

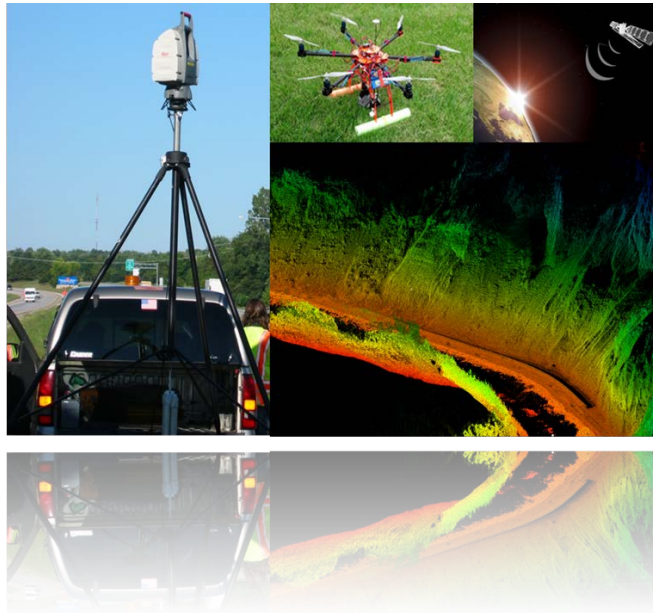
Deliverable 1-A: Requirements for Remote Sensing Based Geotechnical Asset Management System including Types of Geotechnical Assets and their Conditions that need to be assessed in Different Transportation Environments

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GLOSSARY OF TERMS

| | |
|------------|--|
| AASHTO | American Association of State Highway and Transportation Officials |
| CASE | the Connecticut Academy of Science and Engineering |
| DEM | Digital Elevation Model |
| DOPM | Division of Organizational Performance Management |
| DOT | Department of Transportation |
| ENVISAT | Environmental Satellite |
| ERS-1 | European Remote Sensing Satellite 1 |
| ERS-2 | European Remote Sensing Satellite 2 |
| FHWA | Federal Highway Association |
| GAM | Geotechnical Asset Management |
| GIS | Geographic Information Systems |
| InSAR | Interferometric Synthetic Aperture Radar |
| IRB | Internal Review Board |
| LiDAR | Light Detection and Ranging |
| LOS | Level of Service |
| MnDOT | Minnesota Department of Transportation |
| NPS | National Parks Service |
| PCI | Pavement Condition Index |
| RADARSAT-1 | Radar Satellite 1 |
| TAM | Transportation Asset Management |
| TRB | Transportation Research Board |
| SDOT | Seattle Department of Transportation |
| UKDT | United Kingdom Department of Transport |
| WIP | Wall Inventory and Assessment Program |

1. EXECUTIVE SUMMARY: DELIVERABLE 1-A

Requirements for remote sensing based geotechnical asset management system including types of geotechnical assets and their conditions that need to be assessed in different transportation environments

This deliverable 1-A describes the national survey of state and city DOTs, railway operators, and pipeline owners conducted as part of the “Sustainable geotechnical asset management along the transportation infrastructure environment using remote sensing” project under a cooperative agreement, RITARS-14-H-MTU, between Michigan Technological University and the USDOT Office of the Assistant Secretary for Research and Technology (USDOT- OST-R).

The objective of this survey was to gather information on the needs of the users and the intended use of the geotechnical asset management system, types and conditions of geotechnical assets that need to be managed, concepts and constraints of operation, requirements of performance, and needs for database and visualization of results. This survey was critical because there have been no previous official national survey of the transportation agencies to understand the needs of the geotechnical asset management in different transportation environments. The survey was implemented online and 710 individuals were invited to participate in the survey via email messages sent to the addresses compiled in the database. After ca. 2 months from the invitation date, 99 individuals had answered the survey. The survey response rate is well within the national average for online surveys. Approximately, 30% of the respondents have indicated their interest to participate in follow up survey on this topic.

Asset inventory is the foundational block of any asset management system. The majority of the survey respondents indicated that their agency had some inventory of the different geotechnical assets. This indicates that a good number of these agencies are at a mature enough state to either develop an asset management system for geotechnical assets, or may already have one in place. The concept of asset management implies a focus on preventive and proactive action, shifting away from the traditional approach of focusing on only the urgent cases. However, more than half of the respondents indicated that the inspection and maintenance of geotechnical assets was only done when the assets were already damaged or failure was imminent. A large number of respondents indicated that their current method of data collection and analysis are subjective using traditional manual inspections with a majority indicating that the lack of resources is the biggest limitation for asset monitoring. Therefore, developing economically sustainable techniques for asset monitoring and objective decision support systems will be critical for geotechnical asset management along the transportation infrastructure environment.

Acknowledgements

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2. Introduction

The purpose of asset management is to achieve and maintain performance goals over the lifespan of all direct/indirect assets within the transportation environment. Measurable performance goals include safety, mobility, preservation, environmental impacts, and financial/economic aspects. Normally, geotechnical assets within the transportation environment have not received much attention (Sanford Bernhardt, 2003; Stanley & Pierson, 2013). The typical approach to dealing with geotechnical assets has been to repair or reconstruct the asset after it has reached a very poor condition or has completely failed – both of these scenarios negatively impact all the performance goals. Therefore, developing a cost-effective and sustainable Geotechnical Asset Management (GAM) system that can be used by State Department of Transportations (DOTs) and other transportation agencies would be highly beneficial.

The objective of this document is five-fold: (1) to define the term *geotechnical assets* and discuss how asset conditions are assessed; (2) to describe the difference between a GAM and a transportation asset management (TAM) system; (3) to discuss how geotechnical assets fit into an asset management framework and the challenges that are involved; (4) to show the responses from State DOTs and other transportation agencies to a survey, illustrating the current status of GAM in public and private organizations across the country; and (5) to briefly describe how specific remote sensing techniques may allow for successful performance goal accomplishment.

3. Geotechnical Assets

3.1 Definition and Classification

Any transportation infrastructure is composed of many transportation assets such as pavements, bridges, retaining walls, culverts, roadside embankment, and slopes, among others. In order to create and effectively manage these assets, it is important to define and classify the assets based on their design and function. In this study a geotechnical asset will be considered as part of a transportation corridor comprised largely of soil or rock including the soil and bedrock foundation upon which all transportation corridor structures are built (Anderson & Rivers, 2013). However, this is not an easy task since many of these assets have a direct or indirect relation with other assets. An example of this is a structural asset, such as a retaining wall that has been designed and perhaps maintained by structural engineers, has a direct relationship with a geotechnical asset because of its foundation. This creates an unclear boundary between geotechnical assets and other types of assets (Sanford Bernhardt et al. 2003).

In an effort to come up with an effective classification of geotechnical assets, the assets will be classified in terms of their function such as Sanford Bernhardt et al. (2003) have proposed. The function of a geotechnical asset will be classified based on how much it interacts with other assets. An “exclusively geotechnical” asset does not have a direct interaction with other assets, such as a roadside embankment. A retaining wall can be considered “partially geotechnical” based on its direct interaction with its foundation. A “minimally geotechnical” asset example is a pavement subgrade which is the foundation for a pavement but requires little to no geotechnical engineering design and/or maintenance. Since then, additional geotechnical assets have also been identified, including subgrade and land within the right-of-way, buried reinforcing elements, rock bolts, tieback anchors, quarry sites, and horizontal drains, to name a

few (UKDT, 2003; Stanley & Pierson, 2011). In fact, it becomes incredibly difficult to identify all geotechnical assets. Thus, a general term for a geotechnical asset, such as part of a transportation environment "...made up largely of soil or rock or another improvement that has direct bearing on soil or rock performance or influence over the effects of their performance" (Anderson & Rivers, 2013, p 9) may be the safest approach.

Table 1 shows the most common geotechnical assets and their classification based on their function.

Table 1: Listing of geotechnical assets by function (exclusively, partially, and minimally geotechnical). Source: Sanford Bernhardt et al. (2003).

| Asset function category | Interaction with other assets | Asset | Purpose | Performance objectives |
|--------------------------|-------------------------------|--|---|---|
| Exclusively geotechnical | Indirect | Embankments and slopes | To provide for gradual grade changes in vertical alignment | Provide satisfactory support for roadway without intruding on pavement or other transportation structures |
| Partially geotechnical | Direct | Tunnels and earth retaining structures | To retain earthen materials so that highway can be constructed in restricted right-of-way | Satisfactorily retain earthen materials to prevent intrusion or damage to highway structures |
| | | Culverts and drainage channels | To provide control of surface waters | Prevent accumulation of water on pavement and prevent damage to highway structures from erosion |
| | | Foundations | To transmit structural loads to supporting ground | Satisfactorily support structure without excessive deformations |
| Minimally geotechnical | Direct | Pavement subgrade | To serve as foundation for pavement | Satisfactorily support pavement without damaging or reducing the life of the pavement |

3.2 Geotechnical Asset Condition Assessment

Condition assessment is an essential step for an effective management system. The condition assessment is tangible evidence of current asset condition and performance measure. Condition and performance characteristics include but are not limited-to physical condition and cost.

Currently some of the condition assessment procedures used by transportation agencies include the use of inclinometers to measure displacement on retaining walls, also traditional surveys are used to measure movements along slopes and embankments. These methods are very expensive and very labor intensive.

Because of this, very few formal geotechnical asset condition assessment plans are in place for a specific asset. Among the few geotechnical asset condition assessment plans in place, the National Park Service (NPS) has a Wall Inventory and Assessment Program (WIP) for retaining walls in the national parks. The NPS WIP is developed in four steps which are the following: (1) Definition of acceptance criteria for retaining wall inclusion within the inventory program. (2) Definition of approximately 65 wall attributes that are logged, measured, calculated or assessed during field inventories. (3) Development of field data collection procedures, field forms, and associated field guides and cost information. (4) Development of Microsoft Access-based, fully searchable WIP database (DeMarco et al., 2010).

Based on the NPS WIP and a similar program in the City of Cincinnati, Anderson et al. (2008) suggests that the conceptual objective of condition assessment of an asset should capture three broad categories of information (Table 2). The first category should collect static data that describes the asset (i.e. retaining wall) in specific attributes. The second category is condition data collected and used to determine wall ratings prioritization of needs. Last the data should be collected multi-temporal to allow for rate of change detection. A conceptual rating and prioritization system for retaining walls is shown in the following figure. A similar concept can be applied to other geotechnical assets.

Table 2: An example of a condition assessment and reliability rating system from Anderson et al. (2008) for a geotechnical asset.

| | Condition Rating | | | Reliability Factored Rating | |
|--------------------------------------|--------------------------------|-----------------|-------------------------|-----------------------------|-------------|
| | | Input Required | | Input Required | |
| Category | Technical Significance | Condition Score | Cat. Rating | Data Reliability | Cat. Rating |
| <i>Maximum Value</i> | <i>10</i> | <i>10</i> | | <i>10</i> | |
| Performance | 6 | 10 | 60 | 3 | 180 |
| Remaining Age | 4 | 10 | 40 | 9 | 360 |
| Ductility | 2 | 5 | 10 | 9 | 90 |
| Wall Element 1 (Code #) | 7 | 4 | 28 | 9 | 252 |
| Wall Element 2 (Code #) | 4 | 4 | 16 | 9 | 144 |
| Wall Element 3 (Code #) | 2 | 4 | 8 | 9 | 72 |
| Adj. Element 1 (Code #) | 4 | 2 | 8 | 9 | 72 |
| Adj. Element 2 (Code #) | 2 | 2 | 4 | 9 | 36 |
| Adj. Element 3 (Code #) | 1 | 2 | 2 | 9 | 18 |
| APPRAISAL 8 (out of 10) | (APPRAISAL not used in rating) | | TOTAL: | RATING CERTAINTY: | 1224 |
| | | | MAXIMUM POSSIBLE SCORE: | 70 | 3200 |
| | | | RATING: | 55 | 38 |

3.3 Transportation Environments

There are three main transportation environments with geotechnical assets: highways, railways, and pipelines. Each environment has different guidelines and policies for geotechnical asset design and maintenance. This is important when considering geotechnical asset condition assessment, because an asset with acceptable performance characteristics in the railway environment might not necessarily be acceptable in the highway environment.

Highways include geotechnical assets such as foundations for any of the infrastructure, embankments, slopes, culverts and drainage channels, tunnels, earth retaining structures, and pavement subgrade. Some of the geotechnical assets in railway may include subsoil, track foundation, which includes the subgrade, sub-ballast and ballast, culverts, drainage ditches, slopes, embankments, tunnels, and any foundation for railway infrastructure. Geotechnical assets along a pipeline environment include any foundation that supports the pipeline, slopes, and embankments.

4. Transportation Asset Management

The term *transportation asset management* (TAM) is used when discussing the general installation, operation, maintenance, and upgrading of current assets that are located within transportation environments. According to the American Association of State Highway and Transportation Officials (AASHTO), TAM is defined as “a strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively throughout their lifecycle.” (p 3, AASHTO, 2013). The overall purpose of TAM is to generate a cost-effective, intelligent, and efficient system that is able to manage all assets, at all life-cycle points (from brand new to deteriorating), within any transportation environment with, preferably, as little impact to the public as possible.

TAM has become a popular topic within many agencies on all levels, beginning especially in the late 1990s. At the federal level, organizations such as the Federal Highway Administration (FHWA, established in 1999), AASHTO, and the Transportation Research Board (TRB) are at the forefront of nation-wide asset management. Many State DOTs are also focusing on TAM. For example, the Michigan DOT has a Transportation Asset Management Council whose tasks are to (1) collect condition information on road and bridges, (2) collect asset investment data, and (3) report data and analyses to the state legislature. Other state-wide programs exist in Colorado, Connecticut (CASE, 2008), Florida, Georgia (DOPM, 2011), Indiana, Minnesota, Missouri, Montana, New Jersey, North Carolina, Oregon, Pennsylvania, Utah, Virginia, and Washington (Lindquist & Wendt, 2012). TAM has become a vital part of county- and city-wide transportation planning as well. Regional entities such as Cole County, Missouri and the South East Michigan Council of Governments; cities such as Seattle (SDOT, 2010), Cincinnati, and Portland are utilizing and deploying TAM as a foundation of transportation plans (Lindquist & Wendt, 2012).

Many asset subcategories exist within the TAM framework, including pavement asset management, bridge asset management, transit asset management, and geotechnical asset management (GAM). The categorization of assets within subcategories is difficult at best, as discussed by Sanford Bernhardt et al. (2003) when they claim that “all of these transportation assets [pavements, bridges, and railway track] rest (literally) on geotechnical assets” (p 107). The authors proceed to create three geotechnical asset subcategories, and then list the assets that belong (see Section 3.1 and Table 1). By definition, GAM aims to manage the installation, operation, maintenance, and upgrade of these geotechnical assets.

4.1 Asset Management Framework

A GAM approach is similar in set-up and function to a TAM approach, with the exception of the asset-specific variables included. The asset management framework is composed of four key workflow elements, described here for geotechnical assets, but is applicable to any type of asset.

The first element is the initial assessing of the current state and condition of the asset. Current management practices have mostly focused on geotechnical asset remediation and repair, as opposed to mitigation and prevention. Many agencies lack an efficient and effective way of assessing the current state of assets. A good first step is to create a geotechnical asset inventory, within each transportation environment, that includes as many relevant variables. For example, DeMarco et al (2010) created a geotechnical asset inventory, which was completed on-site, for

retaining walls that included wall location data, wall description data, wall condition assessment, wall action assessment, and work order development. A well-developed inventory creates the foundation for the asset management framework.

The second element is the defining of the level of service (LOS) required for the asset and the expected performance delivery of the transportation environment. The LOS is defined as the amount of repair, both in time and cost figures, required to upgrade the current status of the asset to an expected performance level. This repair should increase the condition quality of the asset to an acceptable level and, ideally, a configuration of a future LOS plan would be beneficial as well (e.g., answering questions such as: How often would repairs need to be made on this geotechnical asset? What are the acceptable quality thresholds for each geotechnical asset type?).

The third element is the identification of the assets that are critical to the performance within the transportation environment. Determining the most critical geotechnical assets within the transportation corridor allows for a focused priority system to address any asset repairs or mitigation steps that need to be taken. This element is the transitory step within the framework: it utilizes the data from the previous elements to form a type of ‘work order’ for the geotechnical assets, by prioritizing them based on their current condition, level of service, expected performance delivery, and ranking them on how critical each one is within the transportation environment. Of course, to transition to the actual strategies listed in the fourth element, some sort of GAM system must be created in order to choose the geotechnical assets that need to be repaired or preserved.

The fourth element includes the financial investment strategies for the operation, maintenance, and improvement of each geotechnical asset within the transportation corridor. This is by far the grandest and most challenging element of the framework, as it requires a plan of action for immediate steps that need to be taken, but also a timeline of geotechnical asset maintenance and upgrades that spans a relevant amount of time.

The FHWA released their version of the TAM framework (Figure 1), which basically is a more in-depth version of the four elements listed above (FHWA, 2000).

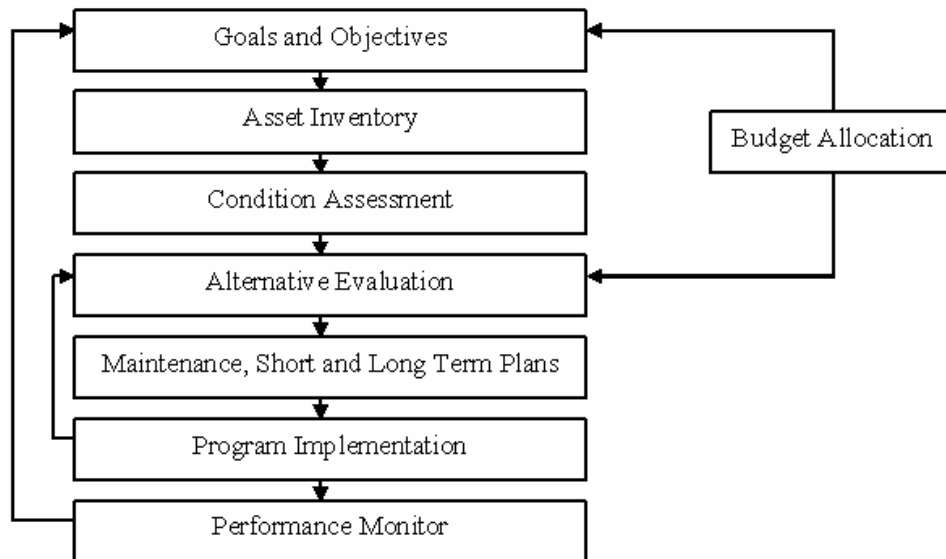


Figure 1: *The FHWA (2000) TAM framework.*

4.2 Challenges

There exist challenges in each of the four elements within the asset management framework that need to be addressed. These challenges are wide-spread GAM problems that will need to be addressed by the greater scientific research and development community, but an understanding of some GAM implementation limitations is helpful.

A major challenge for the first element is figuring out the actual logistics behind acquiring geotechnical asset data relevant to the creation of an effective inventory. What is the most efficient and cost-effective method of acquiring the data required? Ground reconnaissance in the field is a necessary first step, but a method to develop a robust record keeping system to avoid repeated visits to the geotechnical assets is important. Therefore, a detailed literature review and variable analysis on each geotechnical asset is vital prior to field excursions.

The second element poses mainly challenges to DOTs and other transportation agencies. Since GAM is a relatively new concept, many organizations are currently grappling with this framework element, mainly the development of quality expected performance delivery measures (Anderson & Rivers, 2013; Badger et al., 2013). Four challenges are described in the following paragraphs.

The first challenge encompasses the lack of a non-subjective qualitative/quantitative scale or index for measuring geotechnical asset conditions or performance. This problem can be summed up with the following two questions: (1) Can there be a universally accepted rating scale, or better yet purely quantitative method, to be used in a GAM system for condition and/or performance measures? (2) Does each type of geotechnical asset require a separate rating scale? There already exist subjectively quantitative measures for other assets (Table 3) – for example, the pavement condition index (Anderson & Rivers, 2013) and the basic-advanced condition assessment for drainage infrastructure and culverts (Najafi et al., 2008). These types of indices attempt to be quantitative – the conditions are usually rated on a slide scale, such as 1-5 or 0-100 – but the ratings are subjective and dependent on the person in the field performing these observations. Although similar rating scales and indices exist for non-geotechnical assets, it almost seems obvious that such rating systems cannot be used for geotechnical assets. Therefore, it would seem a condition index for slopes would differ from that for bridges, tunnels, culverts, and most other types of assets.

Table 3: *Example of four different condition indices (Stanley & Pierson, 2013).*

| Descriptive State | FHWA Nat Bridge Insp Condition Rating | Corps of Engineers REMR | Navy BASEREP Conformance with Mission Demands | Pavement Condition Index |
|---------------------|---------------------------------------|-------------------------|---|--------------------------|
| New | 7-9 | 70-100 | C1 - Fully Met | 100-70 |
| Minor Deterioration | 4-6 | 40-69 | C2 - Substantially Met | 69-40 |
| Major Deterioration | 3 | 25-39 | C3 - Marginally Met | 39-0 |
| Failure | 0-2 | 0-24 | C4 - Not Met | |

A second challenge arises in the attempt to project the expected performance delivery of a geotechnical asset. Anderson & Rivers (2013) describe the status of this challenge with a series of relevant examples: “[T]he expectation of the frequency of rockfall from a rock cut, the long-term settlement of a bridge approach, movement of an anchored wall, or corrosion of steel reinforcements in mechanically stabilized earth...” (p 13) all illustrate the vast amounts of data required to understand how difficult it is to accurately project asset performance. Fortunately, there is ongoing research and development with regards to acceptable life-cycle performance levels for geotechnical assets and what minimum standards should be expected.

The third challenge is closely related to the previous challenge. Currently, performance delivery metrics for long time periods is underdeveloped. This is mainly due to the lack of historical data on asset repair effectiveness and the life expectancy of such a repair (Badger et al., 2013). With a lack of sufficient temporal data, it is difficult to project the performance of geotechnical assets into the future.

The fourth challenge also incorporates the differences between geotechnical assets and other assets. Deterioration curves are commonly used when attempting to quantify the decrease in condition quality of an asset. A typical deterioration curve plots the condition of the asset (either on a numerical scale or with terms ranging from ‘excellent’ to ‘very poor or failed’) versus the general lifespan of that asset (Figure 2). These curves are generated from mathematical models based on field observations of the asset conditions over time. But can you apply the deterioration curve of one asset to another asset? This is a specific interesting question for geotechnical assets, which have not been observed as in detail as other assets, and which act differently than other assets (e.g., one would surmise the deterioration curve of an embankment differs from that of pavement – see Figure 3 for graphical example).

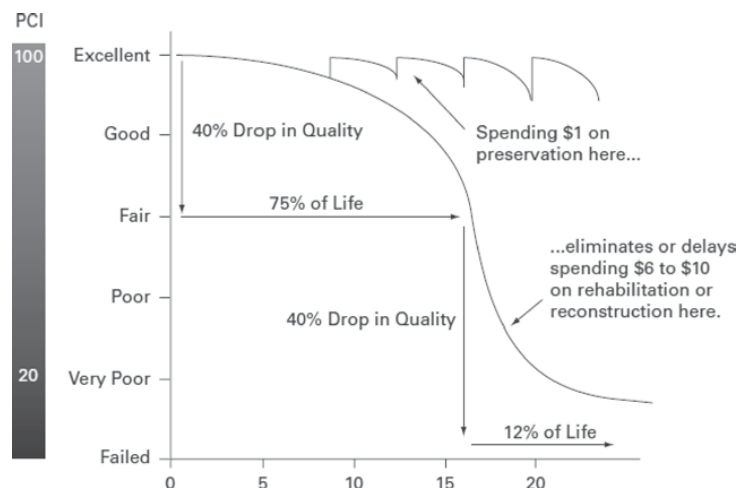


Figure 2: An example of the deterioration curve of pavement assets (Anderson & Rivers, 2013), utilizing the pavement condition index (PCI – y-axis), which ranges from Excellent (100) to Failed (0). The x-axis displays the relevant pavement life-cycle span in unit time. A deterioration curve graphically illustrates the decrease in condition of an asset over time – as shown by the large curve that ranges in PCI from Excellent to Very Poor. The large curve shows what happens to an asset if left alone until it reaches a Very Poor or Failed condition-state. The asset then requires complete reconstruction. The small saw-toothed curve at the top of the plot illustrates the benefits of preservation on assets: mainly, it costs less money to preserve an asset over its lifespan than it does to completely reconstruct it at a time of near-failure or at complete failure.

Not many DOTs or agencies have experience with the third and fourth elements of the asset management framework, especially with respect to geotechnical assets, but there exist many papers discussing the challenges that may be faced (Nafaji et al., 2008; Huang et al., 2009; DeMarco et al., 2010; Harvey, 2012; Anderson & Rivers, 2013; Badger et al., 2013). A challenge within the third element arises in the processes of choosing geotechnical assets that are critical to the transportation environment. The criteria for ranking the most critical assets must be developed from the data obtained from the first two elements. A major challenge within the fourth element will be to project the cost, asset performance, and required maintenance over a period of time equivalent to the expected life-cycle of each figure geotechnical asset. This may be difficult to accomplish without previous information and will definitely be uncharted waters for GAM.

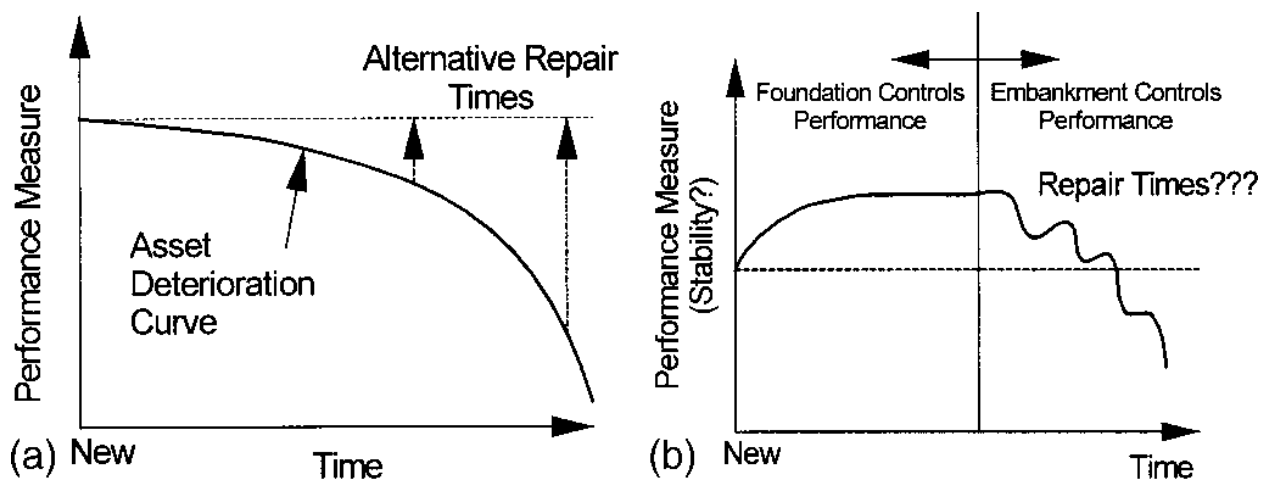


Figure 3: How would the deterioration curves of different assets compare (Sanford Bernhardt et al., 2003)? (a) A general deterioration curve for an asset (e.g., pavement – Figure 2) where the performance measure (y-axis) is asset condition. (b) A hypothetical deterioration curve for a geotechnical asset – in this case a slope – where the performance measure is the stability of the slope.

5. Survey on Current Practices, Perceived Needs, and Limitations of GAM

A survey on current practices, perceived needs, and limitations of geotechnical asset management was performed among transportation infrastructure professionals across the United States, following the goals in the projects proposal. The results of this survey are presented and discussed in this section.

5.1 Methodology

An electronic platform (<https://www.surveymonkey.com>) was chosen to deliver the survey, which is shown in appendix A. The target population was chosen from practitioners working for state and city departments of transportation across the United States, as well as a small sample of professionals working in private railroad companies. A database of potential survey respondents was compiled using publicly available contact information for people working in such agencies. A total of 710 individuals were invited to participate in the survey via email messages sent to the addresses compiled in the database. After ca. 2 months from the invitation date, 99 individuals had answered the survey. All survey design, data collection and analysis procedures were executed in compliance of Federal Regulations on the use of human subjects in survey studies, and monitored and approved by the Michigan Technological University Institutional Review Board.

The survey has 10 mixed, multiple choice / open ended questions, and includes an initial section with information on the respondents background (e. g. what agency they work for, what is their main field of work), followed by a series of questions about their agencies' current practices regarding geotechnical asset management, and a final section about perceived needs and limitations of those practices.

5.2 Survey Results and Discussion

5.2.1 Respondent's Characteristics

Despite the efforts to sample a population as geographically broad as possible (invitations for filling out the survey were sent to potential respondents in all 50 states), some of the States were not sampled. Figure 4 shows a map of the number of respondents per state, and it can be noticed that the survey sampling spans over most of the United States. Up to 6 respondents answered the survey in some states, but the majority of states are only represented by one or two respondents.

The majority (84.2%) of survey respondents come from a geotechnical background (see Figure 5), although the survey was aimed to also sample practitioners in other areas (e. g. asset management, planning, GIS analysis, etc.). A smaller but still significant percentage (16.8%) of respondents work primarily in asset management and the rest (8.4%) work in other fields. The high percentage of respondents in the geotechnical category may represent a self-selection bias, as people from that background may have been more motivated to answer the survey than people who worked in other areas and who also were invited to participate in the survey. This however, should have no significant impact in the validity of the survey, as the questions are not geared to specific respondents. Finally, 35% of the respondents said they would be willing to participate in

a follow up phase of the study (if such a second phase is done) and gave their contact information for that purpose.

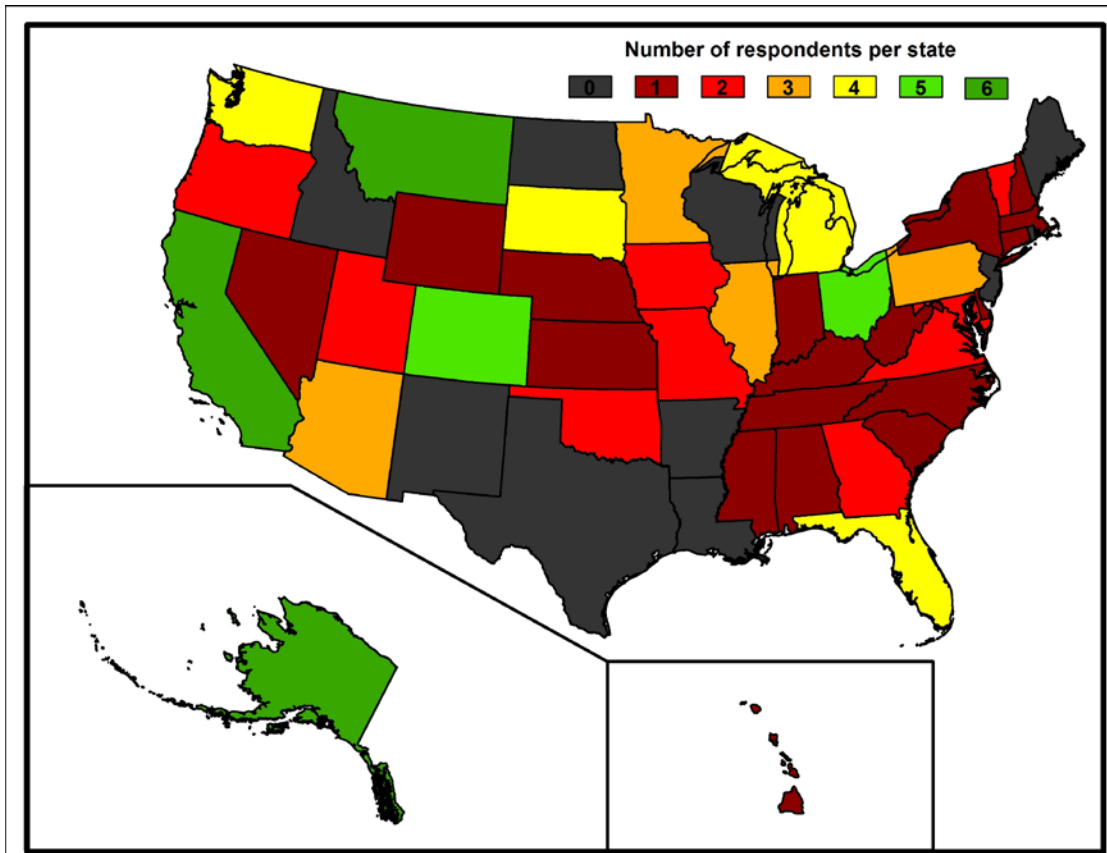


Figure 4: Number of respondents per state. Alaska and Hawaii are shown to the south of the contiguous US for reference.

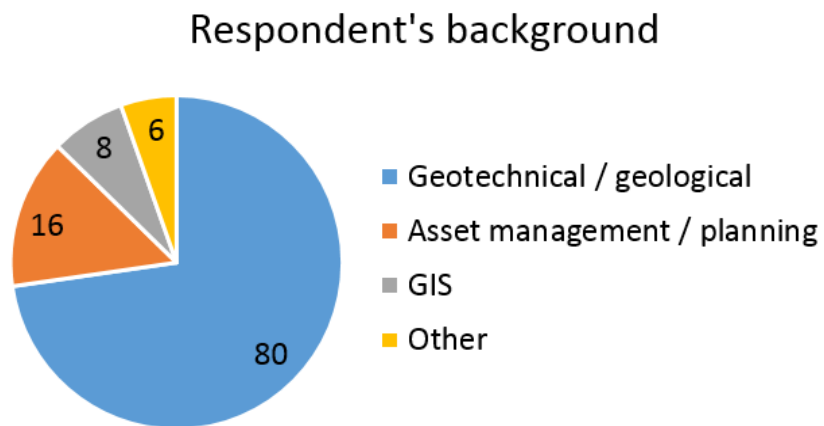


Figure 5: Respondent's background. Labeled numbers are total numbers of responses.

5.2.2 Current Practices involving GAM

One of the founding pieces of information on which an asset management system can be built is the assets inventory. According to the 71 individuals who answered this question, asset inventories for different geotechnical assets are available in many cases (see Figure 6), e. g. 40.8% of respondents mentioned retaining wall inventories, and only 26.8% mentioned that no inventories were available at all. This is a surprising result, as we expected fewer agencies to have such kinds of inventories.

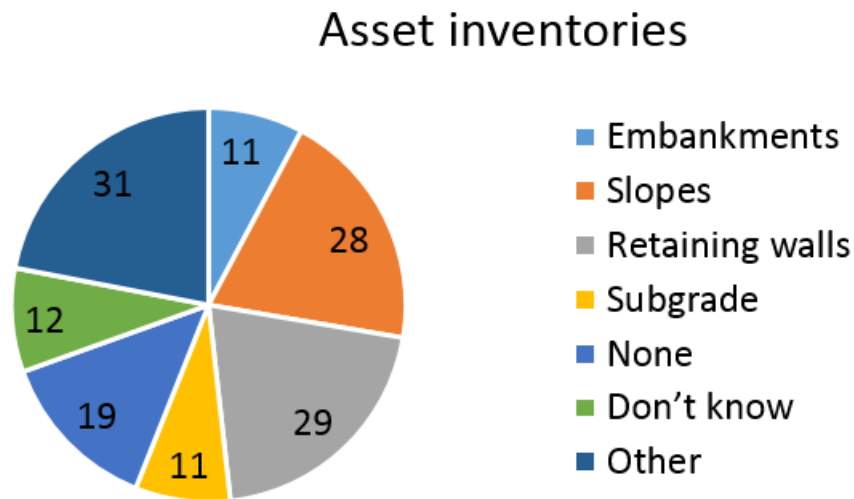


Figure 6: Asset inventories for different asset types. Labeled numbers are total numbers of responses.

The existence of asset inventories for a significant number of cases shows that some agencies are at a mature enough state to either develop an asset management system for geotechnical assets, or may already have one in place. This is an important finding that encourages the applicability of methods aimed at the next steps in the asset management process, e. g. monitoring and evaluating assets performance, which includes the methods that are the central part of this project. The concept of asset management implies a focus on preventive and proactive action (e. g. monitoring and maintenance of the assets), shifting away from the traditional approach of focusing on only the urgent (e. g. failed or near failure infrastructure) cases. In more than half of the cases (54.4%) inspections and maintenance was only done when the assets were already damaged or failure was imminent (see Figure 7). Routine inspection of the listed assets was reported in only 18.4% of cases.

Maintenance of assets

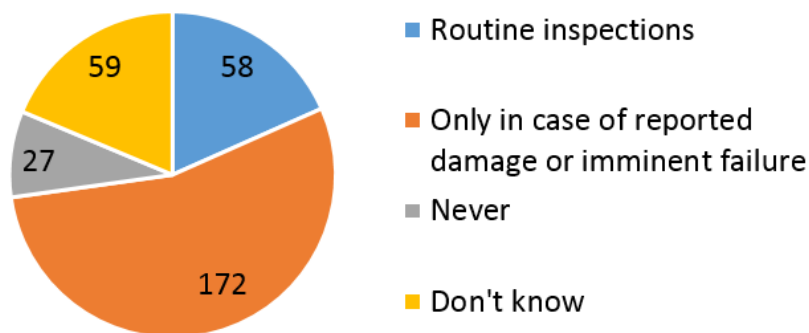


Figure 7: Reasons given for asset intervention. Labeled numbers are total numbers of responses. Notice that in this case 4 types of assets are considered and therefore the number of answers is four-fold from previous questions.

Although many agencies have reached a basic level of maturity in their geotechnical asset data gathering process, as shown by the existence of several asset inventories, most of the monitoring and fieldwork is still being done for crisis and repair purposes. This needs to change for geotechnical asset management to really take hold as a standard practice among some of these agencies. Reducing the costs and required effort in doing such monitoring could certainly contribute to change this trend.

Our project focuses on the use of remote sensing for monitoring geotechnical assets, and in that context we make a special emphasis on displacement monitoring as a tool to infer the state of health of the geotechnical assets. For most assets, respondents reported either that the main data collected routinely for monitoring purposes was just visual information (33.8%) or that no data were collected routinely at all (32.9%, see also Figure 8).

Data types collected

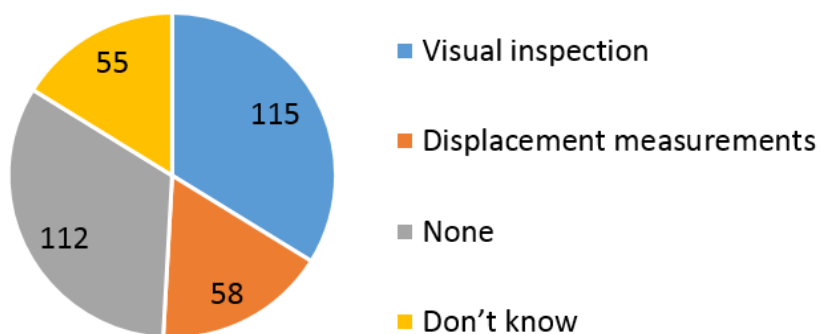


Figure 8: Data types collected for each asset. Labeled numbers are total numbers of responses. Notice that in this case 4 types of assets are considered and therefore the number of answers is four-fold from previous questions (see appendix A for details on the questions).

Although the majority of the responses corresponded to a low technology and more traditional and subjective way of collecting information (visual inspection), there is a significant number of answers expressing that displacement measurements are currently used to monitor geotechnical assets (17.1%). This stresses the importance that such measures have for geotechnical asset monitoring, and as will be discussed further in this section, matches the expectation that such data should be a priority in monitoring geotechnical assets.

The project also proposes to implement analysis methods based on decision support systems and GIS. Respondents of the survey overwhelmingly (79.5%) stated that the main method of analysis was the analysis of the data collected on the assets was by and engineer or an expert, and only 14.1% mentioned that decision support systems or GIS tools were used for that purpose (see Figure 9).

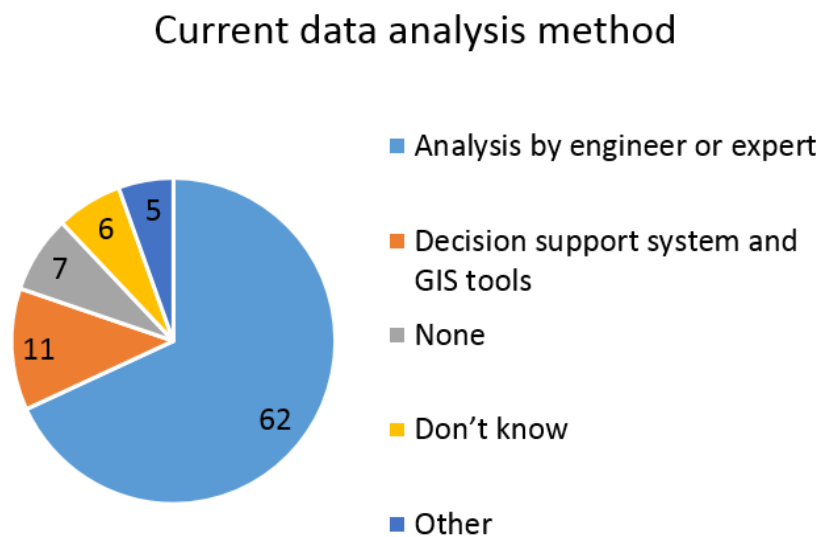


Figure 9: *Currently used data analysis methods. Labeled numbers are total numbers of responses.*

Similarly to displacement monitoring, decision support systems and GIS analysis are still used only in a minority of cases, but by making such techniques more accessible, their value and contribution to geotechnical asset management could be increased.

5.2.3 Perceived Needs and Limitations

The answers related to current practices (previous section) shows a reliance on traditional views on geotechnical asset management, in terms of the data collection and analysis practices. An important question that then arises is what the most crucial problems and needs in this area would be and what would it take to solve them.

When asked about what type of data would be a priority to collect but are not currently being collected by the agencies, the answers varied depending on the state of data collection and analysis capacities for each agency. Agencies that collect little information on geotechnical assets would prioritize the collection of the most basic information, while agencies that already collect

the basic information on those assets, would prioritize other more sophisticated datasets as their next priority. Overall, many agencies would still prioritize the collection of basic information, e.g. 35.5% of responses correspond to visual inspection data, but a significant number of responses (27.6%) focused on displacement measurements (see Figure 10).

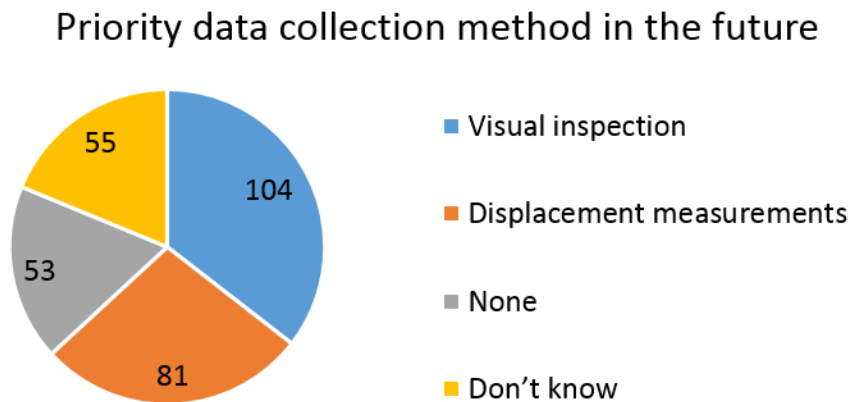


Figure 10: *Data collection methods seen as the next priority to further develop in the future. Labeled numbers are total numbers of responses. Notice that in this case 4 types of assets are considered and therefore the number of answers is four-fold from previous questions (see appendix A for details on the questions).*

In a previously analyzed question in this section, a small number of respondents stated that displacement measurements are currently used as a method to monitor geotechnical assets; but when asked whether they would prioritize that as a monitoring technique, a much large number agreed in the utility of such measurements. Providing an accessible way of monitoring displacement over wider areas may increase the adoption of these types of measures in asset monitoring, and contribute to provide better quality and more objective data for the asset management systems.

The main reasons why the agencies would not collect data on geotechnical assets, according to the survey answers, were due to a lack of material of financial resources (56.8% of responses), followed by the lack of a perceived need to do so (45.9%). In contrast to this, 33.8% of the responses stated that data are being collected on the geotechnical assets (see Figure 11). Strikingly, only 2.7% of the answers acknowledged a lack of within agency expertise as the main reason why geotechnical assets were not monitored.

Although a lack of perceived need for asset monitoring may be a challenging obstacle to overcome for improving geotechnical asset management, a lack of material and financial resources is seen as a bigger problem by more of the respondents. Making less expensive and easier to implement techniques available seems like the smartest way to overcome this obstacle.

Main reasons for current limitations on asset monitoring

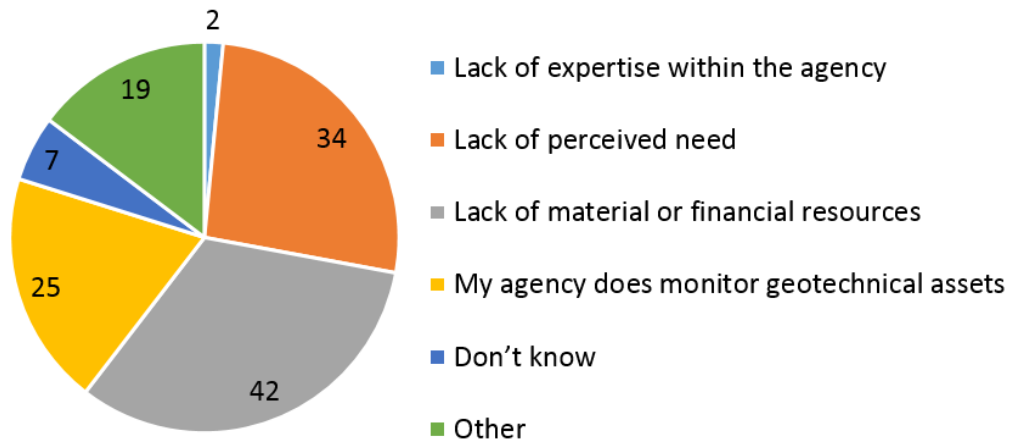


Figure 11: Reasons listed as the main limitation to implement geotechnical asset monitoring. Labeled numbers are total numbers of responses.

5.2.4 General Comments by Respondents

In the open ended questions, some respondents expressed views and opinions that wouldn't fit into the multiple choice options. Constraining the survey to only a few geotechnical assets was noted to be too limiting by some respondents, for instance one respondent expressed:

“I do not understand the limited nature of the survey. Why only embankments, slopes, retaining walls and subgrade. We are currently developing inventories for retaining walls, reinforced soil slopes and chemically stabilized subgrades.”

Another respondent mentioned that:

“Monitoring should also be done in my view on the bridge pile foundations and pavement settlement. But cost is a huge factor.”

This opinion was also extended to rockfall issues by another respondent:

“Some attention also needs to be paid to rockfall, being separate from embankments and slopes where landslides are the major failure mechanism. States with loess such as ours also need monitoring of vertical soil slopes also.”

In part the difficulty also resided in how the geotechnical assets were defined, and as one respondent expressed it:

“I do not like the term geotechnical assets. The walls should be put with bridges/structures assets and the others with pavement asset.”

However, the majority of the respondents didn't seem to have problems with the defined and given categories in the survey.

Some respondents commented on the challenges that geotechnical asset management represents for their agencies and how the process of adopting such a system has been slow. For instance one respondent states that:

“Geotechnical assets have been not typically been given as much attention as pavements and structures, perhaps as these works tend to degrade less or have fewer serviceability issues. Most asset management is linked to high risk or hazard inventories (areas at risk of scour, landslide, etc.). MnDOT keeps track of the performance (by instrumentation) of critical projects [centralized], but most 'typical' geotechnical features are monitored by District maintenance forces.”

Coinciding with the view expressed by other respondents, including the limitation for funding such programs, as expressed by another respondent:

“We have been thwarted in our previous attempts at securing funding for GAM; but there are indications we may a break-thru soon for our walls inventory & insp.”

Such opinions highlight the need to provide cost effective and easy to implement solutions for geotechnical asset monitoring and management. But at the same time, several respondents gave examples on how their agencies are actually developing such geotechnical asset management plant, for instance:

“Our agency is working on a retaining wall inventory system and planning to incorporate rockfall inspection and inventory into a more encompassing geohazard management plan that includes performance measures for rockfall, rockslides, landslides, debris flows, sink holes and embankments.”

Finally, some respondents expressed optimism that remote sensing techniques could help in the monitoring and analysis tasks, as expressed by one of the respondents:

“Remote sensing techniques offer opportunity to monitor geohazard sites much more frequently and efficiently.”

From the quantitative and qualitative data gathered by the survey, we can see the interest by many agencies in implementing geotechnical asset monitoring and management programs, but we can also see the need for cost effective methods to do so. Remote sensing based techniques and decision support systems may just contribute to this goal.

6. Applications of Remote Sensing

After the initial geotechnical asset inventory is created for the foundation of the GAM, the proposed approach for providing cost-effective and efficient data analysis of geotechnical asset conditions is the combined use of three remote sensing techniques. Recent advancements in commercial remote sensing systems, specifically interferometric synthetic aperture radar (InSAR), light detection and ranging (LiDAR), and optical photogrammetry, provide opportunities to obtain precise measurements of displacements and deformations without the laborious site inspections.

All three remote sensing techniques provide unique opportunities to measure ground movement precisely. The benefits of using InSAR include the ability to measure ground displacement and velocity over large areas and to detect these movements down to the millimeter scale. There also exists a relatively large historical archive of data (basically from 1992 to 2011 of almost continuous acquisitions) between many satellites (ERS-1, ERS-2, ENVISAT, and RADARSAT-1). LiDAR allows for the generation of high resolution digital elevation models (DEM) and the ability to measure surficial and volumetric changes between multiple acquisitions. Optical photogrammetry also allows for the generation of high resolution terrain models, which can be used to model the geotechnical assets themselves. There also exists a large historical archive of optical imagery that, alongside with current imagery, allows for observations along a wide temporal span.

These remote sensing techniques complement each other. For example, datasets from LiDAR and optical photogrammetry fieldwork may cover a relatively small region, but InSAR will allow for wide areal coverage; although the pixel resolution of most InSAR imagery ranges from 25x25m to 30x30m, both LiDAR and optical photogrammetry data have much higher resolution (centimeter scale).

The use of all three remote sensing techniques allows for a more robust condition analysis and a multi-tier inventory approach of geotechnical assets within the transportation environment study sites. The multi-tier approach allows for the identification of assets with high hazard probability or potential via a regional search (e.g., using InSAR) that may then be refined to an asset-by-asset search (e.g., using LiDAR and/or optical photogrammetry). A multi-tier approach narrows in on the individual geotechnical assets that may be prone to hazards and can allow for the deployment of teams to a localized area within the transportation environment, which will hopefully yield a more practical and cost-effective management method for DOTs and transportation agencies. The next deliverable of this project will discuss in detail the candidate remote sensing techniques likely to be able to meet the needs of the users in different transportation environments for geotechnical asset management.

7. Conclusion

This report on requirements for remote sensing based geotechnical asset management system included a national survey of state and city DOTs, railway operators, and pipeline owners. The main aim of the survey was to gather information on the needs of the users and the intended use of the geotechnical asset management system, types and conditions of geotechnical assets that need to be managed, concepts and constraints of operation, requirements of performance, and needs for database and visualization of results. As far as the authors know, this presents the first official national survey in the U.S. to understand the needs of geotechnical asset management along the transportation environments. The large sample (99 respondents) of participants indicate that the survey was a great success.

The results of the survey indicate that majority of the agencies currently do inspection and maintenance of geotechnical assets only when the assets were already damaged or failure was imminent. A proactive asset management approach was not practiced commonly for geotechnical assets along the transportation corridor due to lack of resources. Moreover, the current approach of inspection is mostly subjective and labor intensive. Therefore, developing economically sustainable techniques for asset monitoring and objective decision support systems will be a key strategy for advancing proactive geotechnical asset management along the transportation infrastructure environment.

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9. Appendix-A: Geotechnical Asset Management Survey Phase-1

Geotechnical Asset Management Survey phase I

INTRODUCTION

This survey of geotechnical asset management practices, needs and limitations, is part of a nationwide project conducted by the Michigan Technological University in collaboration with other partners and funded by the US Department of Transportation. You were chosen to participate in this survey because we believe that you belong to the community of practicing professionals in the fields of transportation and geotechnical asset management, and the study aims to better understand the professional practices and perceptions of said community, among other things. The broader study will test and compare several technological and analytical solutions for geotechnical asset management problems, and could potentially provide solutions for agencies or companies like yours.

If you accept to take this online survey, you will be asked a total of 13 questions regarding current professional practices, needs and limitations in your field of work. We estimate the survey will take you between 15 and 20 minutes to complete. Your participation is entirely voluntary and you may choose to withdraw from the survey at any moment, or to skip any questions that you don't want to answer. At the end of the survey you will be given the opportunity to provide your contact information in case you were willing to participate in a follow up phase to this survey, but you may choose to remain anonymous or not want to be contacted in the future. Even if you chose to provide your contact information, that information will remain confidential and only accessible to the project researchers.

For more information on the project and on the topic of geotechnical asset management please visit: <http://www.mtri.org/geoasset/>

For specific questions regarding this survey and your participation in it, please contact Dr. Rudiger Escobar-Wolf at the Geological & mining Engineering and Sciences Department, of Michigan Technological University, on following email address: rpescoba@mtu.edu, or at the following phone number: 906-487-2531.

By clicking on the "next" button below you agree to participate in this survey.

Next

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Geotechnical Asset Management Survey phase I

RESPONDENT INFORMATION

1. Please name the agency or company for which you work?

2. What is commonly the type of your work you do within your agency?

- Geotechnical / geological
- Asset management / planning
- GIS

Other (please specify)

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Geotechnical Asset Management Survey phase I

CURRENT PRACTICE

3. For which of the following items does your agency have an inventory?

- Embankments
- Slopes
- Retaining walls
- Subgrade
- None
- Don't know

Other (please specify)

4. When does your agency perform inspections and maintenance for the following items?

| | Routine inspections | Only in case of reported damage or imminent failure | Never | Don't know |
|------------------------|--------------------------|---|--------------------------|--------------------------|
| Embankments | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Slopes | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Retaining walls | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Subgrade | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Other (please specify) | <input type="text"/> | | | |

5. What types of data or information does your agency routinely collect on the items listed below?

| | Visual inspection | Displacement measurements | None | Don't know |
|------------------------|--------------------------|---------------------------|--------------------------|--------------------------|
| Embankments | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Slopes | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Retaining walls | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Subgrade | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Other (please specify) | <input type="text"/> | | | |

6. What methods does your agency use to analyze the information collected on geotechnical features?

Analysis by engineer or expert
 Decision support system and GIS tools
 None
 Don't know
 Other (please specify)

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Geotechnical Asset Management Survey phase I

PERCEIVED NEEDS AND LIMITATIONS

7. What data that your agency currently does NOT collect, would be most important to gather for the following geotechnical items?

| | Visual inspection | Displacement measurements | None | Don't know |
|------------------------|--------------------------|---------------------------|--------------------------|--------------------------|
| Embankments | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Slopes | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Retaining walls | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Subgrade | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Other (please specify) | <input type="text"/> | | | |

8. What is the main reason why your agency does not monitor embankments, slopes, retaining walls or pavement subgrade?

- Lack of expertise within the agency
- Lack of perceived need
- Lack of material or financial resources
- My agency does monitor geotechnical assets
- Don't know

Other (please specify)

9. Are there any other comments or issues you would like to describe related to the content of this survey?

10. If you would be willing to participate in a second phase of this study, please provide your contact information below:

Name:

Email address:

Phone number:

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