominator for IDOT's rock slope category, Landslide Technology (LT) reviewed AADT volumes throughout the state's NHS routes (Figure 128). LT tested four denominator options, 500, 1000, 1500, and 2000 (Figure 129). The recommended denominator option is 1000. All urban routes are expected to score 100 in this category, but using a smaller denominator allows more variation in lower-volume NHS routes and local roads. This recommendation may be revised during the pilot implementation. The scores for this category will be calculated using the equation in Figure 130.

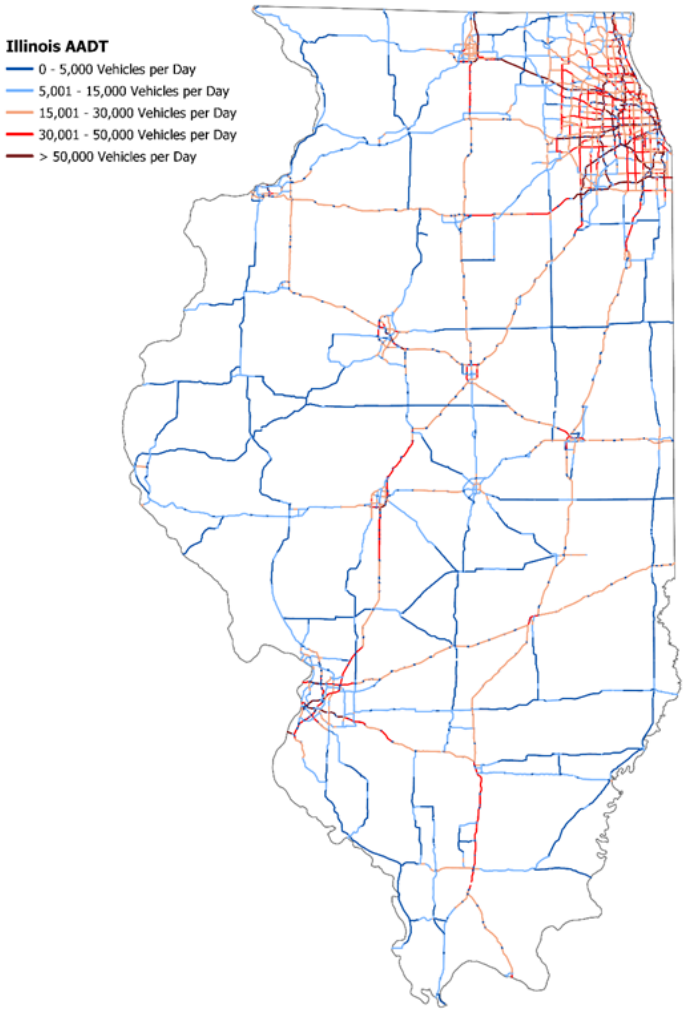


Figure 128. Map. Average annual daily traffic (2019) of IDOT's NHS Routes.

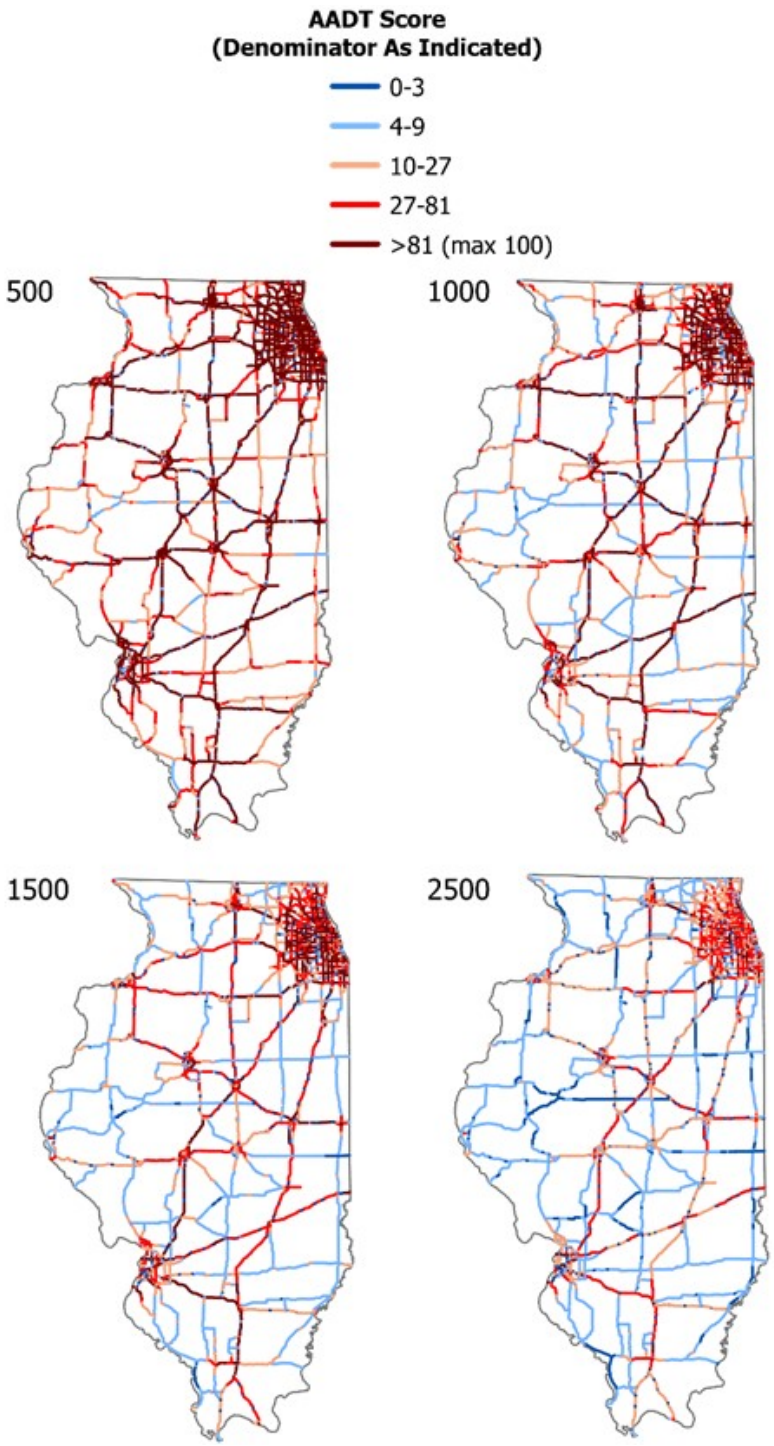


Figure 129. Map. AADT scores for tested denominator ranges.

$$Score = 3^{x}\ (\max 100)\,;\ x = \sqrt{\frac{AADT}{1000}}$$

Figure 130. Equation. Category score calculated by AADT.

Average Vehicle Risk Score

The Average Vehicle Risk Score evaluates the potential for a roadway user to be present at the site during a rockfall event. This risk is associated with the percentage of time a route user is present in the rock slope section. The percentage is obtained by using the formula based on slope length, average annual daily traffic (AADT), and the posted speed limit. A rating of 100% means that, on average, a vehicle will be within the rock slope section 100% of the time. Where high AADT's or longer slope lengths exist, calculated values can be greater than 100%, i.e., more than one vehicle is typically present within the rock slope section. The score also indirectly reflects a route's significance since critical routes often have higher traffic counts. This category is scored using direct measurements following the equation in Figure 131. Example calculated scores are presented in Table 46.

$$Score = 3^{x}\ (\max 100);\ x = \frac{\left(\frac{\frac{AADT}{24} \times slope\ length\ (miles)\ \times 100}{speed\ limit}\right)}{25}$$

Figure 131. Equation. Average vehicle risk score.

Table 46. Average Vehicle Risk Sample Calculated Scores

Score	Description
3 points	Vehicle present 25% of the time
9 points	Vehicle present 50% of the time
27 points	Vehicle present 75% of the time
81 points	Vehicle present 100% of the time

Decision Sight Distance Score

The Decision Sight Distance (DSD) category compares the sight distance through a rock slope section to the recommended minimum sight distance for a speed/path/direction change. For roadways, sight distance is the shortest distance that a six-inch object is continuously visible to a driver along a roadway. DSD is the length of roadway, in feet, a driver requires to perceive a problem, react to the problem, and then bring their vehicle to a stop. The required DSD increases with increased vehicle speed. This distance is critical when obstacles on the road surface are difficult to see or when unexpected or unusual maneuvers are required. Decision sight distances prescribed by AASHTO for rural roads for typical posted speeds are presented in Table 47.

Table 47. AASHTO Recommended Minimum Decision Sight Distance for Typical Speed Limits

Posted Speed Limit (mph)	AASHTO Recommended Minimum Decision Sight Distance (ft)
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1,000
65	1,050

Sight distance can change throughout a rock slope. Horizontal and vertical highway curves along with obstructions such as rock outcrops and vegetation can limit a driver's ability to notice and react to a rock in the road. In calculating this category score, the sight distance is determined in both travel directions, and the most restricted sight distance is used. Both horizontal and vertical sight distances are evaluated. Estimations from mobile LiDAR data collection datasets are possible, but temporary site conditions from vegetation or debris that would inhibit sight distance may not be detectible by office-based estimations.

The measurement, generally made with a roller tape or laser range finder, is the distance required for a six-inch object positioned on the fog line (or on the edge of pavement if there is no fog line) to disappear from view at an eye height of 3.5 feet above the road surface. The posted speed limit throughout the rockfall section is used because unstable slopes are often located within highway curves, where the posted speed limit is lower than the highway design speed. Formal AASHTO standards require placing the object in the travel lanes and measuring it from a driver's position near the centerline; however, ratings are typically performed under live traffic and placing an object in the travel lane would be unsafe. The standard practice of placing an object in the shoulder to get an approximate estimate provides an acceptable level of detail for this rating category.

For roadways, this category is scored based on direct measurements using the equation in Figure 132 with example calculated scores and descriptions in Table 48.

$$Score = 3^{x};\ x = \frac{120 - \left(\frac{Measured\ Minimum\ Sight\ Distance}{AASHTO\ Recommended\ Decision\ Sight\ Distance} \times\ 100\right)}{20}$$

Figure 132. Equation. Percent decision sight distance score.

Table 48. Percent Decision Sight Distance Sample Calculated Scores and Category Narratives

Posted Speed Limit (mph)	Calculated Definition	Narrative
3 points	Adequate, 100% of design value	Rockfall easily avoided
9 points	Moderate, 80% of design value	Rockfall moderately difficult to avoid
27 points	Limited, 60% of design value	Rockfall difficult to avoid
81 points	Very Limited, 40% of design value	Rockfall very difficult to avoid

Roadway Width Score

The roadway captures the space available for a traveler to navigate around an unexpected hazard. The more room there is to maneuver on a roadway, the greater the likelihood the driver will successfully miss a rock without hitting some other roadside hazard or oncoming vehicle. Roadway width is measured perpendicular to the centerline. It includes the entire paved surface. If shoulders are paved, they are included in the paved roadway width. Unpaved shoulders are not included. If the roadway width varies throughout the rock slope section, measure the minimum width. On divided roadways, only the portion of the roadway available to the driver for maneuvering should be measured. This category score is based on direct measurements according to the equation in Figure 133 with sample calculation results provided in Table 49.

$$Score = 3^{x};\ x = \frac{44 - Road\ Width\ (ft)}{8}$$

Figure 133. Equation. Roadway width score.

Table 49. Risk Rating—Roadway Width Sample Calculated Scores

Score	Roadway Width
3 points	36 feet
9 points	28 feet
27 points	20 feet
81 points	12 feet

Rockfall Related Maintenance Frequency Score

The required frequency of maintenance is an indicator of risk, rockfall activity, and long-term direct costs. Deferring required maintenance activity places roadway users at an elevated risk, while performing unscheduled, emergency maintenance elevates risk to Department personnel. Maintenance frequency can be estimated from conditions observed at the site, but category ratings should be confirmed through discussions with maintenance personnel where possible. Category narratives are presented in Table 50.

Table 50. Detailed Rock Slope Rating—Rockfall-Related Maintenance Frequency

Score	Description
3 points	Normal, scheduled ditch maintenance. Only routine, scheduled ditch maintenance is required on an infrequent (3-5 year) basis to prevent rock from reaching the roadway.
9 points	Road Patrols conducted after storm events. Maintenance staff only actively patrol for rock on the roadway after extreme storm events. Ditch cleanout of rock debris is infrequently required beyond scheduled ditch maintenance to address a specific rockfall event(s).
27 points	Routine seasonal road patrols. Maintenance staff routinely patrol for rocks on the road during typical 'high rockfall' seasons (fall, winter, spring). Ditch cleanout of rock debris is occasionally required before scheduled ditch maintenance.
81 points	Year-round road patrols. Maintenance staff routinely patrol for rock year-round. Rock is removed from the roadway multiple times annually, or once annually for a large-volume, severe event. Ditch cleanout of rock debris is required more frequently than the typical schedule for the district/maintenance shed.

Condition Assessment

After inventorying and rating rock slope assets, LT intends to use these ratings to determine rock slope condition. This approach draws heavily on research completed for other state departments of transportation, especially Alaska, Montana, Tennessee, and Missouri.

RHRS Scoring

The RHRS developed in the 1990s remains the basis for most subsequent rock slope inventory and assessment programs. It uses an exponential, 3^x, scoring system, with 100 being the worst possible score for each category. Many categories use an equation to determine the exponent, x, to generate a continuum of scores with 3, 9, 27, and 81 serving as major breaks. In contrast, transportation asset management (TAM) programs typically use a linear scoring system with 100 being the best possible score. LT recommends using RHRS-type scoring for the field rating categories, allowing IDOT to access data from other DOTs for future research projects, such as deterioration or life cycle cost estimates. It is also a well-established scoring system that is used in the Unstable Slope Management Program (USMP) developed by FHWA for federal land management agencies (Beckstrand et al., 2019).

At each inventoried rock slope, the evaluation category scores will be summed to produce an RHRS score for each slope. Hazard and risk components are combined, and a higher score indicates a slope with higher hazard, higher risk, or a combination of the two. It is useful for screening level assessments, and for helping to prioritize projects in a corridor. In practice, a 'high' score is above 500 or 600 points.

Rock Slope Condition

Rock slopes in an asset management program are assessed and assigned to Good/Fair/Poor categories as is done for other transportation assets like bridges and pavements. The exponential condition scores in select rating categories are translated to the linear scores used in TAM. Definitions

for Good, Fair, and Poor condition rock slopes are provided below. Exponential scores are converted for use in Condition State scoring as described in detail in the following section.

Good – Rock slope produces little to no rockfall and catchment is configured such that any falling rocks have low likelihood of reaching the roadway. Any rockfall mitigation elements are in like-new condition and free of significant defects. Preventive maintenance such as regular ditch cleaning keeps the slopes and mitigation elements in good condition. There is a low likelihood of adverse impact on users.

Fair – Rock slope produces minor rockfall that occasionally reaches the roadway. Impacts on roadway operation do not typically interfere with roadway operations or create significant user delays. Rock slope maintenance may include more frequent ditch cleanout. Rockfall mitigation elements exhibit some deterioration or damage but continue to function adequately without significant maintenance effort. Rockfall fences and drapes may require replacement of small amounts of damaged fence panels, braking elements, or cables. A small proportion of roadside barriers may require repair or replacement. There is a moderate likelihood of adverse impact on users.

Poor – Rock slopes and mitigation elements exhibit advanced deterioration and damage, with rockfall regularly reaching the roadway, requiring an immediate maintenance response and impacting traffic. Rockfall mitigation elements are damaged and unable to function adequately without extensive repair or full replacement. Rockfall mitigation elements in good condition are insufficient to provide adequate catchment. Some slopes may have failed catastrophically, requiring major cleanup efforts and emergency repair efforts with attendant impacts on users, including detours and delays. There is a high likelihood of adverse impact on users.

Condition Index and Condition State

The Condition Index is a linear continuum from 100 (ideal condition) to 0 (a failed condition) that is evenly divided into five Condition State Categories. It is a combination of the potential for a rockfall event and the ability of the roadside ditch to contain the rockfall event and prevent it from reaching the roadway. The RHRS “Ditch Effectiveness” and “Rockfall History” categories provide these components. The Condition State category descriptions are presented in Table 51.

The Condition Index is useful to illustrate nuances within Condition State. For instance, an Index score of 100 indicates a totally effective ditch and very low rockfall activity, while an Index score of 87 can indicate a less effective ditch but an equally low rockfall activity and no history of rockfall reaching the road. The two hypothetical sites used in this example are both Condition State 1, ‘Good’ slopes, but one could be less capable of keeping the very infrequent rockfall from reaching the road. Neither site would likely warrant mitigation and therefore it is reasonable to be within the same Condition State 1 classification.

Table 51. Rock Slope Condition Category Descriptions

Condition State	Good Fair Poor Descriptor	Cond. Index Range	Description
1	**Very Good**	**100 - 80**	Rock slope produces little to no rockfall and no history of rock reaching the road. Little to no maintenance needs to be performed due to rockfall activity. Rockfall mitigation measures, if present, are in new or like new condition.
2	**Good**	**80 - 60**	Rock slope produces occasional rockfall that may rarely reach the road. Some maintenance needs to be performed on a scheduled basis due to rockfall activity to address safety. Mitigation measures, if present, are in generally good condition, with only surficial rust or minor apparent damage.
3	**Fair**	**60 - 40**	Rock slope produces many rockfalls with rock occasionally reaching the road. Maintenance is required bi-annually or annually to maintain safety. Mitigation measures, if present, appear to have more significant corrosion or damage to minor elements. Preventative maintenance or replacement of minor mitigation components is warranted.
4	**Poor**	**40 – 20**	Rock slope produces constant rockfall with rocks frequently reaching the road. Maintenance is required annually or more often to maintain ditch performance. Much of the required maintenance response is unscheduled. Mitigation measures, if present, are generally ineffective due to significant damage to major components or apparent deep corrosion.
5	**Very Poor**	**20 – 0**	Rock slope produces constant rockfall and nearly all rockfall reaches the road. Virtually no rockfall catchment exists or is effective. Maintenance must respond to rockfalls regularly, possibly daily during adverse weather. If present, nearly all mitigation measures are ineffectual either due to deferred maintenance, significant damage, or obvious deep corrosion.

Determining Asset Condition from Detailed Field Inspections

Rock slope condition will be determined based on the scores for the ditch effectiveness and rockfall activity categories. Together, these categories describe the likelihood of an event occurring that impacts traffic. Unlike other hazard scores, like slope height or geologic character, scores for these categories can be improved through well-designed mitigation. This allows IDOT to capture the positive impact of mitigation or rehabilitation work on the condition of an individual rock slope and on the average condition of assets in the rock slope inventory.

As part of research work completed for Alaska's Geotechnical Asset Management program, LT developed a set of equations to extract the exponent from the 3^x formula used in RHRS-style ratings and convert it to 1 to 100 scores. This converted score is termed the Condition State Element Score (CSES), and it is used to calculate the asset's Condition State. The formulas used are presented in the equations in Figure 134 and Figure 135. The individual CSES are averaged to calculate the total Condition State score for a site, with a value between 0 and 100. The relationship between field ratings, Condition State score, and Condition State are summarized in Table 52 following the equations.

$$CSES = 100 - \left(25 * \ (RSAMS\ exponent - 1)\right)\ where;$$

$$RSAMS\ exponent = \frac{\ln(RSAMS\ Score)}{(\ln 3)}$$

Figure 134. Equation. Algorithm for converting an individual category score to condition state element score if 0 < category score ≤ 81.

$$CSES = (USMP\ Score\ \times -1.3158) + 131.58$$

Figure 135. Equation. Algorithm for converting category score to condition state score if category score > 81.

Here RSAMS stands for Rock Slope Asset Management System and USMP stands for Unstable Slope Management Program. The equations above convert category scores from these established rating scales to the Condition State Element Score; the scoring procedures for RSAMS and USMP are documented in Beckstrand et al. (2017a, 2019).

Table 52. Summary of Scoring Relationships

			Condition State Score Range		
Field Rating Score	Exponent	CSES Score	Low	High	Condition State
3	1	100	80	100	1, Good
9	2	75	60	79	2, Fair
27	3	50	40	59	3, Fair
81	4	25	20	39	4, Poor
100	~4.19	0	0	19	5, Poor

APPENDIX D: USER AND DEVELOPER GUIDE: DATA COLLECTION PROCEDURES IN SURVEY123 FOR ILLINOIS GEOTECHNICAL ASSET MANAGEMENT PROGRAM

INTRODUCTION

Survey123 for ArcGIS is a powerful data collection tool designed to create, share, and analyze surveys. Built on the ArcGIS platform, it enables users to design smart forms tailored for field data collection while seamlessly integrating spatial data. With its user-friendly interface, Survey123 empowers organizations to efficiently gather information, from basic text inputs to complex geospatial features.

Survey123 offers two ways to create the survey:

- **Survey123 Web Designer**: A no-code platform for creating simple surveys.
- **Survey123 Connect**: A desktop application for advanced users, providing flexibility to design dynamic surveys with XLSForm, enabling features like logic, calculations, and data validation.

As described above, Survey123 Connect is more powerful and providing flexibility and complex structure of the survey, the survey for this project was developed using Survey123 Connect.

NAVIGATING THE SURVEY

Reference Map

The implementation of the Illinois Department of Transportation (IDOT) Geotechnical Asset Management (GAM) field data collection involves a systematic two-step process: the creation of a reference map and the development of a customized survey. These steps ensure the efficient and accurate gathering of geotechnical asset data critical to the department's infrastructure management.

The reference map is a foundational component of the survey, designed to serve as the base map for data collection. This map plays a crucial role in automating the population of essential road information, including road name, county name, and Annual Average Daily Traffic (AADT). The reference map was developed by integrating multiple publicly accessible feature layers from the IDOT GIS database. These layers include high-resolution spatial data and attribute information, ensuring comprehensive coverage and accuracy.

To facilitate the direct population of traffic data from the reference map to the survey form, it is necessary for the user either to select the relevant feature or for their current location to fall within the area of the feature. However, due to the traffic data being represented as a line feature layer, it is difficult for users to select a line feature to populate necessary information during field data collection, particularly on mobile devices in the field.

To address this issue, the traffic line layer was transformed into a polygon layer by generating a 750-foot buffer zone on both sides of each line feature. This buffer effectively creates a polygonal representation of the traffic layer, significantly improving usability during field operations. The transformation ensures that users can automatically populate traffic-related information, such as AADT, whenever their current location falls within the buffered area.

The developed reference map has uploaded to the project GIS database during the pilot study, and linked to the survey (illustrated in Figure 136). The blue lines in Figure 136 represent the buffer created from traffic line layer.

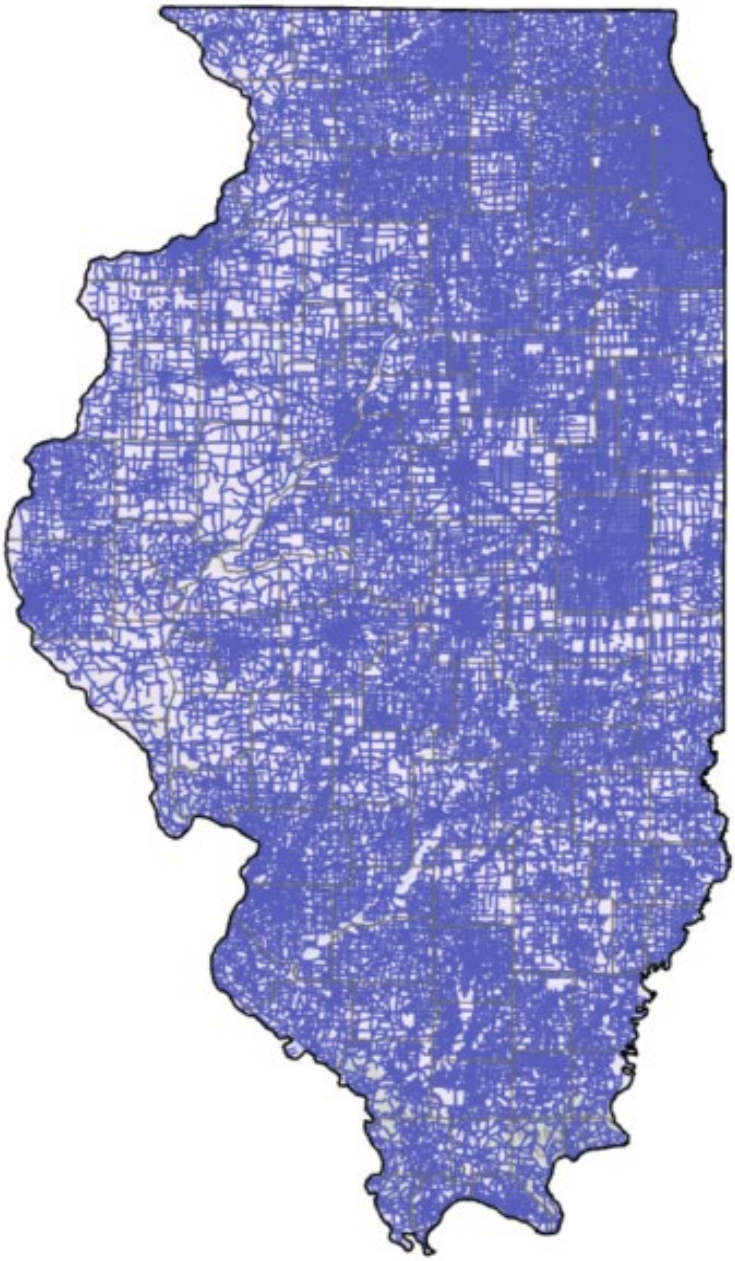


Figure 136. Map. Reference map.

Steps to Create a Survey Using an XLSForm File in Survey123 Connect

To create a survey, Survey123 Connect must be installed on the machine and the developed reference map needs to be uploaded to the IDOT ArcGIS server to establish a link with the survey. After installing Survey123 Connect, a folder named “My Survey Design” is automatically created on the local machine under the directory:

C:\Users\"User Name"\ArcGIS\My Survey Designs

This folder serves as the default location for storing survey files, making it easier to manage and access survey projects.

The current survey package delivered to IDOT and includes all essential files, such as the XLSForm file and JavaScript-based custom scripts. The package name carries its release date; confirm with the research team that the most recent version is in hand before importing the survey.

To import the survey into Survey123 Connect, follow these steps:

1. Locate the survey package (.zip) provided by the research team.
2. Copy the file to the local My Survey Designs folder, located at: C:\Users\"User Name"\ArcGIS\My Survey Designs.
3. Manually unzip the file in this directory.

Once unzipped, the survey will be available for use in Survey123 Connect. Figure 137 presents the interface of Survey123 Connect importing the provided survey.

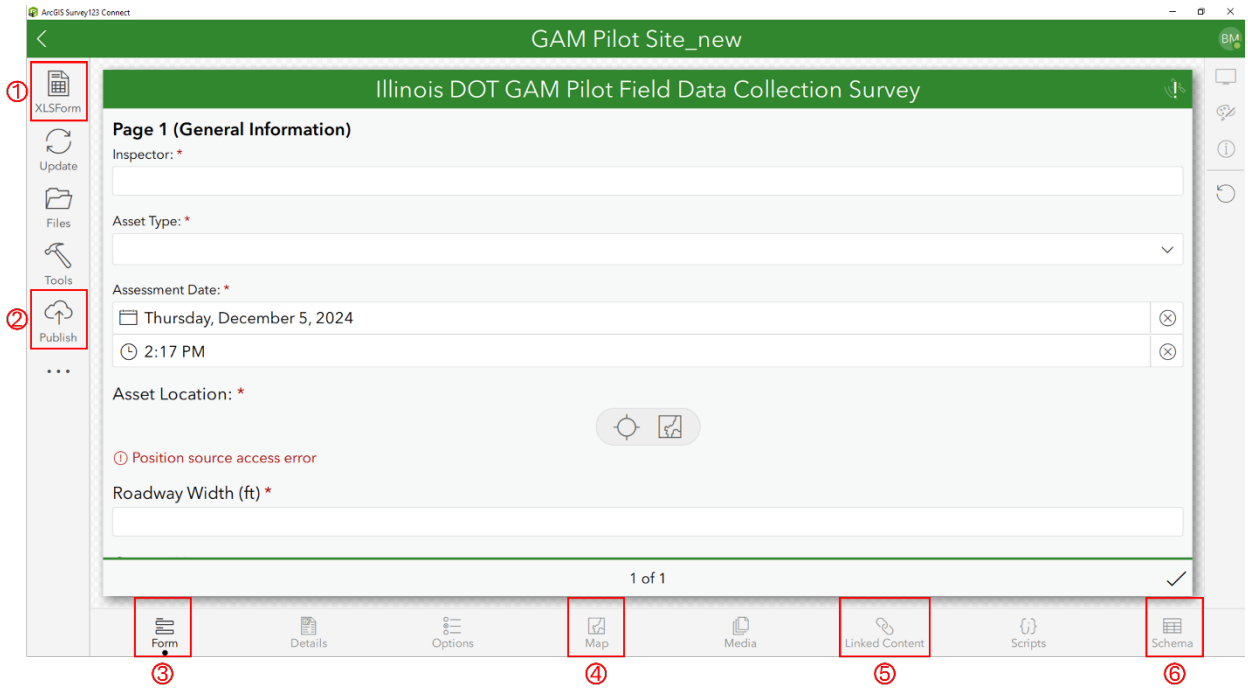


Figure 137. Screenshot. Interface of Survey123 Connect after import the survey.

The Survey123 Connect interface includes the following key features:

1. XLSForm
   - Open the associated XLSForm file for editing.
   - The survey is automatically updated if XLSForm is saved.
2. Publish
   - Save and deploy the current version of the survey to the ArcGIS server.
   - After publishing, the survey is available for use in the field application or web browser.
3. Form Tab
   - Display the survey form layout, including questions and their arrangement.
   - It enables users to preview the survey.
4. Map Tab
   - Allow users to configure and preview the map used within the survey, particularly for geopoint questions like Asset Location in this survey.
5. Linked Content Tab
   - Establish a link between external resources and the survey, such as feature layers, maps, and reference files.
6. Schema Tab
   - Display data structure of the survey, including all the fields and their associated properties.
   - Users can review or adjust the field types and ensure data consistency with the associated feature layers.

Once the survey is published, two key files, Form and Feature Layer, are created on the ArcGIS server. These files serve distinct purposes in the survey workflow:

- Form File
  - The Form file is designed to provide a user-friendly interface for data analysis and visualization.
  - Any submitted survey responses are saved into this file, enabling users to view and analyze results through a web-based application.

- Feature Layer
    - The Feature Layer stores all survey records, including detailed geographic data.
    - It allows users to visualize the assets' locations directly on the ArcGIS Online Map Viewer. This file ensures that all records, including spatial attributes, are readily available for mapping and further geospatial analysis.

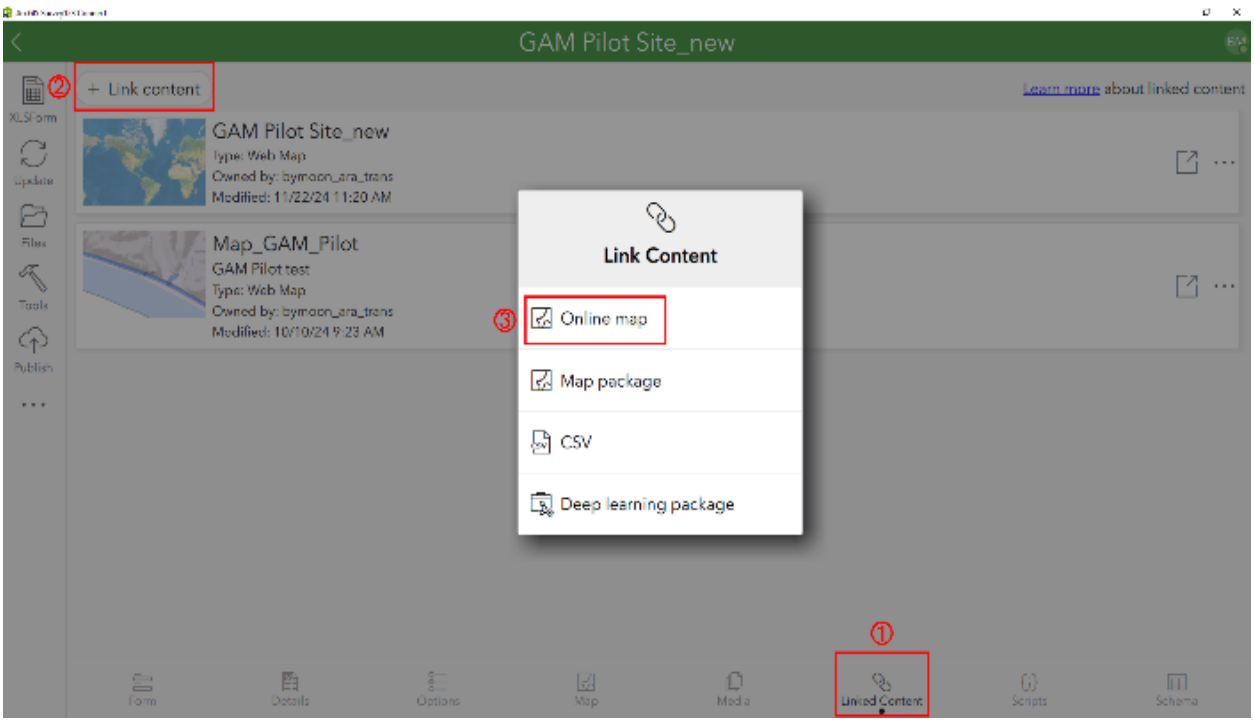
To ensure the survey automatically populates traffic information based on the user's location, the reference map must be linked to the survey. This connection is configured after the survey is published.

Figure 138-a and Figure 138-b show the interface of Link Content Tab and Map Tab, respectively.

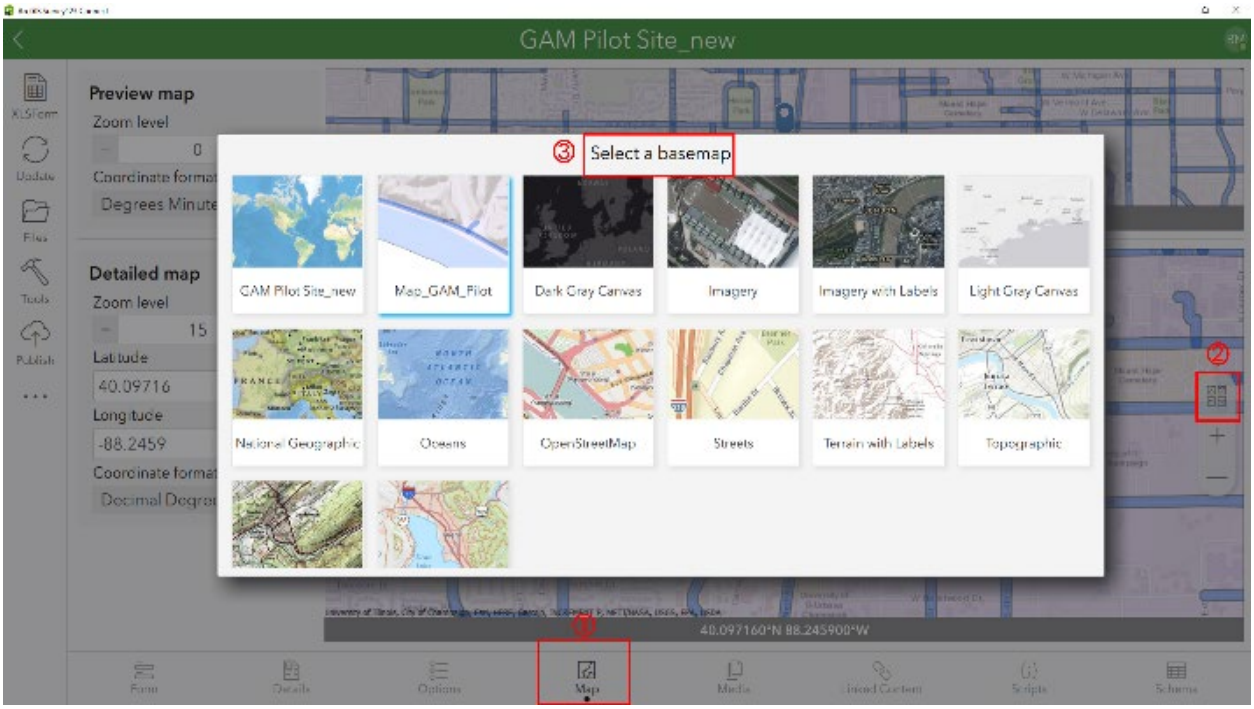
To establish a connection between the survey and the reference map, and to set the reference map as the survey's basemap, follow these steps:

- Click "Linked Content" to open Link Content Tab, labeled ① in Figure 138-a.
- Click "Link content" button to populate Link Content form, labeled ② in the Figure 138-a.
- Click "Online map" and select the reference map that has been uploaded on the ArcGIS server, labeled ③ in Figure 138-a.
- After linking the reference map, click "Map" to navigate to the Map Tab, labeled ① in Figure 138-b.
- Click the "Select Base Map" button, labeled ② in Figure 138-b.
- Select the reference map as a basemap, labeled ③ in Figure 138-b.
- Publish the survey to update and save the changes.

By completing these steps, the reference map will be successfully linked to the survey and applied as the default basemap, enabling the survey to populate traffic data automatically during field data collection.



(a) Link Content Tab



(b) Map Tab

Figure 138. Screenshot. Interface of Link Content Tab (a) and Map Tab (b).

Structure of the Survey

The survey is specifically designed to collect information on geotechnical assets as defined by IDOT and the research team. These assets include rock slopes, slopes/embankments, mechanically stabilized earth (MSE) walls, and generic walls. To ensure precise and quantitative evaluation, multiple categories were established for each asset type, enabling a detailed assessment of their current condition.

Survey123 was selected for its ability to capture multiple photos during data collection and to create hierarchical data structures. The survey architecture includes a parent layer (General Information, providing details about the asset) and four child layers/tables corresponding to the four asset types. Each child layer has an image table to accommodate photographs taken during field inspections.

The schema was developed using Survey123 Connect to enable dynamic form logic, geospatial integration, and efficient data collection workflows. The hierarchical structure of the survey facilitates clear organization of collected data. This schema is visually represented in Figure 139, illustrating the relationships between the parent and child layers along with their associated image tables.

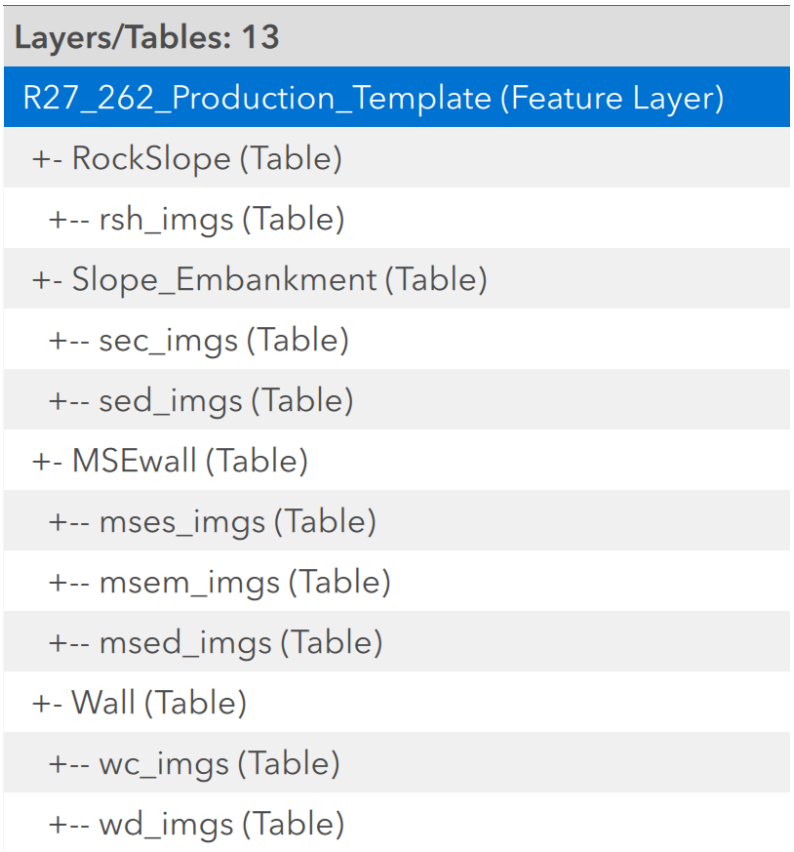


Figure 139. Diagram. Schema of the survey.

Note that the Excel inspection form workbooks are the governing source for condition-state definitions.

General Information (Parent Layer)

The parent layer is designed to collect general questions, and the following survey form is provided based on asset type. The details of General Information, parent layer, are summarized in Table 53.

The parent layer also captures a set of daily field-report attributes and inspection actions. Surface conditions, weather, and temperature record the conditions under which observations were made, since several ratings are sensitive to recent weather. An inspection-limitation note documents any portions of the asset not inspected and the reason (e.g., limited access, excess vegetation, or similar). Two action flags, Requires Maintenance and Requires Detailed Inspection, let the inspector signal a required follow-up action directly rather than leaving it to be inferred from component ratings. Each observation category also provides an optional per-category comment, opened with an Add comment control, to match the comment structure of the Excel inspection forms.

Table 53. Details of General Information

Question	Question Type	Field Name in Database	Esri Type	Required
Inspector	text	name	String	
Asset Type	select_one	asset_type	String	*
Assessment Date	dateTime	assessment_date	Date	*
Asset Location	geopoint	asset_location	Geometry	*
Latitude and Longitude (derived from Asset Location)	calculate	lat, lon	Double	
Roadway Width (ft)	decimal	road_width	Double	*
County Name	text	county	String	
Road Name	text	road	String	
Asset ID	text	AssetID	String	
IDOT Structure Number Assigned?	select_one	structure_no_present	String	
IDOT Structure Number	text	structure_no	String	
Route ID	text	routeID	String	
Route Type	text	route_type	String	
Start Milepost	decimal	start_milepost	Double	
End Milepost	decimal	end_milepost	Double	
Travel Direction	select_one	direction	String	
Speed Limit (mph)	select_one	speedlimit	String	*
Asset Length (ft)	decimal	slope_length	Double	*
AADT	decimal	aadt	Double	*
Average Annual Rainfall (in)	decimal	annual_rainfall	Double	
Surface Condition	text	surface_condition	String	

Question	Question Type	Field Name in Database	Esri Type	Required
Weather	text	weather	String	
Temperature (deg F)	decimal	temperature	Double	
Inspection Limitations / Accessibility Notes	text	inspection_limitations	String	
Requires Maintenance?	select_one	flag_requires_maintenance	String	
Maintenance Needed, Description	text	flag_requires_maintenance_desc	String	
Requires Detailed Inspection?	select_one	flag_requires_detailed	String	
Detailed Inspection, Description	text	flag_requires_detailed_desc	String	
Asset Inclination (H:V ratio) [Page 2]	decimal	slope_inclination	Double	
Maximum Height (ft) [Page 2]	decimal	exposed_height_max	Double	
Typical Height (ft) [Page 2]	decimal	exposed_height_typ	Double	

The general information page contains 26 questions: the core inventory fields listed in Table 53 plus the daily field-report attributes and action flags described above. Asset Length, Asset Inclination, and Maximum and Typical Heights are collected on Page 2 (Asset Characteristics).

Figure 140 presents a screenshot of general information page displaying in the webpage.

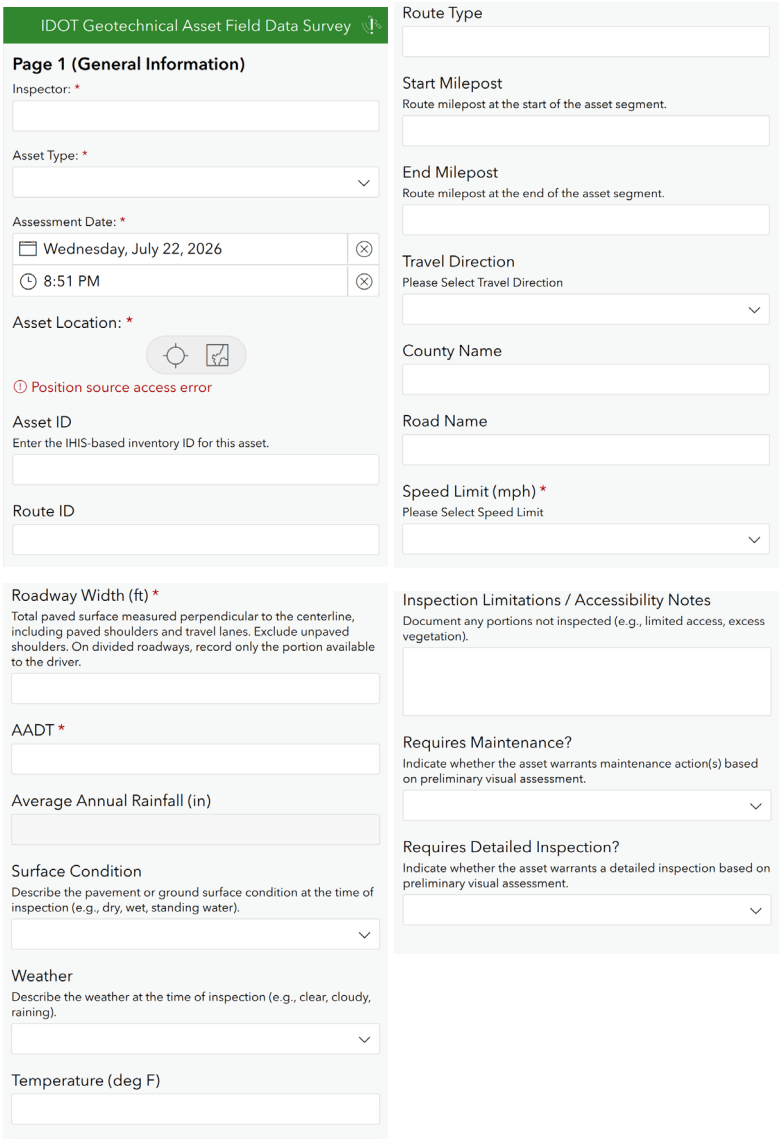


Figure 140. Screenshot. General information of the survey.

Follow these steps to complete the survey:

- Type the inspector name or ID in the provided box.
- Choose the type of geotechnical asset (e.g., Rockslope, Slope/Embankment, MSE Wall, Wall) from the drop-down menu.
- Select date and time (default: current time)
- Use the map to pinpoint the asset's location or tap the "Find My Location" button to autofill the current GPS coordinates.
- Enter the Asset ID based on the IHIS-based inventory ID schema.

    - This field applies to all four asset types and combines the IHIS key route ID, the milepost of the asset midpoint, the route direction, and the two-character asset type abbreviation (e.g., 084 10055 000000 00315 E RW).

- For MSE walls and retaining walls, indicate whether an IDOT structure number has been assigned and, where it has, enter it in the format xxx-xxxx (e.g., 072-0251).

    - The Bureau of Bridges and Structures assigns a structure number to walls at or above the exposed height threshold carried in the Illinois Structure Inventory System (ISIS); walls below that threshold are carried only as geotechnical features and have no structure number, in which case select No and the number field is skipped. Recording it allows a geotechnical asset record to be joined to the corresponding ISIS record; the Asset ID remains the primary identifier for the GAM inventory.

- Enter Route ID or, if enabled, populate it automatically.

- Type Route Type.

- Type Start Milepost.

- Type End Milepost.

- Choose Travel Direction (e.g., Northbound, Southbound, Eastbound, Westbound) from the drop-down menu.

- Type the name of the county where the asset is located or, if enabled, populate it automatically.

- Enter the Road Name, or if enabled, populate it automatically.

- Choose Speed Limit (e.g., 25, 30, 35, 40, 45, 50, 55, 60, 65, or 70) from the drop-down menu.

- Enter the roadway width in feet in the provided box. Where roadway width is the total paved surface measured perpendicular to the centerline, including paved shoulders and travel lanes; unpaved shoulders are excluded. On divided roadways, record only the portion available to the driver for maneuvering. This definition is consistent with the Roadway Width guidance in Appendix C (Risk Categories).

- Enter AADT or, if enabled, it may be populated automatically, otherwise type the AADT where the asset is located.

- Load the Average Annual Rainfall in inches, if enabled.

- Road Name may be populated automatically, otherwise type the name of the road where the asset is located.

- Enter daily field report information at the time of the inspection including surface conditions, weather, and temperature.
- Detail limitations to the inspection or accessibility limits at the time of inspection.
- Flag based on preliminary visual assessment of the site if maintenance or a detailed inspection is recommended. Provide explanatory comments if either action is recommended as prompted on the survey tool.

After completing the initial survey move to the next page and complete asset characteristics. Characteristics are determined based on the asset selected and may include asset length, inclination, maximum height, and typical height when prompted. Figure 141 presents a screenshot of the asset characteristic page for slopes and embankments.

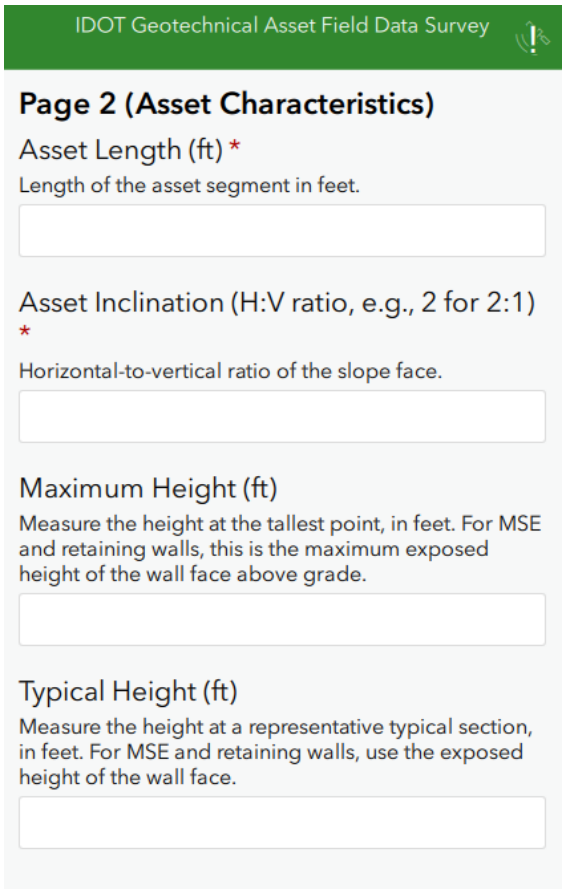


Figure 141. Screenshot. Asset characteristic information of the survey.

Rockslope (Child Layer 1)

The Rockslope survey consists of Hazard Category, Risk Category, and Summary along with image table. The Hazard Category section consists of 6 questions designed to assess various factors contributing to the asset's condition, and the details of Hazard Categories for Rockslope are summarized in Table 54.

Unlike the other three asset types, rock slopes are scored with the RHRS-style exponential system rather than Good/Marginal/Poor category ratings. The field indicators and rating criteria for every rock-slope hazard and risk category are defined in detail in Appendix C and are not repeated here. The Rockcut Slopes inspection form agrees with Appendix C on these categories and their narrative scoring breaks. Table 54 maps each category to its scoring basis and its Appendix C reference so inspectors can locate the applicable narratives, equations, and guidance figures directly.

Table 54. Details of Hazard Categories for Rockslope

Question	Question Type	Field Name in Database	Esri Type
Block Size or Event Volume	select_one	rsh_size_volume	String
Size (ft)	decimal	rsh_size	Double
Volume (yd^3)	decimal	rsh_volume	Double
Score	calculate	rsh_size_volume_score	Double
Slope Height Score (ft)	decimal	rsh_height	Double
Score	calculate	rsh_hscore	Double
Ditch Effectiveness Score	select_one	rsh_ditch	String
Geologic Character Score	select_one	rsh_geochar	String
Case 1: Structural Condition	select_one	rsh_c1_scond	String
Case 1: Rock Friction	select_one	rsh_c1_rfriction	String
Case 2: Structural Condition	select_one	rsh_c2_scond	String
Case 2: Differential Erosion Rate	select_one	rsh_c2_erosion	String
Rockfall Activity Score	select_one	rsh_rascore	String
Water on Slope	select_one	rsh_waterslope	String
Summation	calculate	rsh_summary	Double
Comment	text	rsh_comment	String

Each question in Hazard Categories is followed by a calculated score based on the input provided, with the total score displayed at the end of the section. Additionally, this section includes a space for comments, allowing users to provide further context or observations, and a feature to take or upload photos for visual documentation. Figure 142 presents a screenshot of the Hazard Categories for Rockslope section as displayed on the webpage.

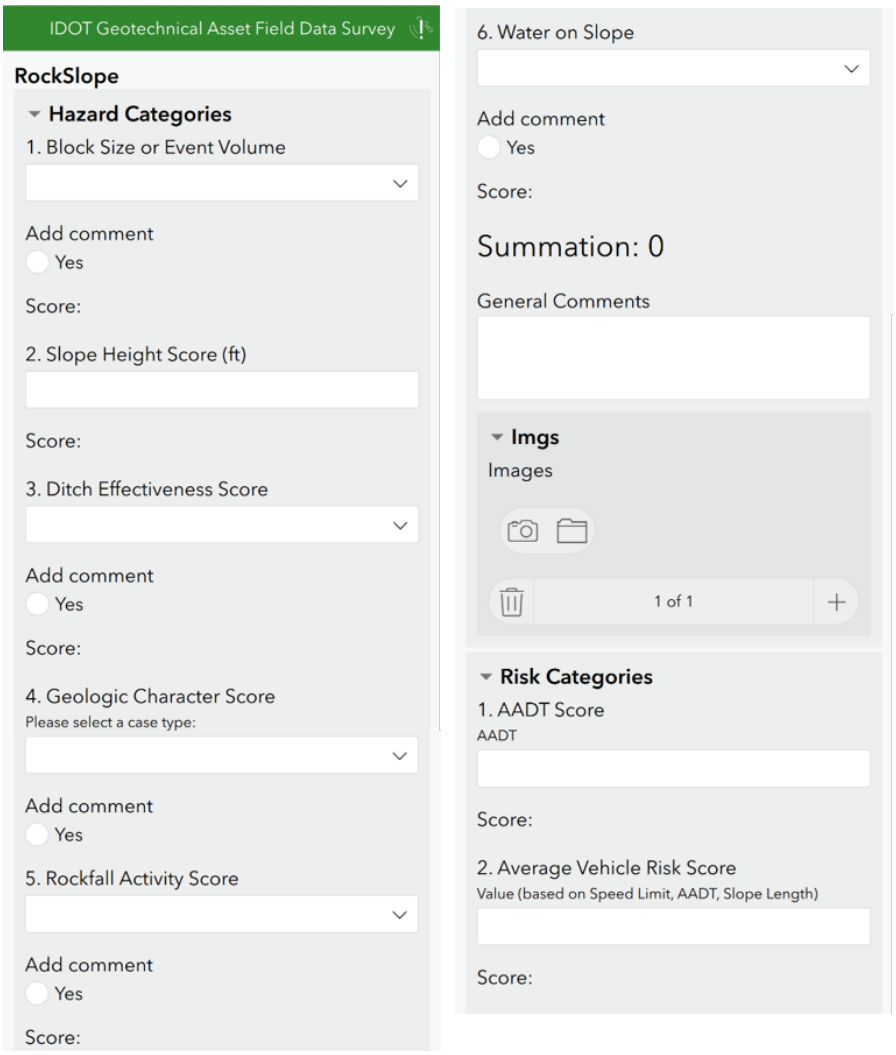


Figure 142. Screenshot. Hazard categories for rockslope.

Follow these steps to complete the Hazard Categories:

- Choose the measurement type (e.g., Size, Volume, Both) from the drop-down menu.
    - If Size is selected, enter observed block size corresponding to the largest prevailing size in ft as discussed in Appendix C.
    - If Volume is selected, enter observed event volume corresponding to the largest prevailing size in yd3 as discussed in Appendix C.
    - If Both is selected, enter observed block size and observed event volume.
- Type observed slope height in ft as discussed in Appendix C.

- Choose the level of observed ditch effectiveness from the drop-down menu that best describes the current condition of the asset. The options include Good, Moderate, Limited and None as discussed in Figure 121 in Appendix C.

- Choose the geologic character case type (e.g., Case 1, Case 2). Case 1 represents conditions where joint, bedding planes, or other discontinuities control rockfall, Case 2 represents conditions where differential erosion is the dominant rockfall contributors.

    If choose Case 1,

    i. Choose the structural condition from drop-down menu. The options include Favorable, Random, Discontinuous, Continuous as described in Table 39.

    ii. Choose the rock friction from drop-down menu. The options include Rough and Irregular, Undulating, Planar, Clay Infilling or Slickensides as described in Table 40.

    If choose Case 2,

    iii. Choose the structural condition from drop-down menu. The options include Few, Occasional, Many, Major as discussed in Table 41.

    iv. Choose the differential erosion rate from drop-down menu. The options include Small, Moderate, Large, Extreme as discussed in Table 42.

- Choose the level of observed rockfall activity from drop-down menu that can best describe the current condition of the asset. The options include Few, Occasional, Many, and Constant as described in Table 43.

- Choose the level of observed water on slope from drop-down menu that can best describe the current condition of asset. The options include Well, Moderately Well, Moderately Poor, and Poor as illustrated in Table 45 and Figure 127.

- Type general comments if any.

- Take a photo that can clearly show the current condition of the asset. Ensure the photo captures key features relevant to the assessment. If needed, you can add multiple photos by clicking ⊕ button.

The Risk Categories section consists of 5 questions designed to assess various factors contributing to the asset's condition, and the details of Risk Categories for Rockslope are summarized in Table 55.

Table 55. Details of Risk Categories for Rockslope

Question	Question Type	Field Name in Database	Esri Type
AADT Score	calculate	rsr_aadtscore	Double
Average Vehicle Risk Score	calculate	rsr_vvalue	Double
Score	calculate	rsr_vscore	Double
Decision Sight Score	decimal	rsr_sdistance	Double
Score	calculate	rsr_sscore	Double
Roadway Width Score	calculate	rsr_wvalue	Double
Score	calculate	rsr_wscore	Double
Rockfall Related Maintenance Frequency Score	select_one	rsr_rmaintenance	String
Summation	calculate	rsr_summary	Double
General Comments	text	rsr_comment	String

Each question in Risk Category is followed by a calculated score based on the input provided, with the total score displayed at the end of the section. Additionally, this section includes space for comments, allowing users to provide further context or observations. Figure 143 presents a screenshot of the Risk Categories for Rockslope section as displayed on the webpage.

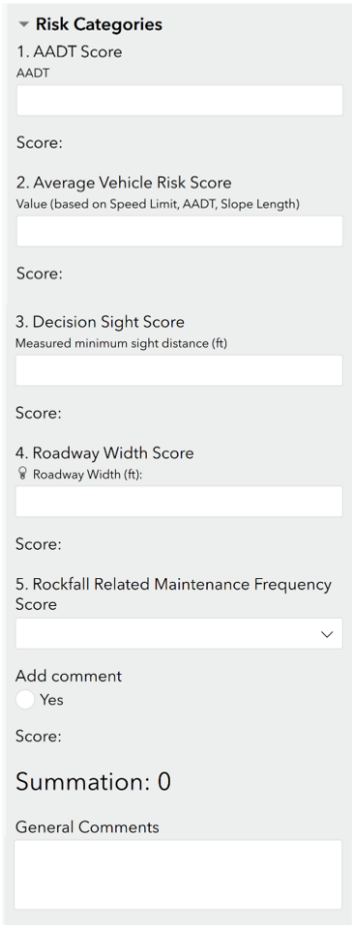


Figure 143. Screenshot. Risk categories for rockslope.

Follow these steps to complete the Risk Categories:

- AADT may be populated automatically, based on current location, otherwise type AADT of a road where the asset is located.
- Average Vehicle Risk Score may be populated automatically, based on provided inputs (e.g., Speed Limit, AADT, Slope Length), otherwise go back to General information section and type corresponding information.
- Type measured minimum sight distance in ft.
- Provided Roadway width (ft) in General Information section will be populated in one line below the question and the score will also be populated in the insert field.
- Choose the Rockfall related maintenance frequency score from drop-down menu. The options include Normal, After Storm, Seasonal, and Year-round. Maintenance can vary significantly from typical ditch cleaning to maintaining fences or rockfall mitigation strategies.
- Type comment if any.

The Summary section records the Rockslope Class and Failure Type, then reports the Hazard Risk and Safety Risk totals with their Combined Risk Score, the Condition State Element Scores for ditch effectiveness and rockfall activity with their averages, and the resulting Rockfall Condition State and Condition Score. Unlike the other three asset types, every calculated value in this section is displayed on the form. The complete set of fields for Summary for Rockslope is listed in Table 56.

Table 56. Details of Summary for Rockslope

Question/Label	Question Type	Field name in database	Esri Type
Rockslope Class	select_one	slope_class	String
Failure Type	select_one	slope_ftype	String
Total value of Hazard Risk	calculate	rsh_summary	Double
Total value of Safety Risk	calculate	rsr_summary	Double
Combined Risk Score	calculate	sum_risk_score	Double
Condition State Element Score of Ditch Effectiveness	calculate	ditch_cs	Double
Condition State Element Score of Rockfall Activity	calculate	rockfall_cs	Double
Average of Condition State	calculate	avg_cs	Double
Average of Field Rating	calculate	avg_fieldrating	Double
Rockfall Condition State	calculate	rockfall_condition	String
Rockfall Condition Score	calculate	rockfall_score	Integer

Figure 144 presents a screenshot of the Summary for Rockslope as displayed on the webpage.

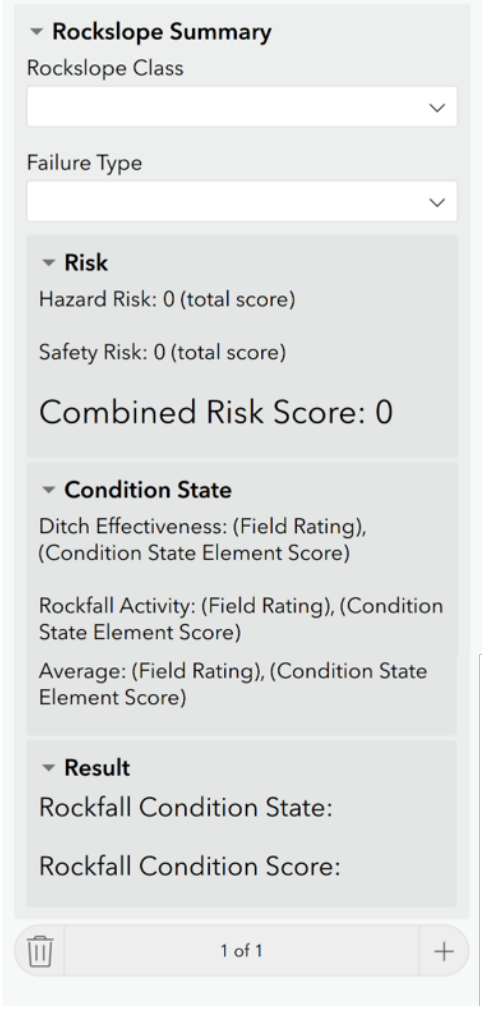


Figure 144. Screenshot. Summary for rockslope.

Summary section includes the following features:

- Choose the Rockslope Class from drop-down menu. The options include A, B, and C as described in Table 34.
- Choose the Failure Type from drop-down menu. The options include Planar, Wedge, Topple, Raveling/Talus, and Multiple Movement as discussed in RHRS Scoring in Appendix C.
- Display a total of Hazard Risk Score.
- Display a total of Safety Risk Score.
- Display a combined Risk Score.
- Display Field Rating of Ditch Effectiveness.
- Display Condition State Element Score of Ditch Effectiveness.

- Display Field Rating of Rockfall Activity.
- Display Condition State Element Score of Rockfall Activity.
- Display Average of Field Rating of Ditch Effectiveness and Rockfall Activity ratings.
- Display Average of Condition State Element Score of Ditch Effectiveness and Rockfall Activity scores.
- Display Rockfall Condition State as discussed in Table 57.
- Display Rockfall Condition Score as discussed in Table 57.

Table 57. Rockslope Rating Categories, Scoring Basis, and Appendix C References

Category	Scoring Basis	Appendix C Reference
Block Size or Event Volume	Measured block size (ft) or event volume (yd3); exponential category-score equation	Figure 120, Table 37
Slope Height	Measured vertical height (ft); category-score equation	Figure 125, Figure 126, Table 44
Ditch Effectiveness	Rated narrative: Good, Moderate, Limited, None	Figure 121; Table 38
Geologic Character, Case 1 (Structural Condition; Rock Friction)	Rated narratives: Favorable to Continuous; Rough and Irregular to Clay Infilling or Slickensides	Figure 124, Table 39, Table 40
Geologic Character, Case 2 (Structural Condition; Differential Erosion Rate)	Rated narratives: Few to Major; Small to Extreme	Table 41, Table 42
Rockfall Activity	Rated narrative: Few, Occasional, Many, Constant	Table 43
Water on Slope	Rated narrative: Well to Poorly Drained	Figure 127, Table 45
AADT (Risk)	AADT value; category-score equation	Figure 128 to Figure 130
Average Vehicle Risk (Risk)	Calculated from AADT, speed limit, and slope length	Figure 131; Table 46
Decision Sight Distance (Risk)	Measured minimum sight distance (ft) versus AASHTO recommended minimum	Figure 132; Table 47 and Table 48
Roadway Width (Risk)	Measured minimum paved width (ft); category-score equation	Figure 133; Table 47
Rockfall-Related Maintenance Frequency (Risk)	Rated narrative: Normal, After Storm, Seasonal, Year-round	Table 50
Condition State and Index	Ditch Effectiveness and Rockfall Activity scores converted to Condition State Element Scores and averaged	Figure 134 and Figure 135; Table 51 and Table 52

Slope/Embankment (Child Layer 2)

The Slope/Embankment survey consists of Slope/Embankment Components, Drainage, and Summary sections along with image tables. The Slope/Embankment Components has 10 questions designed to assess various factors contributing to the asset's condition, and the details of Slope/Embankment Components for Slope/Embankment are summarized in Table 58.

Slope and embankment geometry is not collected in a build-data block within this section. It is recorded on page 2 of the General Information page (Asset Characteristics) and is listed in Table 53. Asset length applies to every asset type; asset inclination is recorded for slopes and embankments as an H:V ratio; and maximum and typical exposed height are recorded for slopes and embankments as well as for MSE walls and walls. As with the wall build-data fields, these values support segmentation and normalize condition and risk across assets of different scale.

The Slope/Embankment child layer documented above is rated in two groups: Slope/Embankment Components (10 categories) and Drainage (6 categories). Table 61 and Table 62 summarize the Good/Marginal/Poor condition-state narratives from the Soil Slopes and Embankments inspection form; the guidance that follows defines each category and the field indicators an inspector should use to select a state.

Table 58. Details of Slope/Embankment Components for Slope/Embankment

Question	Question Type	Field name in database	Esri Type
Foundations	select_one	sec_foundation	String
Foundation Erosion and Scour	select_one	sec_ferosion_scour	String
Utilities	select_one	sec_util	String
Surface Distress	select_one	sec_surface_distress	String
Barrier and Guard Rail	select_one	sec_barrier_gr	String
Slope or Embankment Material Loss	select_one	sec_matloss	String
Apparent Material Saturation	select_one	sec_matsat	String
Localized Horizontal Movement (cracks in slope-embankment/pavement) Parallel to the Slope/Embankment	select_one	sec_lhm	String
Localized Vertical Movement (cracks in slope-embankment/pavement)	select_one	sec_lvm	String
Shallow Surface Failure/Depressions near Top of Slope or Embankment	select_one	sec_surface_failure	String
General Comments	text	sec_comment	String

Figure 145 presents a screenshot of the Slope/Embankment Components displayed on the webpage.

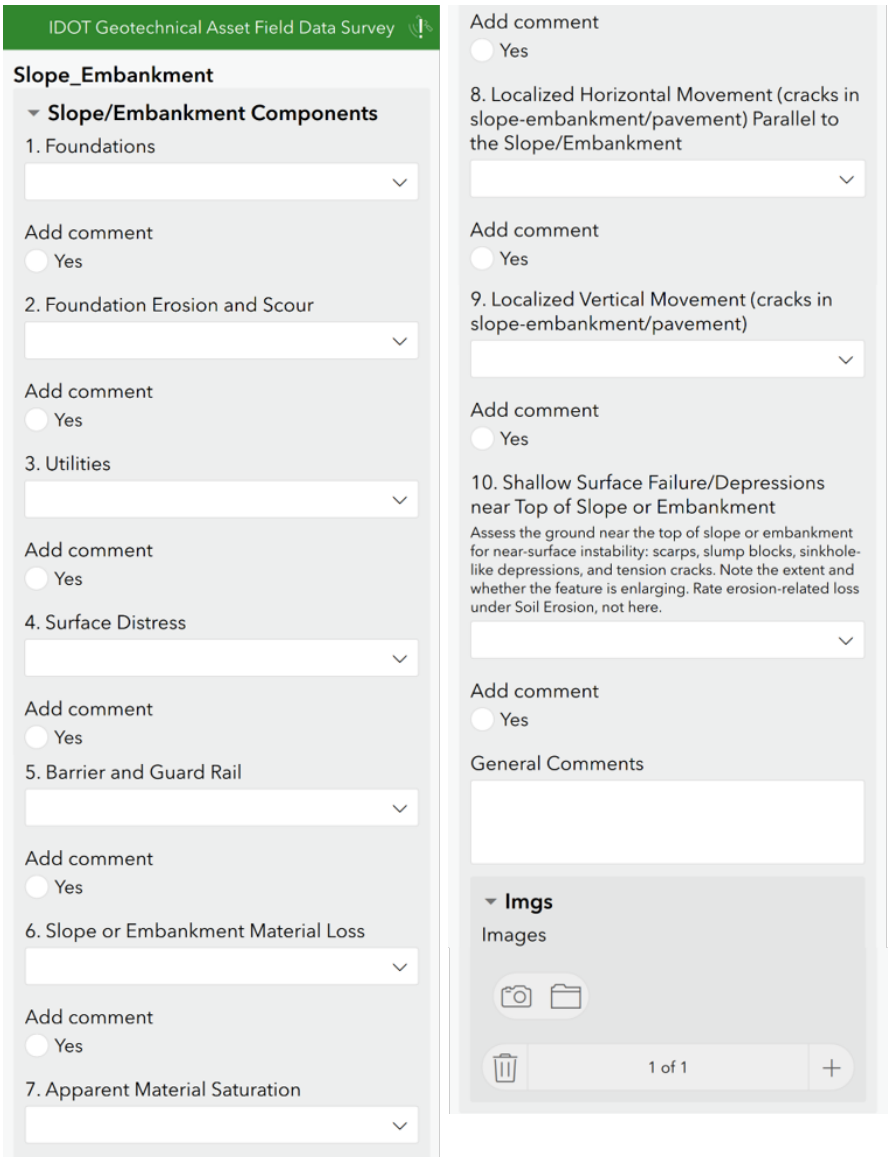


Figure 145. Screenshot. Slope/embankment components.

Follow these steps to complete the Slope/Embankment Components:

1. Choose observed condition of Foundation from the drop-down menu. The options include Good, Marginal, and Poor. Foundation refers to the geomaterials at the slope toe or the embankment and below it.

2. Choose observed condition of Foundation Erosion and Scour from the drop-down menu. The options include Good, Marginal, and Poor.

3. Choose observed condition of Utilities from the drop-down menu. The options include Good, Marginal, and Poor. If the inspector suspects that no utilities are present, leave the rating blank and add a note to the survey.

4. Choose observed condition of Surface Distress from the drop-down menu. The options include Good, Marginal, and Poor.

5. Choose observed condition, related to movements or cracks, of Barrier and Guard Rail from the drop-down menu. The options include Good, Marginal, and Poor. Leave the field empty if there is no barrier or guard rail and add a note to the survey.

6. Choose observed condition of Slope or Embankment Material Loss from the drop-down menu. The options include Good (no material loss) and Poor (observable and significant material loss).

7. Choose observed condition of Apparent Material Saturation from the drop-down menu. The options include Good, Marginal, and Poor.

8. Choose observed condition of Localized Horizontal Movement (cracks in slope-embankment/pavement) Parallel to the Slope/Embankment from drop-down menu. The options include Good, Marginal, and Poor.

9. Choose observed condition of Localized Vertical Movement (cracks in slope-embankment/pavement) from drop-down menu. The options include Good, Marginal, and Poor.

10. Choose observed condition of Shallow Surface Failure/Depressions near Top of Slope or Embankment from drop-down menu. The options include Good, Marginal, and Poor.

11. Type comment if any.

12. Take a photo that can clearly show the current condition of the asset. Ensure the photo captures key features relevant to the assessment. If needed, add multiple photos by clicking the ⊕ button.

The Drainage section has 6 questions designed to assess various factors contributing to the asset's condition, and the details of Drainage for Slope/Embankment are summarized in Table 59.

Table 59. Details of Drainage for Slope/Embankment

Question	Question Type	Field name in database	Esri Type
Soil Erosion	select_one	sed_serosion	String
Vegetation	select_one	sed_vegetation	String
Drainage System (Surface and Subsurface)	select_one	sed_drainage	String
Water Accumulation (top of slope)	select_one	sed_wateracc_top	String
Water Accumulation (bottom)	select_one	sed_wateracc_bot	String
Gutter / Ditch Condition	select_one	sed_gutter_ditch	String
General Comments	text	sed_comment	String

Figure 146 presents a screenshot of the Drainage section displayed on the webpage.

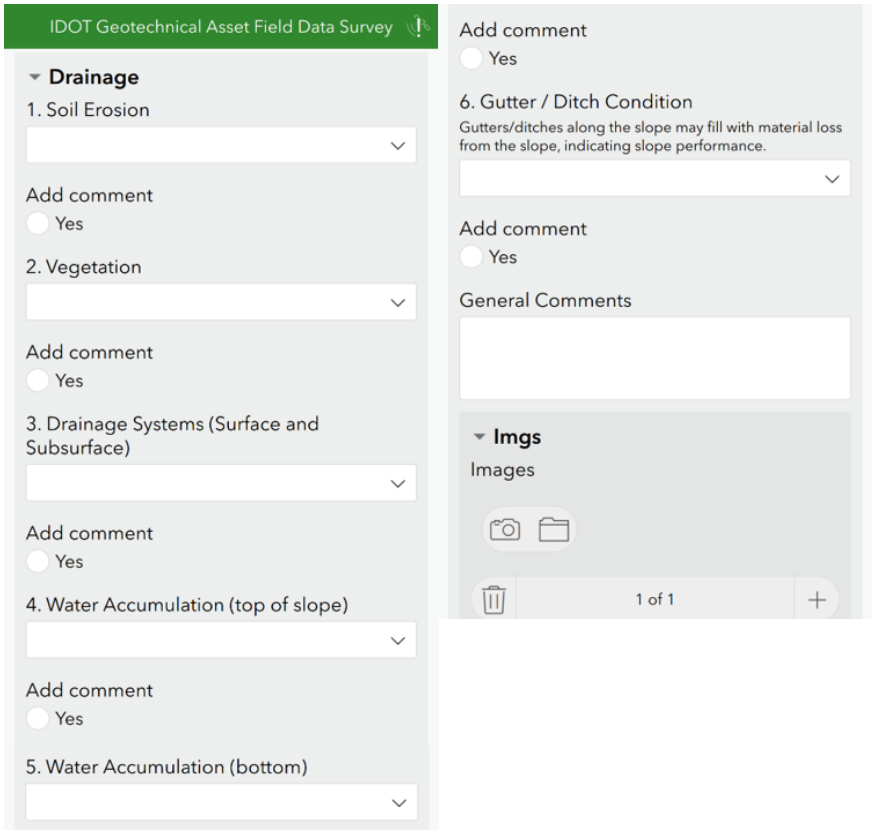


Figure 146. Screenshot. Drainage for slope/embankment.

Follow these steps to complete the Drainage:

- Choose observed condition of Soil Erosion from the drop-down menu. The options include Good, Marginal, and Poor.
- Choose observed condition of Vegetation from the drop-down menu. The options include Good, Marginal, and Poor. Where the slope is paved, hard armored, or covered with riprap rather than vegetated, select Not Applicable; the category rates vegetative cover, and Not Applicable is excluded from the group average. Record the surface type in the comment field, and rate the condition of the armored surface under Soil Erosion.
- Choose observed condition of Drainage System (Surface and Subsurface) from the drop-down menu. The options include Good, Marginal, and Poor.
- Choose observed condition of Water Accumulation (top of slope) from the drop-down menu. The options include Good, Marginal, and Poor.
- Choose observed condition of Water Accumulation (bottom) from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Gutter / Ditch Condition from the drop-down menu. The options include Good, Marginal, and Poor.
- Type general comments if any.
- Take a photo that can clearly show the current condition of the asset. Ensure the photo captures key features relevant to the assessment. If needed, add multiple photos by clicking the ⊕ button.

The Summary section reports the overall rating condition and value for Slope/Embankment Components and for Drainage, followed by the Overall Rating group, which holds the relative weights and Total Performance Rating. Each group also includes a Type Adjusted Overall Rating entry and a Select Overall Rating Type control, allowing the calculated value to be accepted or overridden; both are explained under Overall Rating Summary. Some fields are background calculations, including the group average and mode, that are stored with the record but not shown on the form. Table 60 lists the complete field set for Summary for Slope/Embankment.

Table 60. Details of Summary for Slope/Embankment

Label	Question Type	Field name in database	Esri Type
Average value of Slope/Embankment Component	calculate	sec_avg	Double
Condition of Slope/Embankment Component	calculate	sec_avg_cond	String
Average value of Drainage	calculate	sed_avg	Double
Condition of Drainage	calculate	sed_avg_cond	String
Mode value of Slope/Embankment Component	calculate	sec_mode	Double
Mode condition of Slope/Embankment Component	calculate	sec_mode_cond	String
Mode value of Drainage	calculate	sed_mode	Double
Mode condition of Drainage	calculate	sed_mode_cond	String
Type Adjusted Overall Rating (Components)	decimal	g2_s_ta_overall	Double
Select Overall Rating Type (Components)	select_one	g2_s_overall	String
Overall Rating value (Components)	calculate	g2_s_overall_val	Double
Overall Rating condition (Components)	calculate	g2_s_overall_condition	String
Type Adjusted Overall Rating (Drainage)	decimal	g2_d_ta_overall	Double
Select Overall Rating Type (Drainage)	select_one	g2_d_overall	String
Overall Rating value (Drainage)	calculate	g2_d_overall_val	Double
Overall Rating condition (Drainage)	calculate	g2_d_overall_condition	String
Slope/Embankment Components Relative Weight	decimal	g2_s_r_weight	Double
Drainage Relative Weight	decimal	g2_d_r_weight	Double
Total Performance Rating	calculate	g2_total_perform_rating	Double
Total Performance Condition	calculate	g2_total_perform_condition	String

Figure 147 presents a screenshot of the Summary section as displayed on the webpage.

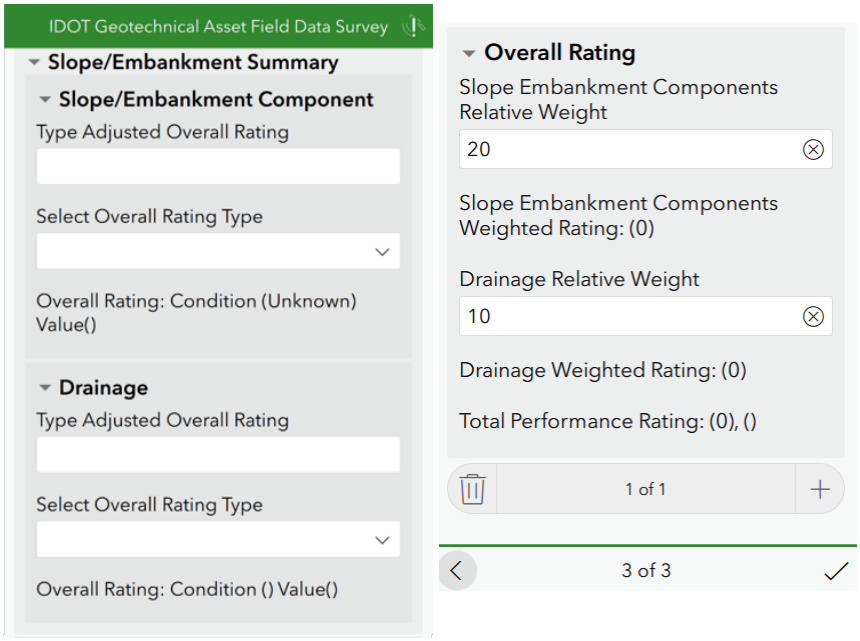


Figure 147. Screenshot. Summary for slope/embankment.

Summary section includes the following features:

- Display Slope/Embankment Component condition.
- Display an average value of Slope/Embankment Component.
- Display Drainage condition.
- Display an average value of Drainage.

Category Descriptions – Slope/Embankment Components

Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are drawn from the Soil Slopes and Embankments inspection form and summarized in Table 61 (Slope/Embankment Components) and Table 62 (Drainage).

Foundations

The foundation is the native or prepared ground supporting the slope or embankment. Foundation distress typically manifests as settlement or cracking near the base and can drive global instability if left unchecked. The area of interest is the slope toe and the ground supporting it; concentrate the assessment where loss of support at the toe would affect overall stability.

- ***Field indicators*** –Examine the slope or embankment base and the adjacent pavement for field indicators which include differential settlement, heave, and cracking, estimating vertical offset where it is visible.

- ***Cross-references –*** Rate this category alongside Localized Vertical Movement (Category 9); when both indicate settlement, cross-check against the Drainage findings, since saturation (Category 7) is a common driver.

Foundation Erosion and Scour

Erosion or scour at the toe removes material that confines and supports the slope, undermining stability from the base upward. Water-crossing and drainage-adjacent slopes are most susceptible.

- ***Field indicators*** –Look along the slope face and at the base for rilling, undercutting, exposed roots or geosynthetics, and loss of toe material; note proximity to concentrated flow paths or waterways.

- ***Cross-references –*** Toe erosion should be read together with the Drainage category, since concentrated surface flow and inadequate conveyance are the usual causes (Anderson et al. (2022)).

Utilities

Utility lines, poles, and masts crossing or bordering the asset both impose loads and serve as movement indicators; their distress can signal ground movement and can itself create hazards.

- ***Field indicators*** –Check for broken or leaking lines, tilted or deformed poles and masts, and separation at connections; note any leakage that could saturate the slope.

Surface Distress

Surface distress captures bulging, cracking, and displacement on the slope face, embankment crest, or overlying pavement, which are surface expressions of shallow instability or fill movement.

- ***Field indicators*** –Scan the slope face, crest, and pavement for bulges, longitudinal or transverse cracks, and offsets; estimate crack widths and displacement magnitudes where measurable.

Barrier and Guard Rail

Barriers and guardrails are safety appurtenances whose alignment is sensitive to ground movement; their displacement can both indicate slope movement and reduce their protective function.

- ***Field indicators*** –Sight along the rail or barrier for offsets, rotation, and cracking at posts or panels; note whether displacement is large enough to impair crash performance.

Slope or Embankment Material Loss

Material loss refers to the removal or displacement of slope or embankment material from the body of the asset, reducing its cross section and, over time, its stability.

- ***Field indicators*** –Look for missing fill, sloughed material, void development, and displaced riprap or surfacing across the slope body; distinguish true loss of the asset body from surficial erosion rated in Category 2.

- ***Condition state note –***This category has Good and Poor states only; a Marginal state is intentionally omitted.

Material Loss (Category 6) and Foundation Erosion and Scour (Category 2) are differentiated by the location of loss. Category 2 covers erosion/scour concentrated at the toe and foundation; Category 6 covers loss of material from the slope body (sloughing, voids, displaced surfacing). Surficial rilling is rated under Category 2. Material loss should not be double counted between these categories (Anderson et al. 2022).

Apparent Material Saturation

Apparent saturation is a proxy for pore-water conditions in the slope. Elevated saturation reduces effective stress and shear strength and is a common precursor to movement and surface failure.

- ***Field indicators*** –Judge moisture from seepage, damp or dark soil, standing water, and vigorous hydrophilic vegetation; assess after a sustained wet period where practical, since seasonal drying can mask conditions.

- ***Related material*** –Saturation should be corroborated with the Drainage group ratings and with any seepage noted under Surface Distress. See Appendix C, Slope Drainage guidance for analogous field cues (Beckstrand et al., 2017a).

Localized Horizontal Movement Parallel to the Slope/Embankment

Cracks running parallel to the slope crest or face indicate localized shear (incipient sliding) within the slope or embankment; crack width is a direct measure of movement severity.

- ***Field indicators*** –Trace cracks that parallel the slope alignment across the crest, bench, and pavement; measure width and note any vertical offset or a stepped, overlapping arrangement of short parallel crack segments (en-echelon pattern) suggesting an emerging failure surface.

Localized Vertical Movement

Localized vertical movement captures settlement or heave expressed as vertical offset at cracks in the slope, embankment, or pavement, distinct from the parallel shear cracks of Category 8.

- ***Field indicators*** –Measure vertical offset across cracks and joints on the crest and pavement; distinguish uniform settlement from differential movement, which is more indicative of localized instability.

- ***Cross-references –***Read together with Foundations (Category 1); persistent vertical movement with base cracking points to a foundation rather than a surficial cause.

Shallow Surface Failure or Depressions near Top of Slope or Embankment

Shallow failures and depressions near the crest indicate near-surface instability or internal erosion (piping) and often precede larger surficial slides. The area of interest is near the top of slope or embankment, which can generally be considered as within one slope height of the crest.

- ***Field indicators*** –Look near the top of slope for scarps, slump blocks, sinkhole-like depressions, and tension cracks; note extent and whether the feature is enlarging or vegetated over.

Vertical movement is often related to affected area and scarp height (e.g., isolated shallow depressions are Marginal; continuous scarp or slump affecting the crest and roadway are Poor) (Anderson et al. 2022).

Condition-State Narratives

Narratives corresponding to these categories are summarized in Table 61, which defines the Good, Marginal, and Poor states for each of the 10 Slope/Embankment Components categories.

Table 61. Slope/Embankment Components Condition-State Narratives

Category	Good	Marginal	Poor
Foundations	Negligible local or differential settlement near the slope or embankment base.	Local or differential settlement within permissible and tolerable limits (settlement < 2.0 inch), with minor cracks near the slope or embankment base.	Local or differential settlement exceeding permissible or tolerable limits, and/or cracks at the slope or embankment base.
Foundation Erosion and Scour	Insignificant erosion along the slope or at the slope or embankment base.	Moderate erosion along the slope or at the slope or embankment base.	Significant erosion along the slope or at the slope or embankment base.
Utilities	No observable broken utility lines, no utility pipe leakage, and no damage or significant tilt to surrounding utility poles or masts.	Moderate movement or deformation of utility lines, utility poles, or masts.	Observable broken utility lines, utility pipe leakage, or significant damage or deformation to utility poles or masts.
Surface Distress	No bulging or displacement along the slope face or at the embankment crest or pavement surface.	Moderate cracks or displacements along the slope face or at the embankment crest or pavement surface.	Significant bulging or excessive cracks or displacements along the slope face or at the embankment crest or pavement surface.
Barrier and Guard Rail	Insignificant barrier or guard rail displacement or cracks.	Permissible barrier or guard rail displacement or cracks.	Offset or displacement of barrier or guard rail that can affect performance.
Slope or Embankment Material Loss	No slope or embankment material loss.	Not defined; this category has Good and Poor states only (intentional).	Presence of slope or embankment material loss.
Apparent Material Saturation	Almost dry or dry.	Moist.	Almost saturated or saturated.

Category	Good	Marginal	Poor
Localized Horizontal Movement Parallel to the Slope/Embankment	Absence of localized shear failure in the slope or embankment.	Presence of localized shear failure in the slope or embankment (permissible cracks < 1 inch).	Presence of localized shear failure in the slope or embankment (wide cracks > 1 inch).
Localized Vertical Movement	Negligible settlement.	Localized settlement within allowable limits (settlement < 2.0 inch).	Localized settlement exceeding allowable limits (settlement > 2.0 inch).
Shallow Surface Failure or Depressions near Top of Slope or Embankment	Insignificant.	Moderate.	Significant.

Category Descriptions – Drainage

Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are summarized in Table 62.

Soil Erosion

Surface soil erosion within the drainage envelope removes the protective soil cover and can progress into the slope body if not addressed.

- ***Field indicators*** –Look for rills, gullies, and bare soil at the base, crest, and side slopes, especially along concentrated flow paths.

- ***Condition state note –***A Marginal state applies where minor surficial erosion is present on the slope face but does not reach the slope toe or expose the foundation. Poor is reserved for erosion at the base or crest, along the side slopes, or where material loss undermines the toe.

Vegetation

Vegetative cover protects the slope from surface erosion and helps regulate near-surface moisture; its condition is an indirect indicator of slope health and drainage performance.

- ***Field indicators*** –Assess cover continuity across the side slopes, noting barren patches, die-off, and areas of unusually vigorous growth that may signal persistent seepage.

Drainage Systems (Surface and Subsurface)

Surface and subsurface drainage systems (ditches, chutes, underdrains, weep systems) convey water away from the slope; their condition governs how much water reaches and saturates the asset.

- ***Field indicators*** –Inspect ditches, pipes, and outlets for blockage, damage, sediment, and misalignment; distinguish problems fixable by routine maintenance from those requiring rehabilitation.

Water Accumulation (top of slope)

Ponding at the top of the slope drives infiltration into the crest and can raise pore pressures within the slope body.

- ***Field indicators*** –Look for unintended standing water persisting after precipitation has ended, ponding scars, saturated soil and sediment deposits at the crest, water-tolerant vegetation, and closed depressions with no positive outlet. Note whether the accumulation could be resolved by routine maintenance such as regrading or clearing an outlet, since that distinction separates the Marginal and Poor condition states in Table 62.

Water Accumulation (bottom of slope)

Ponding at the base of the slope keeps the toe wet, promoting toe erosion and softening of the material that confines the slope.

- ***Field indicators*** –Look for unintended standing water and saturated ground at the toe persisting after precipitation ends. Note sediment deposits, saturated soil, water-tolerant vegetation, and softened or rutted ground. Check whether outlets are submerged, crushed, or blocked, and whether ponding is chronic. Note whether the accumulation could be resolved by routine maintenance, since that distinction separates the Marginal and Poor condition states in Table 62.

Gutter or Ditch Condition

Gutters and ditches along the slope or embankment collect material shed from the slope face; the volume and character of accumulated material are an indirect measure of slope performance and drainage function.

- ***Field indicators –***Check gutters and ditches for sediment, debris, and blockage; note whether accumulation reflects active surface loss from the slope above or routine maintenance buildup, and whether flow is impeded.

Condition-State Narratives

Narratives corresponding to these categories are summarized in Table 62, which defines the Good, Marginal, and Poor states for each of the 6 Drainage categories.

Table 62. Slope/Embankment Drainage Condition-State Narratives

Category	Good	Marginal	Poor
Soil Erosion	No erosion.	Minor surficial erosion on the slope face that does not reach the slope toe; Poor is reserved for erosion at the base or crest, along the side slopes, or undermining the toe	Soil erosion at the base or crest of the slope or along the side slopes.
Vegetation	Vegetation growth is consistent and lush along the side slopes.	Vegetation growth is generally intact with several barren patches along the side slopes.	Vegetation growth is inconsistent along the side slopes with significant bare areas.
Drainage Systems (Surface and Subsurface)	No observable surface or subsurface drainage problems.	Presence of surface and subsurface drainage problems that can be addressed by routine maintenance.	Presence of surface and subsurface drainage problems that cannot be addressed by routine maintenance.
Water Accumulation (top of slope)	No water accumulation at the top of the slope (for example, no water ponding).	Water accumulation at the top of the slope (for example, water ponding) that can be addressed by routine maintenance.	Water accumulation at the top of the slope (for example, water ponding) that cannot be addressed by routine maintenance.
Water Accumulation (bottom of slope)	No water accumulation at the base of the slope (for example, no water ponding).	Water accumulation at the base of the slope (for example, water ponding) that can be addressed by routine maintenance.	Water accumulation at the base of the slope (for example, water ponding) that cannot be addressed by routine maintenance.
Gutter or Ditch Condition	Gutters and ditches are clear or contain only minor accumulation; flow is not impeded.	Sediment or debris accumulation partially impedes flow or indicates active surface loss from the slope; can be addressed by routine maintenance.	Gutters or ditches are blocked or filled; flow is impeded or accumulation indicates significant ongoing material loss; cannot be addressed by routine maintenance.

Scoring

Each category is rated Good (1), Marginal (2), or Poor (3), with Not Applicable excluded from the average. The category ratings within a group are averaged to produce the group performance rating: one for Slope/Embankment Components and one for Drainage. The group ratings are then combined into a total performance rating using the relative weights from the Overall Rating sheet (Slope/Embankment Components at a relative weight of 20, Drainage at a relative weight of 10; total weight 30; Table 75). The total weighted rating is divided by the total weight to yield the total performance rating, which maps to the action bands in Table 76.

MSE Wall (Child Layer 3)

The MSE Wall survey consists of Wall System Component Distress, Metallic Components, Drainage, and Summary along with image tables. The Wall System Component Distress includes 13 rated distress categories, together with the build-data field (panel / facing unit type and reinforcement type) and fence and general-erosion items; the details of Wall System Component Distress for MSE Wall are summarized in Table 63. Figure 148 presents a screenshot of the Wall System Component Distress for MSE Wall displayed on the webpage.

Table 63. Details of Wall System Component Distress for MSE Wall

Question	Question Type	Field name in database	Esri Type
Build data (recorded, not scored)			
Panel / Facing Unit Type	select_one	mse_facing_type	String
Reinforcement Type	select_one	mse_reinf_type	String
Scored distress categories (13)			
Foundation	select_one	mses_foundation	String
Foundation Erosion and Scour	select_one	mses_ferosion_scour	String
Surrounding	select_one	mses_surrounding	String
Utilities	select_one	mses_util	String
Facing Distress	select_one	mses_fdistress	String
Coping and Parapets	select_one	mses_coping	String
Facing Joint	select_one	mses_fjoint	String
Geotextile Joint Material	select_one	mses_jmat	String
Backfill Spill-Out	select_one	mses_bspillout	String
Backfill Saturation	select_one	mses_bsaturation	String
Localized Horizontal Movement (cracks in retained fill/pavement) Parallel to the Wall	select_one	mses_lhm	String
Localized Vertical Settlement (cracks in retained fill/pavement)	select_one	mses_lvs	String
Shallow Surface Failure/Depressions near Top of Wall	select_one	mses_surface_failure	String
Supplemental observations (recorded, not scored)			
General Erosion / Scour	select_one	mses_general_erosion	String
Fence / Non-Traffic Barrier Present?	select_one	mses_fence_present	String
Fence / Non-Traffic Barrier Condition	select_one	mses_fence_cond	String
General Comments	text	mses_comment	String

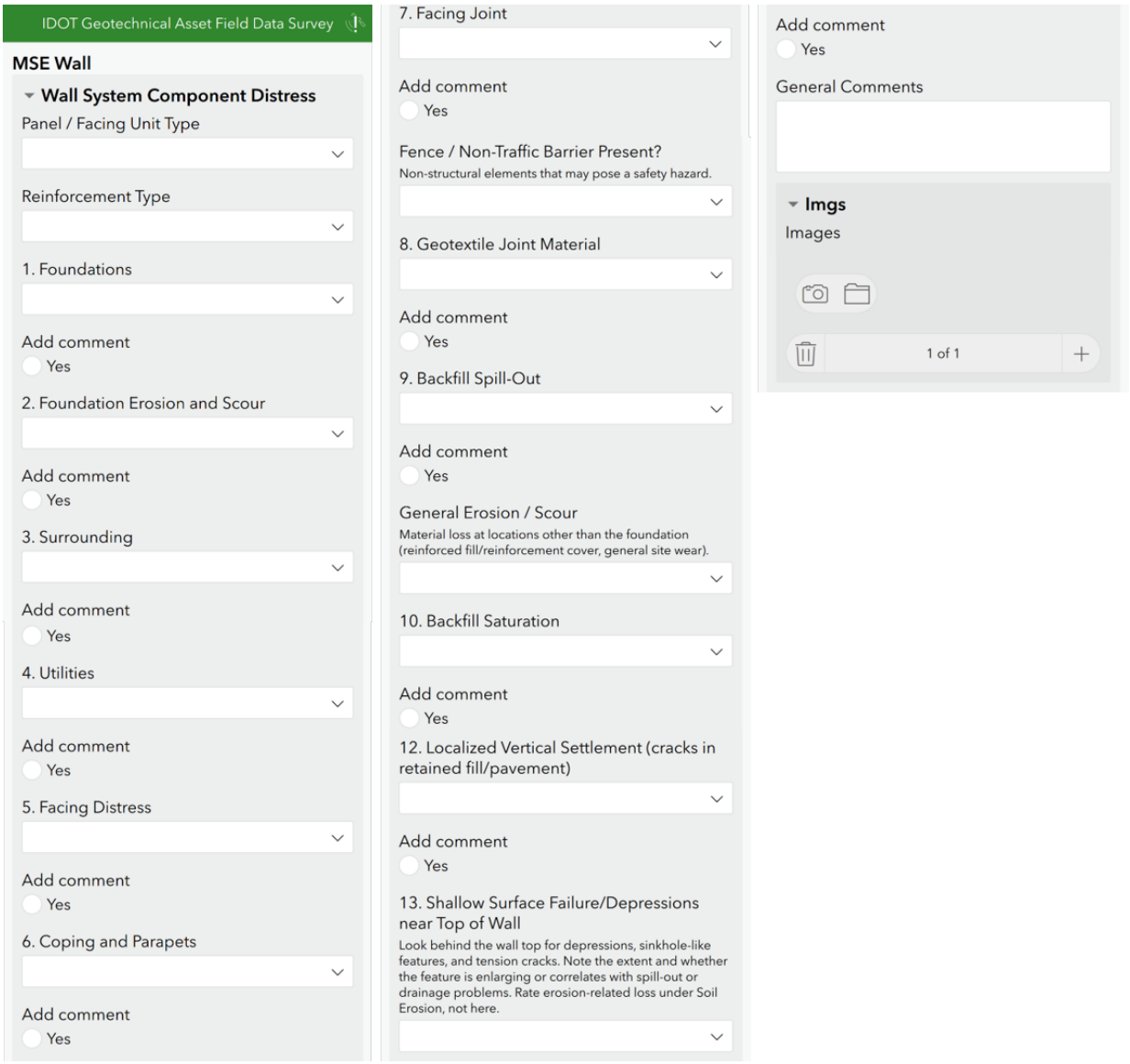


Figure 148. Screenshot. Wall system component distress for MSE wall.

Follow these steps to complete the Wall System Component Distress:

- Choose observed condition of Foundation from the drop-down menu. The options include Good, Marginal, and Poor. Foundation includes geomaterials supporting the reinforced backfill, which typically extends to base of the facing or below the leveling pad.

- Choose observed condition of Foundation Erosion and Scour from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Surrounding such as utility lines, pavements, or other adjacent assets from the drop-down menu. The options include Good and Poor.

- Choose observed condition of Utilities from the drop-down menu. The options include Good, Marginal, and Poor. If the inspector suspects that no utilities are present, leave the rating blank and add a note to the survey.

- Choose observed condition of Facing Distress from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Coping and Parapets from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Facing Joint from the drop-down menu. The options include Good and Poor.

- Choose observed condition of Geotextile Joint Material from the drop-down menu. The options include Good, Marginal, Poor, and Not Visible.

- Choose observed condition of Backfill Spill-Out from the drop-down menu. The options include Good and Poor.

- Choose observed condition of Backfill Saturation from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Localized Horizontal Movement (cracks in retained fill/pavement) Parallel to the Wall from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Localized Vertical Settlement (cracks in retained fill/pavement) from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Shallow Surface Failure/Depressions near Top of Wall from the drop-down menu. The options include Good, Marginal, and Poor. These movements typically extend along the wall near the facing the top.

- Type general comments if any.

- Take a photo that can clearly show the current condition of the asset. Ensure the photo captures key features relevant to the assessment. If needed, add multiple photos by clicking the ⊕ button.

Supplemental observations. The two items below are recorded but not scored. Both are excluded from the group average, so neither affects the group performance rating or the total performance rating.

- Select whether a fence or non-traffic barrier is present. Where none is present, select No; the condition question is then skipped and no rating is recorded.

- Where a fence or non-traffic barrier is present, choose its observed condition from the drop-down menu. The options include Good, Marginal, Poor, and Not Applicable.

- Choose observed condition of General Erosion and Scour from the drop-down menu. The options include Good, Marginal, Poor, and Not Applicable. Record material loss at locations away from the foundation here; where loss concentrates at the wall base, rate it under Foundation Erosion and Scour (Category 2) instead.

The Metallic Components section has 4 questions designed to assess various factors contributing to the asset's condition, and the details of Metallic Components for MSE Wall are summarized in Table 64.

Table 64. Details of Metallic Components for MSE Wall

Question	Question Type	Field name in database	Esri Type
Reinforcement or Facing Displacement	select_one	msem_fdisp	String
Overall (Vertical and Horizontal) Alignment	select_one	msem_overallalign	String
Local Facing Displacement	select_one	msem_lfd	String
Reinforcement or Connection Corrosion	select_one	msem_ccorrosion	String
General Comments	text	msem_comment	String

Figure 149 presents a screenshot of the Metallic Components for MSE Wall displayed on the webpage.

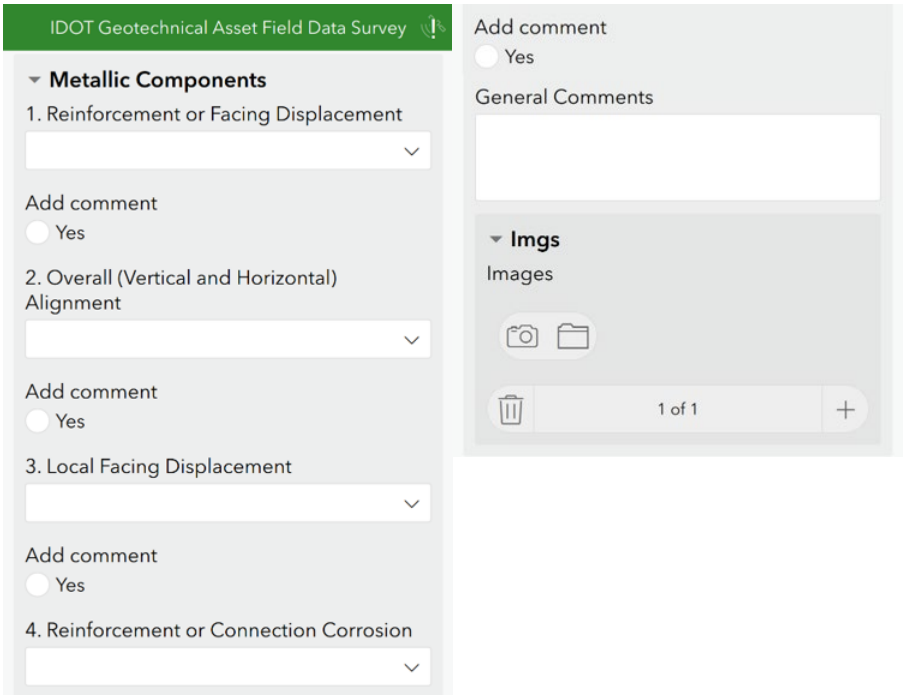


Figure 149. Screenshot. Metallic components for MSE wall.

Follow these steps to complete the Metallic Components:

- Choose observed condition of Reinforcement or Facing Displacement from the drop-down menu. The options include Good (No facing connection rupture or reinforcement pullout) and Poor (facing connection rupture or reinforcement pullout). Since reinforcement may not be visible in many instances, the facing movement at reinforcement locations is considered an indicator of the reinforcement condition.

- Choose observed condition of Overall (Vertical and Horizontal) Alignment from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Local Facing Displacement from the drop-down menu. The options include Good, Marginal, and Poor. These movements are observed within a confined area of the wall reflecting a localized distress and not across the full wall length.

- Choose observed condition of Reinforcement or Connection Corrosion from the drop-down menu. The options include Good and Poor. This rating relates to the corrosion and deterioration of reinforcement and not full rupture or pullout as opposed to the first rating of metallic components.

- Type comment if any.

- Take a photo that can clearly show the current condition of the asset. Ensure the photo captures key features relevant to the assessment. If needed, add multiple photos by clicking the ⊕ button.

The Drainage has 5 questions designed to assess various factors contributing to the asset's condition, and the details of Drainage for MSE Wall are summarized in Table 65.

Table 65. Details of Drainage for MSE Wall

Question	Question Type	Field name in database	Esri Type
Soil Erosion	select_one	msed_serosion	String
Vegetation	select_one	msed_vegetation	String
Drainage Systems (Surface and Subsurface)	select_one	msed_drainage	String
Water Accumulation (top)	select_one	msed_wateracc_top	String
Water Accumulation (bottom)	select_one	msed_wateracc_bot	String
General Comments	text	msed_comment	String

Figure 150 presents a screenshot of the Drainage for MSE Wall displayed on the webpage.

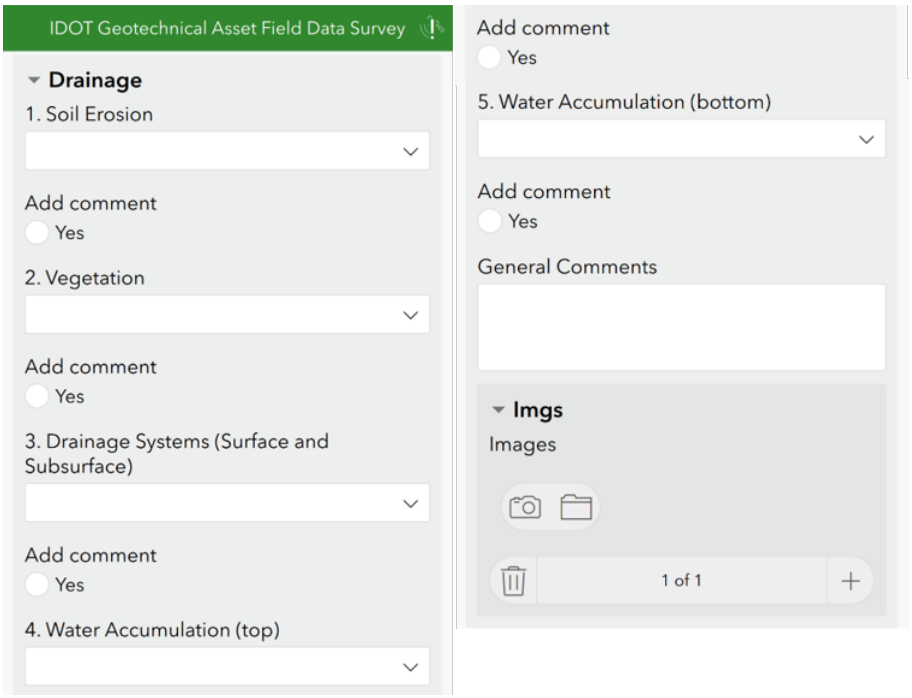


Figure 150. Screenshot. Drainage for MSE wall.

Follow these steps to complete the Drainage:

- Choose observed condition of Soil Erosion from the drop-down menu. The options include Good, Marginal, and Poor. The assessment is trying to capture erosion related to drainage damage or inefficiency.

- Choose observed condition of Vegetation from the drop-down menu. The options include Good (No unintended vegetation growth in facing and construction joints), Marginal (Unintended vegetation growth in facing and construction joints that can be addressed by routine maintenance), and Poor (Unintended vegetation growth in facing and construction joints that cannot be addressed by routine maintenance).

- Choose observed condition of Drainage Systems (Surface and Subsurface) from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Water Accumulation (top) from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Water Accumulation (bottom) from the drop-down menu. The options include Good, Marginal, and Poor.

- Type comment if any.

- Take a photo that can clearly show the current condition of the asset. Ensure the photo captures key features relevant to the assessment. If needed, add multiple photos by clicking the ⊕ button.

The Summary section reports the overall rating condition and value for Wall System Component Distresses, Metallic Components, and Drainage, followed by the Overall Rating group, which holds the relative weights and the Total Performance Rating. Each group also provides a Type Adjusted Overall Rating entry and a Select Overall Rating Type control, which allow the calculated value to be accepted or overridden; both are explained under Overall Rating Summary. Some of the fields recorded in this section are background calculations, including the group average and mode, that are stored with the record but are not displayed on the form. The complete set of fields for Summary for MSE Wall is listed in Table 66.

Table 66. Details of Summary for MSE Wall

Label	Question Type	Field name in database	Esri Type
Average value of Wall System Component Distresses	calculate	mses_avg	Double
Condition of Wall System Component Distresses	calculate	mses_avg_cond	String
Average value of Metallic Components	calculate	msem_avg	Double
Condition of Metallic Components	calculate	msem_avg_cond	String
Average value of Drainage	calculate	msed_avg	Double
Condition of Drainage	calculate	msed_avg_cond	String
Mode value of Wall System Component Distresses	calculate	mses_mode	Double
Mode condition of Wall System Component Distresses	calculate	mses_mode_cond	String
Mode value of Metallic Components	calculate	msem_mode	Double
Mode condition of Metallic Components	calculate	msem_mode_cond	String
Mode value of Drainage	calculate	msed_mode	Double
Mode condition of Drainage	calculate	msed_mode_cond	String
Type Adjusted Overall Rating (Component Distresses)	decimal	g3_w_ta_overall	Double
Select Overall Rating Type (Component Distresses)	select_one	g3_w_overall	String
Overall Rating value (Component Distresses)	calculate	g3_w_overall_val	Double
Overall Rating condition (Component Distresses)	calculate	g3_w_overall_condition	String
Type Adjusted Overall Rating (Metallic)	decimal	g3_m_ta_overall	Double
Select Overall Rating Type (Metallic)	select_one	g3_m_overall	String
Overall Rating value (Metallic)	calculate	g3_m_overall_val	Double
Overall Rating condition (Metallic)	calculate	g3_m_overall_condition	String
Type Adjusted Overall Rating (Drainage)	decimal	g3_d_ta_overall	Double

Label	Question Type	Field name in database	Esri Type
Select Overall Rating Type (Drainage)	select_one	g3_d_overall	String
Overall Rating value (Drainage)	calculate	g3_d_overall_val	Double
Overall Rating condition (Drainage)	calculate	g3_d_overall_condition	String
Wall System Component Distress Relative Weight	decimal	g3_w_r_weight	Double
Metallic Relative Weight	decimal	g3_m_r_weight	Double
Drainage Relative Weight	decimal	g3_d_r_weight	Double
Total Performance Rating	calculate	g3_total_perform_rating	Double
Total Performance Condition	calculate	g3_total_perform_condition	String

Figure 151 presents a screenshot of the Summary Section as displayed on the webpage.

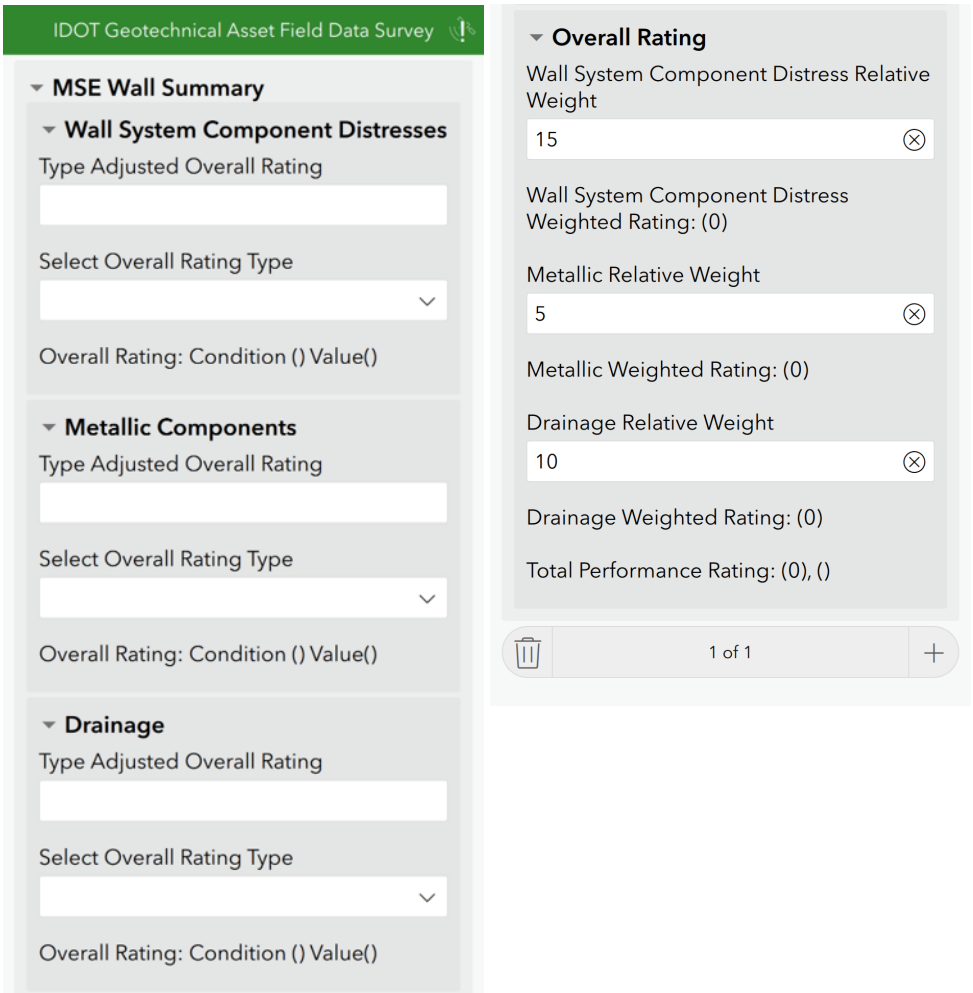


Figure 151. Screenshot. Summary for MSE wall.

The Summary section includes the following features:

- Display Wall System Component Distresses condition.

- Display an average value of Wall System Component Distresses.
- Display Metallic Components condition.
- Display an average value of Metallic Components.
- Display Drainage condition.
- Display an average value of Drainage.
- Display Overall Wall System rating.

The MSE Wall child layer is rated across three category groups: Wall System Component Distress (13 categories), Metallic Components (4 categories), and Drainage (5 categories). Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are drawn from the MSE Walls inspection form and summarized in Table 67 (Wall System Component Distress), Table 68 (Metallic Components), and Table 69 (Drainage).

Category Descriptions – Wall System Components

Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are summarized in Table 67.

Build Data

Before rating condition, confirm the wall's basic build information. Recorded on page 2 of the General Information page (Asset Characteristics), and listed in Table 53, are maximum and typical exposed height. Recorded in this section are the panel or facing-unit type and the reinforcement type. Where a value cannot be determined in the field, select Unknown. These fields support segmentation and normalize condition and risk across walls of different scale.

- ***Field indicators –*** Measure exposed height at the tallest point and at a representative typical section; identify facing type (precast panel, modular block, or welded-wire faced) and, where visible or documented, reinforcement type (e.g., steel strip, steel grid, geogrid, or geotextile).

Foundations

The foundation and leveling pad support the MSE mass. Foundation settlement or leveling-pad cracking can rack the facing and compromise the wall system.

- ***Field indicators –*** Examine the base, leveling pad, and adjacent grade for differential settlement, cracking, and evidence of marginal foundation materials; estimate vertical offset where visible.
- ***Cross-references –*** Read with Localized Vertical Settlement (Category 12).

Foundation Erosion and Scour

Erosion of the soil berm and loss of embedment expose the leveling pad and undermine bearing support; scour is especially critical at water-crossing walls. The soil berm is the soil that extends out in front of the wall face at its base and covers the leveling pad.

- ***Field indicators –***Check berm width and wall embedment for erosion; look for exposed leveling pad and, at water crossings, evidence of scour at the base.

- ***Cross-references –***Loss of embedment and exposed leveling pad are among the highest-priority MSE inspection findings (Kulesza, Parsons & Han, 2024).

Surrounding

The wall surroundings capture external agents (deicing salts, efflorescence-inducing moisture, vehicular impact) that accelerate facing and reinforcement deterioration.

- ***Field indicators –***Look for salt deposits, concrete efflorescence, and impact damage on and near the facing; note nearby sources such as roadway drainage carrying deicing chemicals.

- ***Condition state note –***This category has Good and Poor states only; a Marginal state is intentionally omitted.

- ***Cross-references –***Efflorescence and staining are early indicators of moisture movement and potential reinforcement corrosion (Kulesza, Parsons & Han, 2024).

Utilities

Utilities penetrating or bordering the wall can leak water into the reinforced fill and can act as movement indicators for the wall system. Broken or leaking storm sewers deserve particular attention as they can act as conduits that carry reinforced fill out of the wall, producing voids and surface depressions behind the wall before any distress becomes visible at the facing.

- ***Field indicators –*** Check for broken or leaking lines, tilted poles or masts, and deformation at penetrations; note leakage that could saturate the reinforced backfill.

General Erosion and Scour

General erosion and scour capture material loss at locations other than the foundation, including erosion of the reinforced-fill cover, loss of surfacing on the reinforced mass, and scour along the wall face away from the base.

- ***Field indicators –*** Look for rilling, voids, and displaced surfacing across the reinforced-fill cover and along the face. Distinguish this general loss from the toe- and embedment-focused loss rated under Foundation Erosion and Scour (Category 2); where loss concentrates at the base, rate it there instead.

- ***Cross-references –*** Read with Foundation Erosion and Scour (Category 2).

Fences and Non-Traffic Barriers

Fences and other non-traffic barriers mounted on or adjacent to the wall are non-structural but can pose a safety hazard if damaged or displaced.

- ***Field indicators –*** Where present, check fences and non-traffic barriers for damage, displacement, corrosion, and loose or missing sections; record a condition only where such an element is present.

Facing Distress

The facing retains the reinforced fill at the wall face; its distress (bulging, cracking, spalling, unit offset) reflects both facing durability and movement of the reinforced mass behind it.

- ***Field indicators –*** Scan the face for bulging or bowing, buckling, cracking within or across units, popped corners, water staining, chipping, and wear; note lateral deformation and whether cracks traverse multiple units.

- ***Cross-references –*** Facing distress is among the most important MSE inspection items. Distinguish facing-only distress here from system-level movement rated in the Metallic Components group (Kulesza, Parsons & Han, 2024).

Coping and Parapets

Coping and parapets cap the wall and manage runoff at the top; displacement or loss can admit water to the reinforced fill and signal movement at the wall top.

- ***Field indicators –*** Check coping and parapet units for offset, cracking, and loose or detached segments; note gaps that could channel water behind the facing.

Facing Joint

Facing joint openings reflect the fit and movement between facing units; excessive openings admit fill loss and water and can indicate differential movement.

- ***Field indicators –*** Measure horizontal and vertical joint openings across the face; note any progressive widening or misalignment between courses.

- ***Condition state note –*** This category has Good and Poor states only; a Marginal state is intentionally omitted.

Geotextile Joint Material

Geotextile behind the facing joints retains fines while allowing drainage; missing or displaced geotextile allows backfill to pipe out through the joints.

- ***Field indicators –*** Inspect behind panel joints for displaced, torn, or missing geotextile, and correlate with any backfill spill-out at the face (Category 9).

- ***Condition state note –*** A Marginal state applies where wear or partial displacement is observed but joint material remains in place and continues to retain fines. Where the geotextile cannot be seen behind the facing, record Not Visible rather than a condition rating, so that an unrated joint is not read as a defect.

Backfill Spill-Out

Spill-out is reinforced backfill escaping through the facing joints, a direct sign of internal erosion and a precursor to void development and settlement behind the wall.

- ***Field indicators –*** Look for soil staining, fans of spilled fines at the base, and material emerging at joints; correlate with geotextile condition (Category 8).

- ***Condition state note –*** This category has Good and Poor states only; a Marginal state is intentionally omitted.

Backfill Saturation

Saturation of the reinforced fill raises pore pressures, adds load, and accelerates reinforcement corrosion; it is a key driver of MSE performance.

- ***Field indicators –*** Judge moisture from seepage at joints, staining, and damp fill visible at the top or through openings; assess after a wet period where practical.

- ***Cross-references –*** Read together with the Drainage group.

Localized Horizontal Movement Parallel to the Wall

Cracks parallel to the wall in the retained fill or pavement indicate localized shear behind the wall, an early sign of global or compound instability.

- ***Field indicators –*** Trace cracks paralleling the wall across the fill surface and pavement; measure width and note offset or stepping.

Localized Vertical Settlement

Vertical settlement in the retained fill or pavement behind the wall reflects consolidation or loss of fill and can indicate internal erosion or foundation movement.

- ***Field indicators –*** Measure vertical offset at cracks and joints on the fill surface and pavement; distinguish uniform from differential settlement.

- ***Cross-references –*** Read with Foundations (Category 1) and Backfill Spill-Out (Category 9).

Shallow Surface Failure or Depressions near Top of Wall

Depressions and shallow failures behind the wall top indicate void development or internal erosion in the reinforced or retained fill.

- ***Field indicators –*** Look behind the wall top for depressions, sinkhole-like features, and tension cracks; note extent and any correlation with spill-out or drainage problems.

Condition-State Narratives

Narratives corresponding to these categories are summarized in Table 67, which defines the Good, Marginal, and Poor states for each of the 13 MSE Wall System Component categories. Note that Fences and Non-Traffic Barriers and General Erosion and Scour are recorded but not scored. Both are excluded from the Wall System Component Distress group average, so neither affects the group performance rating or the total performance rating; this follows the MSE wall inspection workbook, which places both items under supplemental observations. The Good, Marginal, and Poor descriptions given for these two items are typical indicators intended to promote consistent recording between inspectors, not rating criteria.

Table 67. MSE Wall System Component Condition-State Narratives

Category	Good	Marginal	Poor
Foundations	Negligible local or differential settlement, no cracks near the base or in the leveling pad, and no marginal materials.	Local or differential settlement within permissible limits (settlement < 2.0 inch), with minor cracks near the base.	Local or differential settlement exceeding permissible limits, and/or cracks in the leveling pad.
Foundation Erosion and Scour	Insignificant erosion to berm with sufficient wall embedment depth.	Moderate erosion to the berm that reduces cover but does not expose the leveling pad or undermine embedment.	Erosion exposing the leveling pad or undermining embedment; or scour at the base of water-crossing walls.
Surrounding	No salt deposits or concrete efflorescence near the wall, and no signs of impact-related damage.	Not defined; this category has Good and Poor states only (intentional).	Presence of salt deposits or concrete efflorescence near the wall, or signs of impact-related damage.
Utilities	No observable broken utility lines, no utility pipe leakage, and no damage or significant tilt to surrounding utility poles or masts.	Moderate movement or deformation of utility lines, utility poles, or masts.	Observable broken utility lines, utility pipe leakage, or significant damage or deformation to utility poles or masts.
Facing Distress	No bulging or bowing, no buckling, no water staining, chipping, or wearing, and negligible lateral deformation.	Moderate facing cracks; facing scratches and chipping; moderate facing deterioration (wear and tear); admissible lateral deformation.	Offset of units; bulging or bowing; buckling; excessive cracks (within individual units or traversing multiple units); popped unit corners.
Coping and Parapets	Insignificant concrete coping and parapet displacement or cracks.	Permissible concrete coping and parapet displacement or cracks.	Offset of concrete coping and parapets, and/or loose or detached coping and parapets.
Facing Joint	Permissible or adequate horizontal and vertical joints (< 0.75 inch).	Not defined; this category has Good and Poor states only (intentional).	Excessive or inadequate horizontal and vertical joints (> 0.75 inch).
Geotextile Joint Material	Geotextile joint material covering all joints.	Wear observed but joint material remains in place; where the geotextile cannot	Displaced or missing geotextiles behind panel joints.

Category	Good	Marginal	Poor
		be seen, Not Visible is recorded instead of a rating.	
Backfill Spill-Out	No spilled-out reinforced backfill material.	Not defined; this category has Good and Poor states only (intentional).	Presence of spilled-out reinforced backfill material.
Backfill Saturation	Almost dry or dry.	Moist.	Almost saturated or saturated.
Localized Horizontal Movement Parallel to the Wall	Absence of localized shear failure in the reinforced backfill.	Presence of localized shear failure in the reinforced backfill (permissible cracks < 0.25 inch).	Presence of localized shear failure in the reinforced backfill (wide cracks > 0.25 inch).
Localized Vertical Settlement	Negligible settlement.	Localized settlement within allowable limits (settlement < 2.0 inch).	Localized settlement exceeding allowable limits (settlement > 2.0 inch).
Shallow Surface Failure or Depressions near Top of Wall	Insignificant.	Moderate.	Significant.
Supplemental observations (recorded, not scored)			
Fences and Non-Traffic Barriers	Fence or non-traffic barrier is intact and plumb, with no significant damage, displacement, or corrosion.	Damage, displacement, or corrosion is present, but the element remains in place and functional.	Damaged, displaced, or missing sections that create a safety hazard.
General Erosion and Scour	No material loss at locations away from the foundation.	Localized material loss that does not expose reinforcement or reduce reinforcement cover.	Material loss that exposes reinforcement, reduces reinforcement cover, or affects safety features.

Category Descriptions – Metallic Components

Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are summarized in Table 68.

Reinforcement or Facing Displacement

This category captures failure of the connection between soil reinforcement and facing, or pullout of reinforcement, which directly threatens the internal stability of the MSE system.

- ***Field indicators –*** Look for evidence of connection rupture at the facing and for signs of reinforcement pullout such as facing separation or sudden bulging; much of this is inferred from facing behavior since the reinforcement is buried.

- ***Condition state note –*** This category has Good and Poor states only; a Marginal state is intentionally omitted.

- ***Cross-references –*** Distinguish this system-level connection/pullout failure from the unit-scale movement rated as Local Facing Displacement (Category 3).

Overall (Vertical and Horizontal) Alignment

Overall alignment measures global plumbness and line of the wall face; deviation reflects movement of the reinforced mass or foundation.

- ***Field indicators –*** Sight or string-line the face vertically and horizontally for bulges, leans, and dishing; note loose or detached units.

Local Facing Displacement

Local facing displacement captures movement of individual facing units relative to their neighbors, distinct from the global alignment of Category 2 and the connection failure of Category 1.

- ***Field indicators –*** Look for individual units that are offset, rotated, or protruding relative to adjacent units; measure the offset.

- ***Cross-references –*** See Category 1 for the distinction from connection/pullout failure.

Reinforcement or Connection Corrosion

Corrosion of metallic reinforcement or connections reduces tensile capacity over time and is a primary long-term durability concern for metallic-reinforced MSE walls. This rating reflects what is observable by external visual inspection. Unless exposure or instrumentation is available, it defaults to facing-connection and displacement evidence and does not by itself confirm the internal condition of the reinforcement.

- ***Field indicators –*** Look for rust staining on the facing, corrosion at exposed connections, and measurable section loss where reinforcement or hardware is visible; estimate the proportion of rusted surface.

- ***Condition state note –*** This category has Good and Poor states only; a Marginal state is intentionally omitted.

- ***Cross-references –*** **R**einforcement corrosion is a top-ranked MSE inspection concern despite being largely concealed; rust staining at the face is the primary surface cue (Kulesza, Parsons & Han, 2024).

Condition-State Narratives

Narratives corresponding to these categories are summarized in Table 68, which defines the Good, Marginal, and Poor states for each of the 4 Metallic Components categories.

Table 68. MSE Wall Metallic Components Condition-State Narratives

Category	Good	Marginal	Poor
Reinforcement or Facing Displacement	No facing connection rupture or reinforcement pullout.	Not defined; this category has Good and Poor states only (intentional).	Facing connection rupture or reinforcement pullout.
Overall (Vertical and Horizontal) Alignment	Negligible facing displacement and no loose or detached units.	Facing displacement within permissible limits.	Facing displacement beyond permissible limits, and/or presence of loose or detached units.
Local Facing Displacement	No displacement on the facing.	Displacement on the facing within permissible limits.	Excessive displacement on the facing.
Reinforcement or Connection Corrosion	No corrosion; no rust staining on the facing; no measurable section loss of reinforcement or connections.	Not defined; this category has Good and Poor states only (intentional).	Observable corrosion: rust staining on the facing, corrosion at exposed connections or reinforcement, or measurable section loss (10% or more rusted surface).

Category Descriptions – Drainage

Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are summarized in Table 69.

Soil Erosion

Erosion around the wall removes protective cover at the top, base, and wingwalls and can progress to undermine the structure.

- ***Field indicators –*** Look for rills and gullies at the top and base of the wall and along the wingwalls, particularly along concentrated flow paths.

Vegetation

Unintended vegetation in facing and construction joints can pry units apart, retain moisture, and obscure developing distress.

- ***Field indicators –*** Check facing and construction joints for plant growth; judge whether it is removable by routine maintenance or established enough to cause damage.

Drainage Systems (Surface and Subsurface)

Surface and subsurface drainage systems keep water out of the reinforced fill; their condition governs backfill saturation and reinforcement durability.

- ***Field indicators –*** Inspect ditches, pipes, weeps, and outlets for blockage, damage, and sediment; distinguish routine-maintenance problems from those requiring rehabilitation.

- ***Cross-references –*** Read together with Backfill Saturation (Wall System Component Distress, Category 10).

Water Accumulation (top of wall)

Ponding at the top of the wall drives infiltration into the retained and reinforced fill.

- ***Field indicators –*** Look for unintended standing water persisting after precipitation has ended, ponding scars, sediment deposits or staining, water-tolerant vegetation, and closed depressions with no positive outlet. Note whether the accumulation could be resolved by routine maintenance such as regrading or clearing an outlet, since that distinction separates the Marginal and Poor condition states in Table 69.

- ***Cross-references*** – Read together with Backfill Saturation (Wall System Component Distress, Category 10); ponding at the top of the wall is a common source of the infiltration rated there.

Water Accumulation (bottom of wall)

Unintended ponding at the base keeps the toe wet, promoting erosion and softening of the supporting ground.

- ***Field indicators –*** Look for unintended standing water and saturated ground at the base persisting after precipitation ends. Note sediment deposits, staining, water-tolerant vegetation, and softened or rutted ground. Check whether outlets are submerged, crushed, or blocked, and whether ponding is chronic. Note whether the accumulation could be resolved by routine maintenance, since that distinction separates the Marginal and Poor condition states in Table 69.

Condition-State Narratives

Narratives corresponding to these categories are summarized in Table 69, which defines the Good, Marginal, and Poor states for each of the 5 Drainage categories.

Table 69. MSE Wall Drainage Condition-State Narratives

Category	Good	Marginal	Poor
Soil Erosion	No erosion.	Minor surficial soil erosion at the top, base, or wingwalls that does not undermine the wall or expose the foundation.	Soil erosion at the top, base, or wingwalls that undermines the wall or exposes the foundation.
Vegetation	No unintended vegetation growth in facing and construction joints.	Unintended vegetation growth in facing and construction joints that can be addressed by routine maintenance.	Unintended vegetation growth in facing and construction joints that cannot be addressed by routine maintenance.
Drainage Systems (Surface and Subsurface)	No drainage problems.	Presence of drainage problems that can be addressed by routine maintenance.	Presence of drainage problems that cannot be addressed by routine maintenance.
Water Accumulation (top of wall)	No water accumulation at the top of the wall (for example, no water ponding).	Water accumulation at the top of the wall (for example, water ponding) that can be addressed by routine maintenance.	Water accumulation at the top of the wall (for example, water ponding) that cannot be addressed by routine maintenance.
Water Accumulation (bottom of wall)	No unintended water accumulation at the base of the wall (for example, no water ponding).	Unintended water accumulation at the base of the wall (for example, water ponding) that can be addressed by routine maintenance.	Unintended water accumulation at the base of the wall (for example, water ponding) that cannot be addressed by routine maintenance.

Scoring

Each category is rated Good (1), Marginal (2), or Poor (3), with Not Applicable excluded from the average. The category ratings within each group are averaged to produce three group performance ratings: Wall System Component Distress (13 categories), Metallic Components (4 categories), and Drainage (5 categories). The three group ratings are then combined into a single total performance rating using the relative weights from the Overall Rating sheet: Wall System Component Distress at a relative weight of 15, Metallic Components at 5, and Drainage at 10, for a total weight of 30 (Table 75). The total weighted rating is divided by the total weight to yield the total performance rating, which maps to the action bands in

Table 76. This combined total performance rating is the recommended family-level rating for an MSE wall and is reported above its three constituent group ratings.

Wall (Child Layer 4)

Wall survey consists of Wall Components, Drainage, and Summary along with image tables. The Wall Component has 9 questions designed to assess various factors contributing to the asset's condition, and the details of Wall Component for Wall are summarized in Table 70.

Table 70. Details of Wall Component for Wall

Question	Question Type	Field name in database	Esri Type
Build data (recorded, not scored)			
Wall Type / Facing Style	text	rw_wall_type	String
Scored wall component categories (9)			
Foundation	select_one	wc_foundation	String
Foundation Erosion and Scour	select_one	wc_ferosion_scour	String
Utilities	select_one	wc_util	String
Surface Distress	select_one	wc_sdistress	String
Barrier and Guard Rail	select_one	wc_barrier	String
Material Saturation	select_one	wc_matsat	String
Localized Horizontal Movement (cracks in wall/pavement) Parallel to the Wall	select_one	wc_lhm	String
Localized Vertical Movement (cracks in wall/pavement)	select_one	wc_lvm	String
Shallow Surface Failure/Depressions near Top of Wall	select_one	wc_surface_failure	String
General Comments	text	g4_w_comment	String

Figure 152 presents a screenshot of the Wall Components for Wall displayed on the webpage.

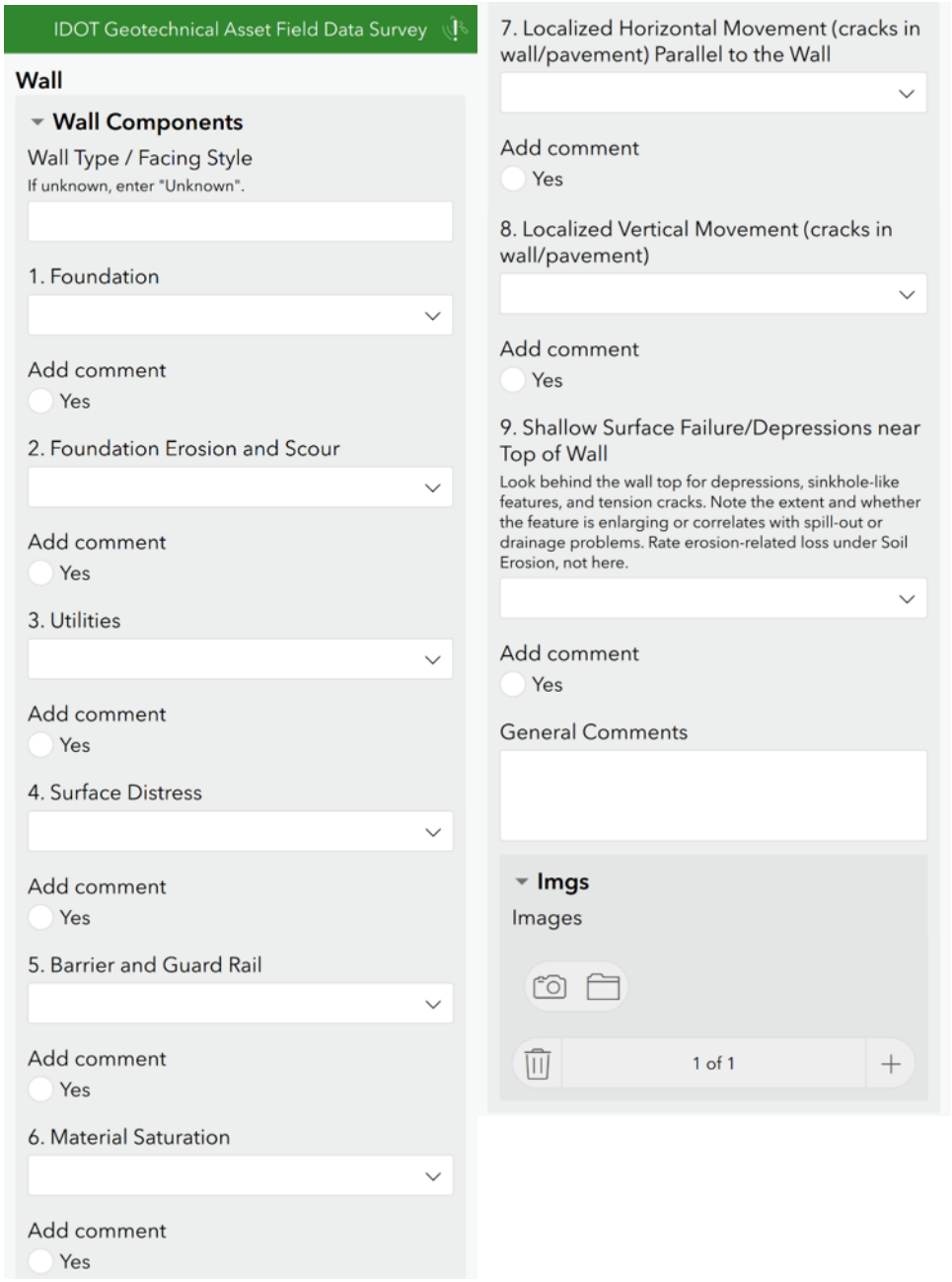


Figure 152. Screenshot. Wall Components for wall.

Follow these steps to complete the Wall Components:

- Choose observed condition of Foundation from the drop-down menu. The options include Good, Marginal, and Poor. Foundations refer to the geomaterials supporting the base of the wall.
- Choose observed condition of Foundation Erosion and Scour from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Utilities from the drop-down menu. The options include Good, Marginal, and Poor. If the inspector suspects that no utilities are present, leave the rating blank and add a note to the survey.

- Choose observed condition of Surface Distress from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition, related to movements or cracks, of Barrier and Guard Rail from the drop-down menu. The options include Good, Marginal, and Poor. Leave the field empty if there is no barrier or guard rail and add a note to the survey.

- Choose observed condition of Material Saturation from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Localized Horizontal Movement (cracks in wall/pavement) Parallel to the Wall from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Localized Vertical Movement (cracks in wall/pavement) from the drop-down menu. The options include Good, Marginal, and Poor.

- Choose observed condition of Shallow Surface Failure/Depressions near Top of Wall from the drop-down menu. The options include Good, Marginal, and Poor. These movements typically extend along the wall near the top of the facing.

- Type comment if any.

- Take a photo that can clearly show the current condition of asset. Ensure the photo captures key features relevant to the assessment. If needed, add multiple photos by clicking the ⊕ button.

The Drainage has 5 questions designed to assess various factors contributing to the asset's condition, and the details of Drainage for Wall are summarized in Table 71.

Table 71. Details of Drainage for Wall

Question	Question Type	Field name in database	Esri Type
Soil Erosion	select_one	wd_serosion	String
Vegetation	select_one	wd_vegetation	String
Drainage Systems (Surface and Subsurface)	select_one	wd_drainage	String
Water Accumulation (top of wall)	select_one	wd_wateracc_top	String
Water Accumulation (bottom)	select_one	wd_wateracc_bot	String
General Comments	text	g4_d_comment	String

Figure 153 presents a screenshot of the Drainage for Wall displayed on the webpage.

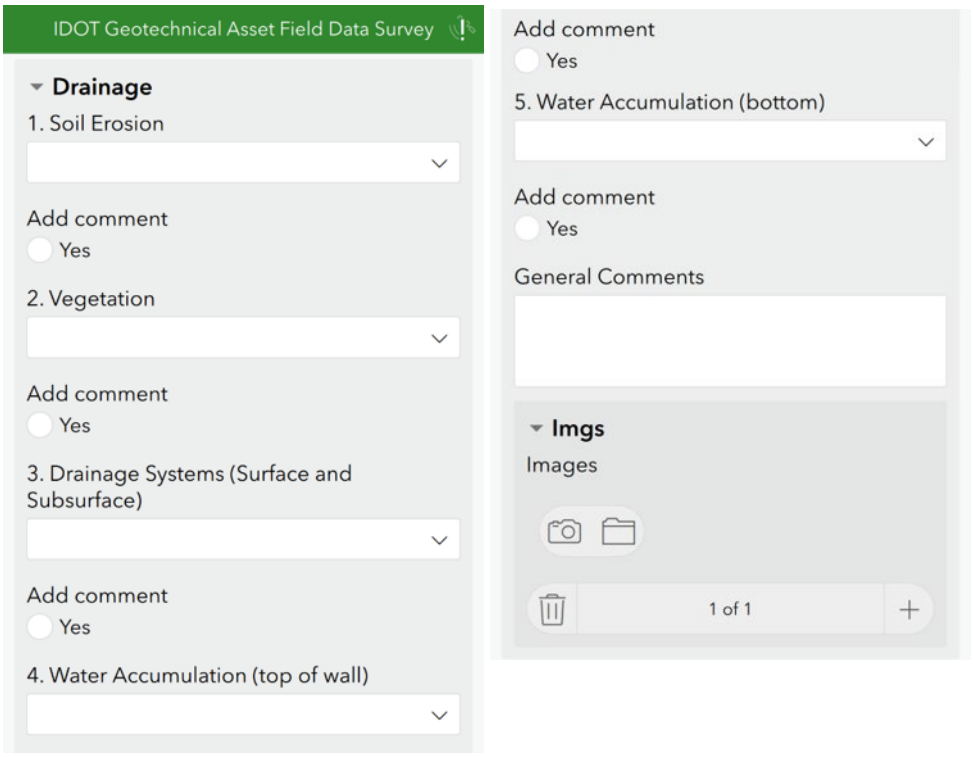


Figure 153. Screenshot. Drainage for wall.

Follow these steps to complete the Drainage:

- Choose observed condition of Soil Erosion from the drop-down menu. The options include Good, Marginal, and Poor.
- Choose observed condition of Vegetation from the drop-down menu. The options include Good, Marginal, and Poor. Where the slope above or below the wall is paved, hard armored, or covered with riprap rather than vegetated, select Not Applicable; the category rates vegetative cover, and Not Applicable is excluded from the group average. Record the surface type in the comment field, and rate the condition of the armored surface under Soil Erosion, including displaced or undersized stone, scour beneath the armor, and loss of the underlying material.
- Choose observed condition of Drainage Systems (Surface and Subsurface) from the drop-down menu. The options include Good, Marginal, and Poor.
- Choose observed condition of Water Accumulation (top) from the drop-down menu. The options include Good, Marginal, and Poor.
- Choose observed condition of Water Accumulation (bottom) from the drop-down menu. The options include Good, Marginal, and Poor.
- Type comment if any.

- Take a photo that can clearly show the current condition of the asset. Ensure the photo captures key features relevant to the assessment. If needed, add multiple photos by clicking the ⊕ button.

The Summary section reports the overall rating condition and value for Wall Components and for Drainage, followed by the Overall Rating group, which holds the relative weights and the Total Performance Rating. Each group also provides a Type Adjusted Overall Rating entry and a Select Overall Rating Type control, which allow the calculated value to be accepted or overridden; both are explained under Overall Rating Summary. Some of the fields recorded in this section are background calculations, including the group average and mode, that are stored with the record but are not displayed on the form. The complete set of fields for Summary for Wall is listed in Table 72.

Table 72. Details of Summary for Wall

Label	Question Type	Field name in database	Esri Type
Average value of Wall Components	calculate	wc_avg	Double
Condition of Wall Components	calculate	wc_avg_cond	String
Average value of Drainage	calculate	wd_avg	Double
Condition of Drainage	calculate	wd_avg_cond	String
Mode value of Wall Components	calculate	wc_mode	Double
Mode condition of Wall Components	calculate	wc_mode_cond	String
Mode value of Drainage	calculate	wd_mode	Double
Mode condition of Drainage	calculate	wd_mode_cond	String
Type Adjusted Overall Rating (Wall Components)	decimal	g4_w_ta_overall	Double
Select Overall Rating Type (Wall Components)	select_one	g4_w_overall	String
Overall Rating value (Wall Components)	calculate	g4_w_overall_val	Double
Overall Rating condition (Wall Components)	calculate	g4_w_overall_condition	String
Type Adjusted Overall Rating (Drainage)	decimal	g4_d_ta_overall	Double
Select Overall Rating Type (Drainage)	select_one	g4_d_overall	String
Overall Rating value (Drainage)	calculate	g4_d_overall_val	Double
Overall Rating condition (Drainage)	calculate	g4_d_overall_condition	String
Wall Components Relative Weight	decimal	g4_w_r_weight	Double
Drainage Relative Weight	decimal	g4_d_r_weight	Double
Total Performance Rating	calculate	g4_total_perform_rating	Double
Total Performance Condition	calculate	g4_total_perform_condition	String

Figure 154 presents a screenshot of the Summary Section as displayed on the webpage.

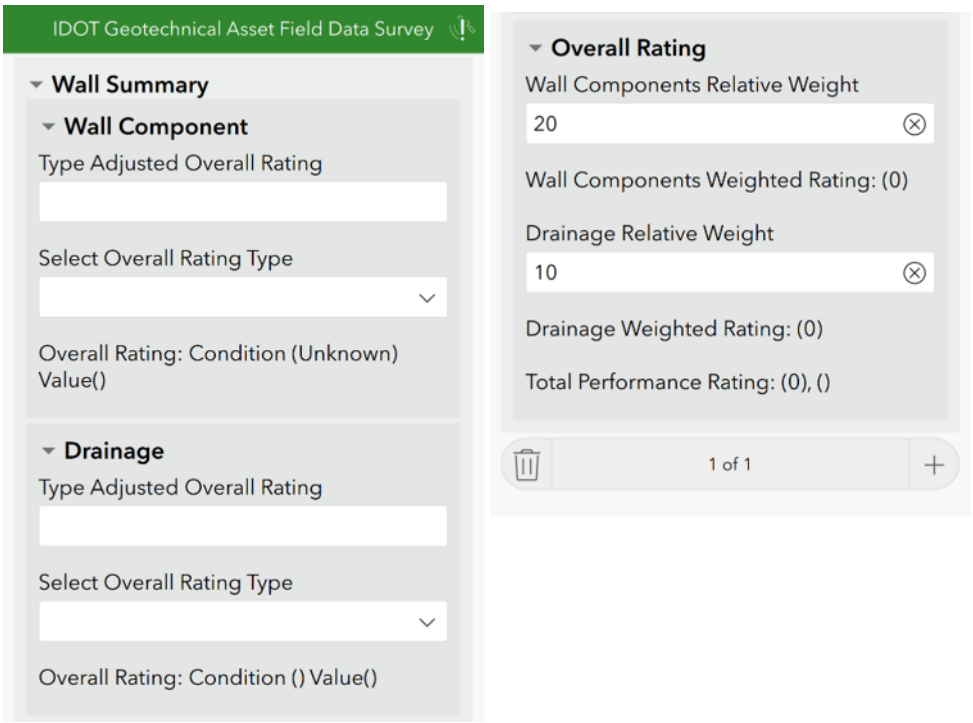


Figure 154. Screenshot. Summary for wall.

Summary section includes the following features:

- Display Wall Components condition.
- Display an average value of Wall Components.
- Display Drainage condition.
- Display an average value of Drainage.
- Display Overall Wall rating.

The generic Wall child layer documented above is rated in two groups: Wall Components (9 categories) and Drainage (5 categories). Table 73 and Table 74 summarize the Good/Marginal/Poor condition-state narratives from the Retaining Wall inspection form; the guidance that follows defines each category and the field indicators an inspector should use to select a state.

The generic Wall inspection form and the Survey123 Wall child layer contain no Metallic Components group; metallic reinforcement assessment is specific to MSE walls and appears only under the MSE Wall asset type. This is intentional. Generic retaining walls (for example, gravity, cantilever, and modular-block walls without metallic soil reinforcement) are rated on Wall Components and Drainage only.

Category Descriptions – Wall Components

Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are summarized in Table 73.

Build Data

Before rating condition, confirm the wall's basic build information. Recorded on page 2 of the General Information page (Asset Characteristics), and listed in Table 53, are maximum and typical exposed height. Recorded in this section is the wall type or facing style. Where a value cannot be determined in the field, enter Unknown. These fields support segmentation and normalize condition and risk across walls of different scale.

- ***Field indicators –*** Measure exposed height at the tallest point and at a representative typical section, and identify the wall type or facing style from field observation or available records.

Foundations

The foundation supports the retaining wall stem and any spread or pile footing. Foundation settlement or base cracking can rotate or translate the wall and compromise stability.

- ***Field indicators –*** Examine the wall base and adjacent grade for differential settlement and cracking; note that tolerable settlement varies with wall type and can differ longitudinally.

- ***Cross-references –*** Read with Localized Vertical Movement (Category 8).

Foundation Erosion and Scour

Erosion or scour at the wall base or front slope removes toe support and can undermine the footing.

- ***Field indicators –*** Look for undercutting, exposed footing, and loss of material at the base and along any fronting slope; note proximity to flow paths or waterways.

Utilities

Utilities crossing or bordering the wall can leak water into the retained soil and can act as indicators of wall movement. Broken or leaking storm sewers deserve particular attention as they can act as conduits that carry reinforced fill out of the wall, producing voids and surface depressions behind the wall before any distress becomes visible at the facing.

- ***Field indicators –*** Check for broken or leaking lines and tilted or deformed poles and masts; note leakage that could saturate the retained soil.

Surface Distress

Surface distress captures bulging, cracking, and displacement on the wall face, crest, or overlying pavement, reflecting stem distress or movement of the retained soil.

- ***Field indicators –*** Scan the wall face, crest, and pavement for bulges, cracks, and offsets; estimate crack widths and displacement where measurable.

Barrier and Guard Rail

Barriers and guardrails atop or beside the wall are movement indicators and safety appurtenances; their displacement can signal wall movement and reduce protective function.

- ***Field indicators –*** Sight along the rail or barrier for offsets, rotation, and cracking; note displacement large enough to impair performance.

Material Saturation

Saturation of the retained soil raises lateral earth pressures and pore pressures behind the wall, a common driver of wall distress.

- ***Field indicators –*** Judge moisture from seepage at the face and weeps, staining, and damp ground behind the wall; assess after a wet period where practical.

- ***Condition state note –*** *Material saturation is not always readily assessed by external visual inspection. Saturation* should be judged based on external indicators to the extent achievable by the inspector with comments added if the rating is of low confidence.

- ***Cross-references –*** Read together with the Drainage group. See Appendix C, Slope Drainage guidance for analogous field cues.

Localized Horizontal Movement Parallel to the Wall

Cracks parallel to the wall in the wall or pavement indicate localized shear behind the wall, an early sign of instability.

- ***Field indicators –*** Trace cracks paralleling the wall across the pavement and retained-soil surface; measure width and note offset.

Localized Vertical Movement

Localized vertical movement captures settlement expressed as vertical offset at cracks in the wall or pavement, distinct from the parallel shear cracks of Category 7.

- ***Field indicators –*** Measure vertical offset at cracks and joints on the wall crest and pavement; distinguish uniform from differential settlement.

- ***Cross-references –*** Read with Foundations (Category 1).

Shallow Surface Failure or Depressions near Top of Wall

Depressions and shallow failures behind the wall top indicate void development or internal erosion in the retained soil.

- ***Field indicators –*** Look behind the wall top for depressions, sinkhole-like features, and tension cracks; note extent and any correlation with drainage problems.

Condition-State Narratives

Narratives corresponding to these categories are summarized in Table 73, which defines the Good, Marginal, and Poor states for each of the 9 Wall Component categories.

Table 73. Wall Components Condition-State Narratives

Category	Good	Marginal	Poor
Foundations	Negligible local or differential settlement near the wall base.	Local or differential settlement within permissible and tolerable limits (settlement can vary longitudinally between 1 in and 4 in depending on the wall type).	Local or differential settlement exceeding permissible or tolerable limits, and/or cracks at the wall base.
Foundation Erosion and Scour	Insignificant erosion along the slope or at the wall base.	Moderate erosion along the slope or at the wall base that does not undermine the foundation.	Significant erosion undermining the wall base or foundation; or scour at the base of water-crossing walls.
Utilities	No observable broken utility lines, no utility pipe leakage, and no damage or significant tilt to surrounding utility poles or masts.	Moderate movement or deformation of utility lines, utility poles, or masts.	Observable broken utility lines, utility pipe leakage, or significant damage or deformation to utility poles or masts.
Surface Distress	No bulging or displacements along the wall face or at the embankment crest or pavement surface.	Moderate cracks or displacements along the wall face or at the embankment crest or pavement surface.	Significant bulging or excessive cracks or displacements along the wall face or at the embankment crest or pavement surface.
Barrier and Guard Rail	Insignificant barrier or guard rail displacement or cracks.	Permissible barrier or guard rail displacement or cracks.	Offset or displacement of barrier or guard rail that can affect performance.
Material Saturation	Almost dry or dry.	Moist.	Almost saturated or saturated.
Localized Horizontal Movement Parallel to the Wall	Absence of localized shear failure in the wall.	Presence of localized shear failure in the wall (permissible cracks < 1.0 inch).	Presence of localized shear failure in the wall (wide cracks > 1.0 inch).
Localized Vertical Movement (movements at shorter segments and not the full wall)	Negligible settlement.	Localized settlement within allowable limits (settlement < 1.0 inch).	Localized settlement exceeding allowable limits (settlement > 1.0 inch).
Shallow Surface Failure or Depressions near Top of Wall (movements near the surface and no deep movements)	Insignificant.	Moderate.	Significant.

Category Descriptions – Drainage

Each category is presented below in two parts: a description defining the component and the field indicators used to assess it, followed by the condition-state narratives that specify its Good, Marginal, and Poor states. The narratives are summarized in Table 74.

Soil Erosion

Surface soil erosion within the drainage envelope removes cover at the base and crest and can progress toward the wall.

- ***Field indicators –*** Look for rills and gullies at the base and crest of the wall along concentrated flow paths.

- ***Condition state note –*** A Marginal state applies where minor surficial soil erosion is present at the base or crest of the wall but does not undermine the wall or expose the foundation. Poor is reserved for erosion that undermines the wall or exposes the foundation.

Vegetation

Vegetative cover on the slopes above or below the wall protects against surface erosion; its condition indirectly reflects drainage performance.

- ***Field indicators –*** Assess cover continuity on slopes above and below the wall, noting barren patches and unusually vigorous growth that may signal seepage.

Drainage Systems (Surface and Subsurface)

Surface and subsurface drainage systems keep water away from the retained soil; their condition governs material saturation behind the wall.

- ***Field indicators –*** Inspect ditches, weeps, pipes, and outlets for blockage, damage, and sediment; distinguish routine-maintenance problems from those requiring rehabilitation.

- ***Cross-references –*** Read together with Material Saturation (Wall Components, Category 6).

Water Accumulation (top of wall)

Ponding at the top of the wall drives infiltration into the retained soil.

Field indicators – Look for unintended standing water persisting after precipitation has ended, ponding scars, sediment deposits or staining, water-tolerant vegetation, and closed depressions with no positive outlet. Note whether the accumulation could be resolved by routine maintenance such as regrading or clearing an outlet, since that distinction separates the Marginal and Poor condition states in Table 74.

- ***Cross-references*** – Read together with Material Saturation (Wall Components, Category 6); ponding at the top of the wall is a common source of the infiltration rated there.

Water Accumulation (bottom of wall)

Ponding at the base of the wall keeps the toe wet, promoting erosion and softening of the supporting ground.

Field indicators – Look for unintended standing water and saturated ground at the base persisting after precipitation ends. Note sediment deposits, staining, water-tolerant vegetation, and softened or rutted ground. Check whether outlets are submerged, crushed, or blocked, and whether ponding is chronic. Note whether the accumulation could be resolved by routine maintenance, since that distinction separates the Marginal and Poor condition states in Table 74.

Condition-State Narratives

Narratives corresponding to these categories are summarized in Table 74, which defines the Good, Marginal, and Poor states for each of the 5 Drainage categories.

Table 74. Wall Drainage Condition-State Narratives

Category	Good	Marginal	Poor
Soil Erosion	No erosion.	Minor surficial soil erosion at the base or crest of the wall that does not undermine the wall or expose the foundation.	Soil erosion at the base or crest of the wall that undermines the wall or exposes the foundation.
Vegetation	Vegetation growth is consistent and lush along the side slopes above or below the wall.	Vegetation growth is generally intact with several barren patches along the slopes above or below the wall.	Vegetation growth is inconsistent along the slopes above or below the wall.
Drainage Systems (Surface and Subsurface)	No surface or subsurface drainage problems.	Presence of surface and subsurface drainage problems that can be addressed by routine maintenance.	Presence of surface and subsurface drainage problems that cannot be addressed by routine maintenance.
Water Accumulation (top of wall)	No water accumulation at the top of the wall (for example, no water ponding).	Water accumulation at the top of the wall (for example, water ponding) that can be addressed by routine maintenance.	Water accumulation at the top of the wall (for example, water ponding) that cannot be addressed by routine maintenance.
Water Accumulation (bottom of wall)	No water accumulation at the base of the wall (for example, no water ponding).	Water accumulation at the base of the wall (for example, water ponding) that can be addressed by routine maintenance.	Water accumulation at the base of the wall (for example, water ponding) that cannot be addressed by routine maintenance.

Scoring

Each category is rated Good (1), Marginal (2), or Poor (3), with Not Applicable excluded from the average. The category ratings within a group are averaged to produce the group performance rating: one for Wall Components and one for Drainage. The group ratings are then combined into a total performance rating using the relative weights from the Overall Rating sheet (Wall Components at a relative weight of 20, Drainage at a relative weight of 10; total weight 30; Table 75). The total weighted rating is divided by the total weight to yield the total performance rating, which maps to the action bands in Table 76.

Overall Rating Summary

The three Good/Marginal/Poor asset types (Slope/Embankment, MSE Wall, and Wall) share the same roll-up logic. Category ratings are averaged within each group, group ratings are weighted and combined per Table 75, and the resulting total performance rating maps to the action bands in Table 76.

The action bands and their inspection and rehabilitation timelines are identical across the three inspection forms; the band descriptions below use "asset" where the forms say "Slope" or "Wall." Rock slopes follow the separate RHRS and Condition State scoring in Appendix C.

Each group summary offers two ways to set the group performance rating, governed by the Select Overall Rating Type control. Average, the default, carries the arithmetic mean of the scored categories through to the group rating. Adjusted Overall Rating instead uses the value entered in the Type Adjusted Overall Rating field; the calculated average remains displayed for reference but no longer drives the rating.

The override exists because an arithmetic mean can understate a condition governed by a single severe distress. A group of otherwise sound categories containing one Poor rating averages to Good or Marginal, which may not reflect the condition of the asset. Where the calculated value does not represent what was observed, the inspector selects Adjusted Overall Rating, enters the rating that does, and records the basis in the group comment field. The adjusted value should be supported by the observations and photographs recorded elsewhere in the form.

Two behaviors are worth noting. A value entered in Type Adjusted Overall Rating has no effect unless Adjusted Overall Rating is also selected, and selecting Adjusted Overall Rating without entering a value leaves the group rating blank. Inspectors who intend to accept the calculated result should leave the control set to Average and leave the adjusted field empty.

The available rating types differ by asset family. Slope and embankment summaries offer Average and Adjusted Overall Rating. Retaining wall summaries add Case 1, and MSE wall summaries add Case 1 and Case 2. Selecting a Case forces a group rating of 3 (Poor) and mandates a follow-up invasive investigation; the Cases are reserved for the specific conditions defined in the inspection workbooks and are not a general-purpose override.

Table 75. Group Relative Weights by Asset Type (from the Overall Rating Sheets)

Asset Type	Group	Relative Weight
Slope/Embankment	Slope/Embankment Components	20
Slope/Embankment	Drainage	10
Slope/Embankment	Total weight	30
MSE Wall	Wall System Component Distress	15
MSE Wall	Metallic Components	5
MSE Wall	Drainage	10
MSE Wall	Total weight	30
Wall	Wall Components	20
Wall	Drainage	10
Wall	Total weight	30

Table 76. Total Performance Rating Action Bands (All Good/Marginal/Poor Asset Types)

Total Performance Rating	Descriptor	Description and Action
< 1.5	Very Good	Asset is safe; no action needed; schedule field assessment in 5 years.
1.5 to 2.0	Good	Asset is safe; routine maintenance may be needed; schedule condition assessment in 5 years.
2.0 to 2.5	Marginal	Asset may be safe but requires field inspection (performance state assessment) within 3 years to verify condition.
2.5 to 2.75	Poor	Asset may be potentially unsafe and may require immediate replacement or rehabilitation.
> 2.75	Very Poor	Asset is unsafe and likely requires immediate replacement or rehabilitation.

Asset Segmentation Break Points

To prevent over-smoothing of condition and risk along long or variable assets, inspectors should segment assets at natural break points. General triggers include maximum asset length and changes in exposed height; for soil slopes and embankments, a change to steeper than 2:1 inclination and exposed heights above about 15 feet; for retaining and MSE walls, exposed heights above about 8 feet.


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