

TRANSPORTATION RESEARCH BOARD

# Advances in Unstable Slope Instrumentation and Monitoring

**November 23, 2020**

**@NASEMTRB**  
**#TRBwebinar**

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- 1.5 Professional Development Hour (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact Reggie Gillum at [RGillum@nas.edu](mailto:RGillum@nas.edu)

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**REGISTERED CONTINUING EDUCATION PROGRAM**

**#TRBwebinar**

# Learning Objectives

1. Discuss current practices for use of instrumentation and monitoring technology in state highway departments
2. Apply practices to instrumentation and monitoring on unstable slopes
3. Assess instrumentation and monitoring technologies for treatment of unstable slopes

**#TRBwebinar**



# Advances in Unstable Slope Instrumentation and Monitoring

## NCHRP Synthesis Report 554

PREPARED FOR NCHRP  
TRANSPORTATION RESEARCH BOARD  
OF THE NATIONAL ACADEMIES

BGC Engineering, Inc.

Speakers: Mark Vessely, P.E.  
Scott Anderson, PhD, P.E.  
Cole Christiansen, P.E.

November 2020

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# Learning Objectives

- Understand the current practices for instrumentation and monitoring of unstable slopes in state highway departments
- Assess and apply instrumentation and monitoring technology for use on unstable slopes

# Defining Unstable Slopes



Deteriorating cut slopes and embankments

# Defining Unstable Slopes



Beyond the right-of-way natural hazard sites

# Presence of Unstable Slopes

At least 42 state DOTs report  
having unstable slopes

# Outcomes from Instrumentation and Monitoring on Unstable Slopes

- Data to inform decision making
- Warning systems
- Visualization and communication

## What can be measured?

- 2D and 3D location
- Displacement
- Rate of change
- Orientation
- Pressure
- Temperature
- Moisture and water
- Geophysical parameters

# Instrumentation and Monitoring

Two categories:

- Installed or insitu instruments and devices
- Remote monitoring from ground, aerial, or space-based platforms

# Ground-Based instruments

Examples:

- Extensometers
- Inclinometers
- Pressure cells
- Fiber optics

# Remote Sensing Technologies

Examples:

- Ground-based survey (e.g. GPS)
- Ground-based and aerial photogrammetry
- Ground-based and aerial LiDAR
- Ground and space-based InSAR

# Why Monitor

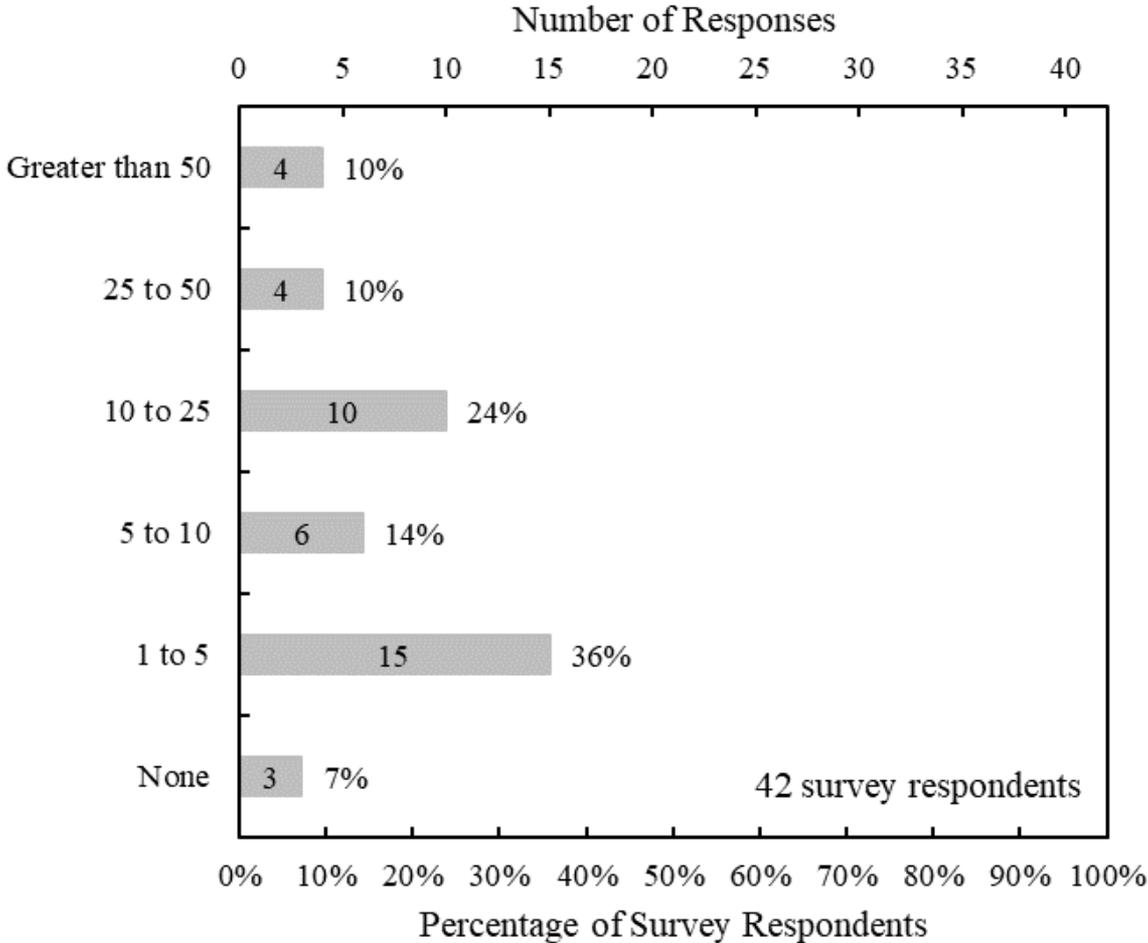
- Public and worker safety
- Reducing uncertainty about slope performance
- Optimizing risk and asset management decision

# NCHRP Synthesis Study Objective

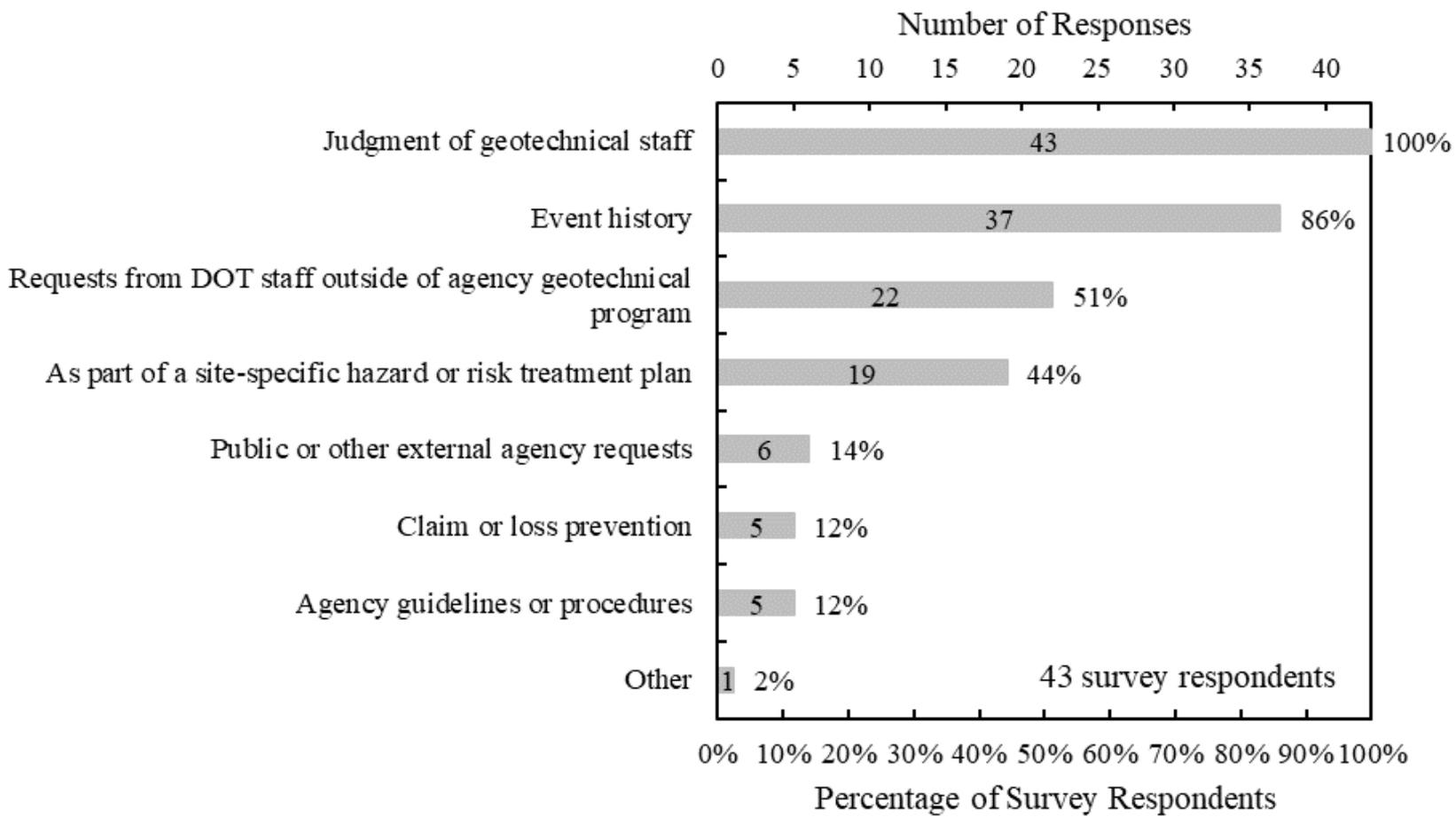
- Document the state of practice for geotechnical instrumentation and monitoring of unstable slopes
- Understand the application of new technology in the last decade.



# Number of Slopes Monitored



# Why slopes are selected for monitoring



**Understanding the evolution  
for state of practice for  
instrumentation and  
monitoring (I&M) in  
state DOTs**

## **What I&M types are established with over 10 years of use?**

- Greater than 80% of respondents:
  - Inclinometer systems (traversing probe)
  - Ground-based survey
- Greater than 50% of respondents:
  - Groundwater level measurement
  - Aerial photography
  - Tilt measurement devices

# What are I&M system types that are new uses within last 10 years?

- Ground-based LiDAR:  
> 70% of responses
- Aerial LiDAR:  
40% of responses
- Ground-based and aerial photogrammetry:  
Approximately 35% each

# **Understanding trends in data collection, viewing of data, and communication of I&M results**

## **What are the established data collection, viewing and communication methods**

- Manual monitoring and paper-based records:  
85% of responses
- Manual monitoring and electronic recording:  
49% of responses

# **What are emerging data collection, viewing and communication methods within the last 10 years**

- Web-based access and data presentation: 48% of responses
- Remote real-time viewing of data: 47% of responses
- Remote viewing of recorded data: 46% of responses

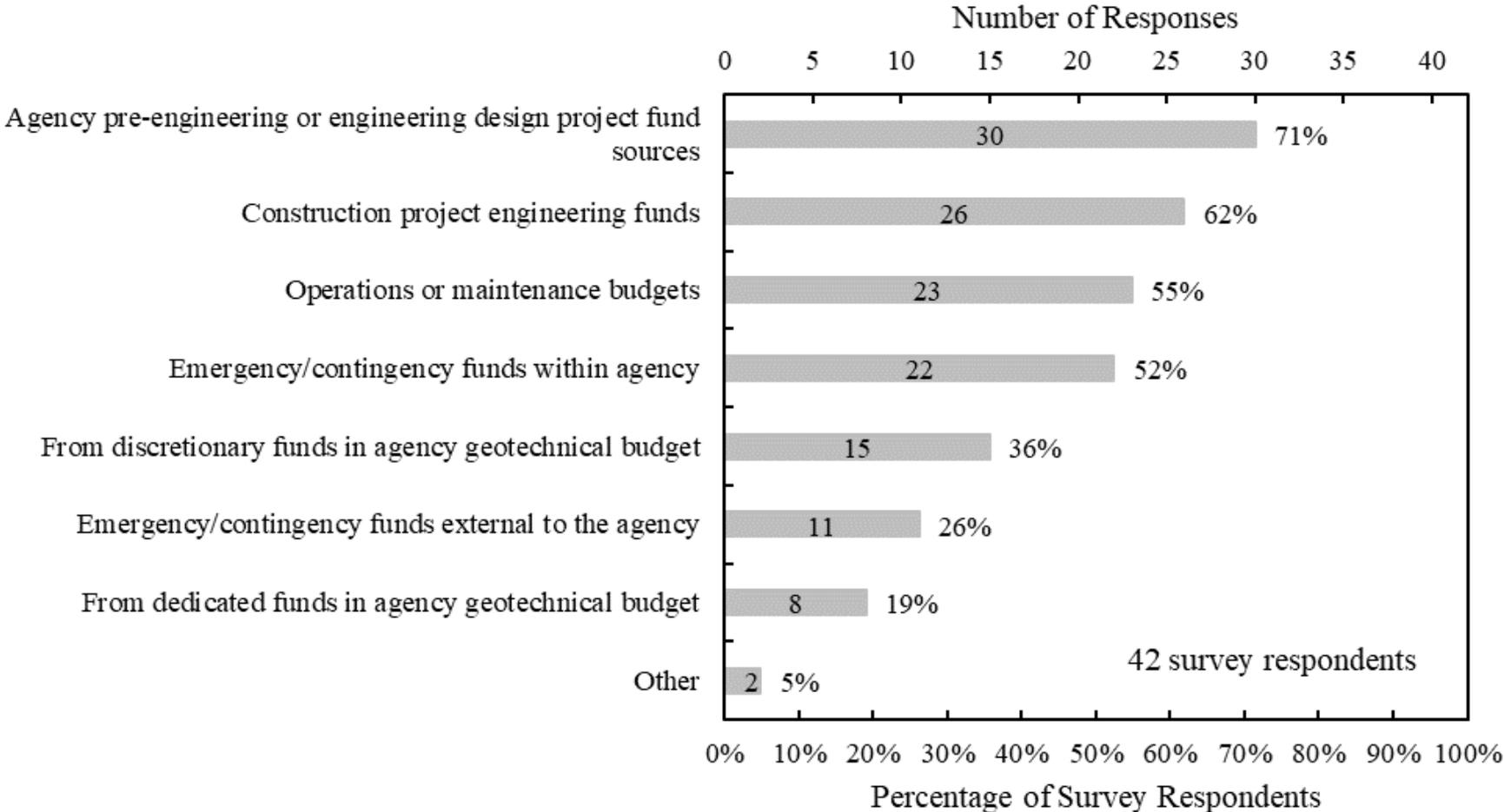
**State DOT perspectives on  
implementation of  
innovative technology  
within last 10 years**

# Innovation Categories

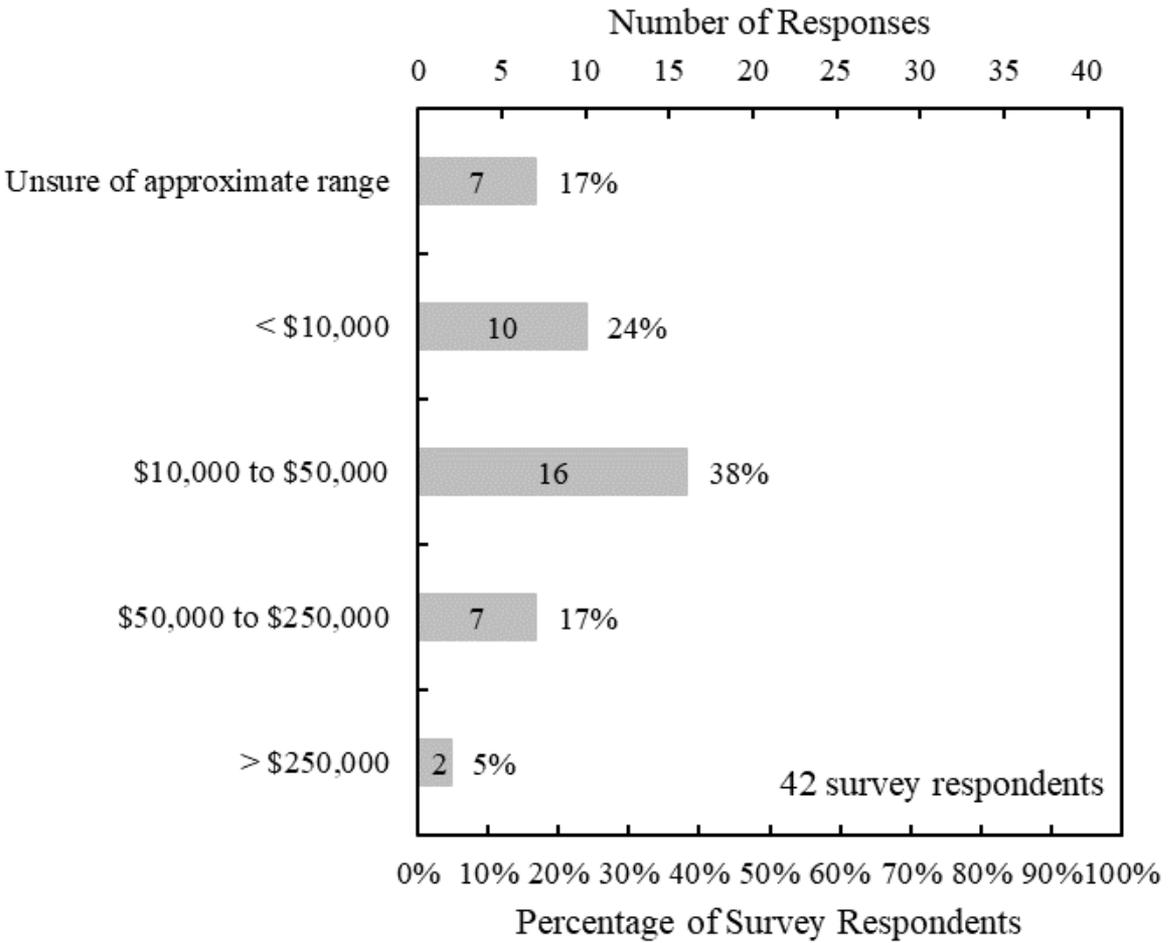
- Improvements in ground-based instrumentation
- Remote sensing
- Data Management

# Funding and Procurement for Instrumentation and Monitoring

# Sources of Funds for I&M



# Range in Funds for I&M



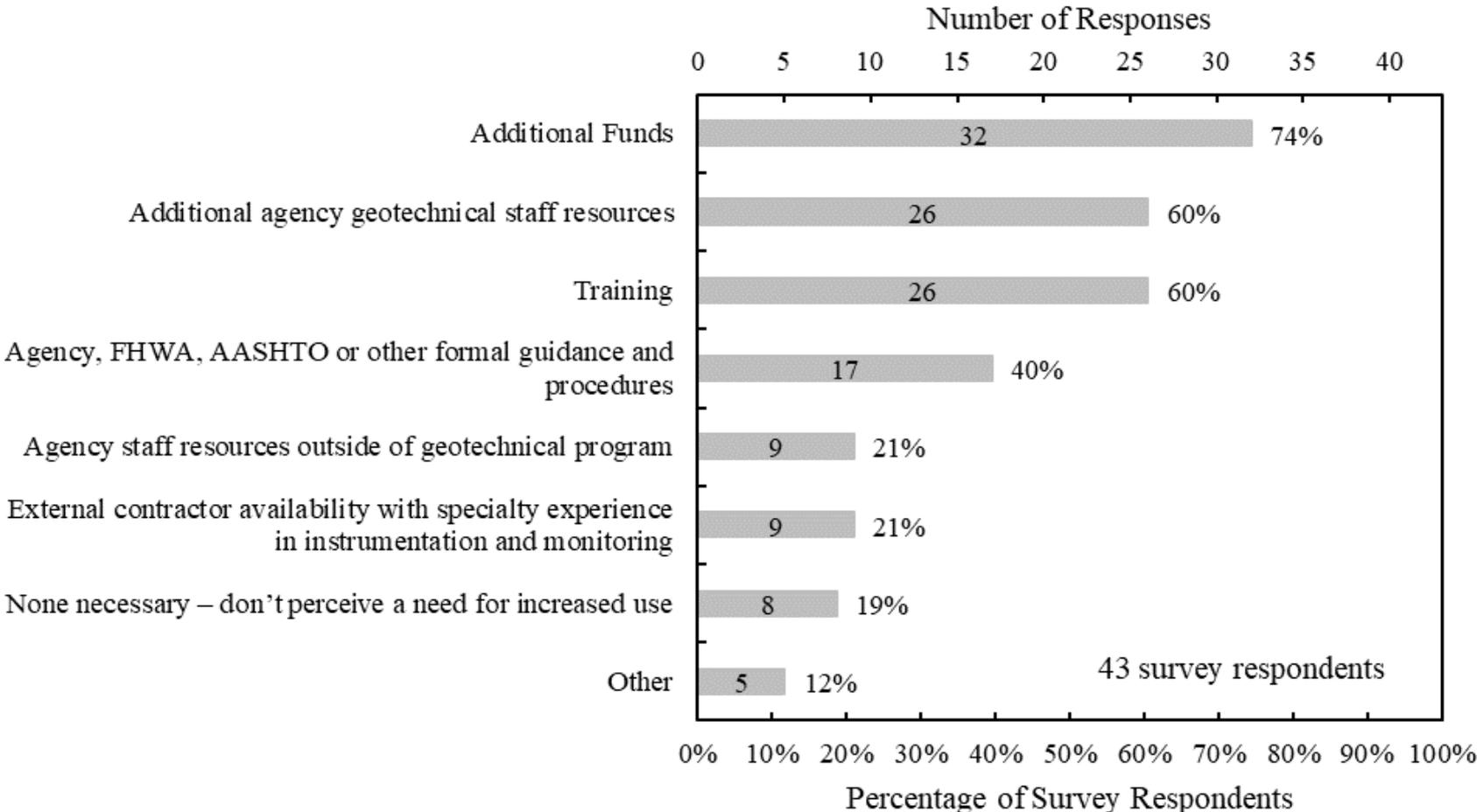
**Understanding the  
contributions from staff  
within a DOT and external  
vendors, consultants, etc.**

# Trends in Internal and External I&M Support

- Within the DOT:  
Staff are performing the majority of installations and data management activities
- External to the DOT:  
Remote sensing and installation of warning systems are commonly performed by vendors/consultants

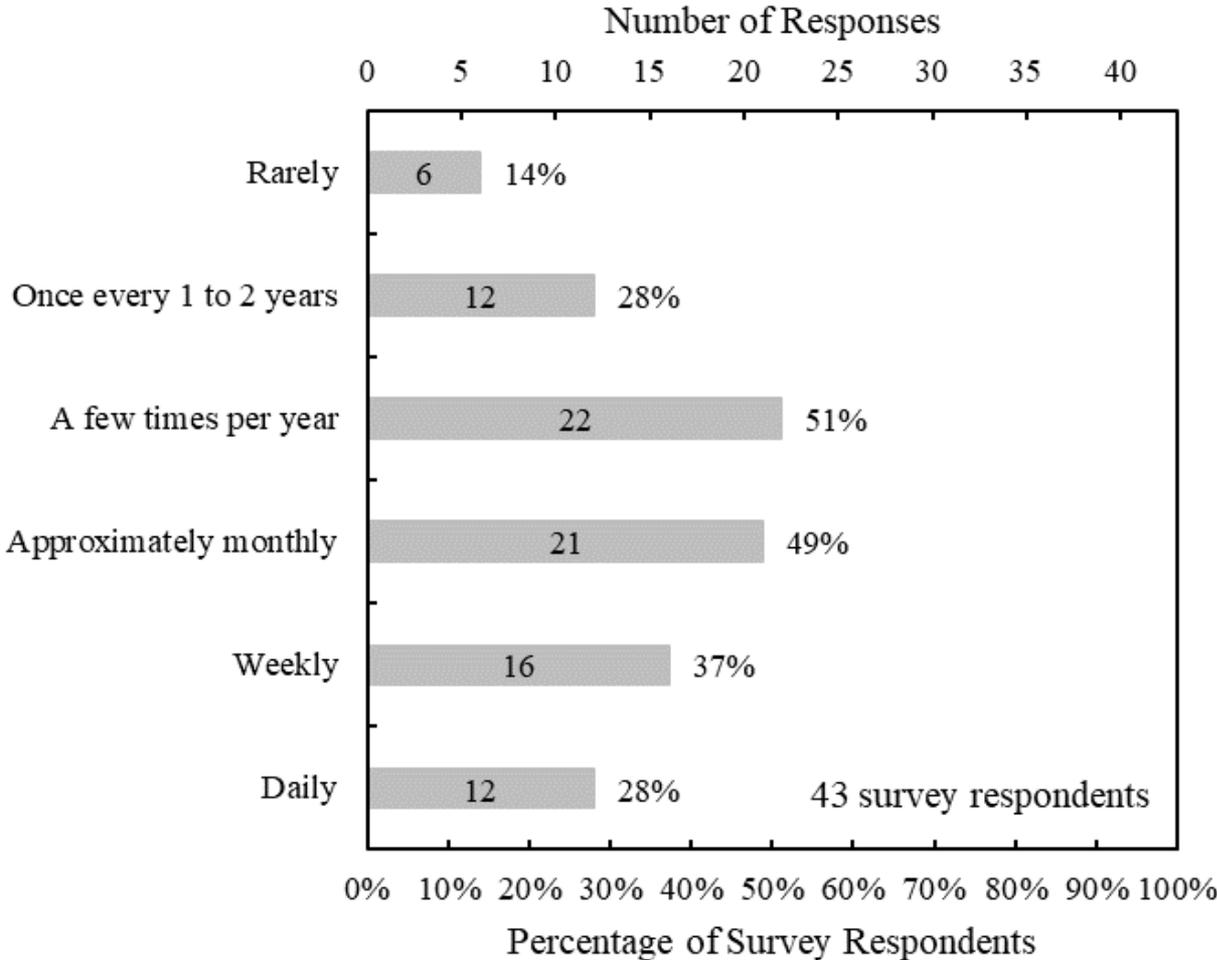
# Enabling increased use of I&M for unstable slopes

# Range in Funds for I&M

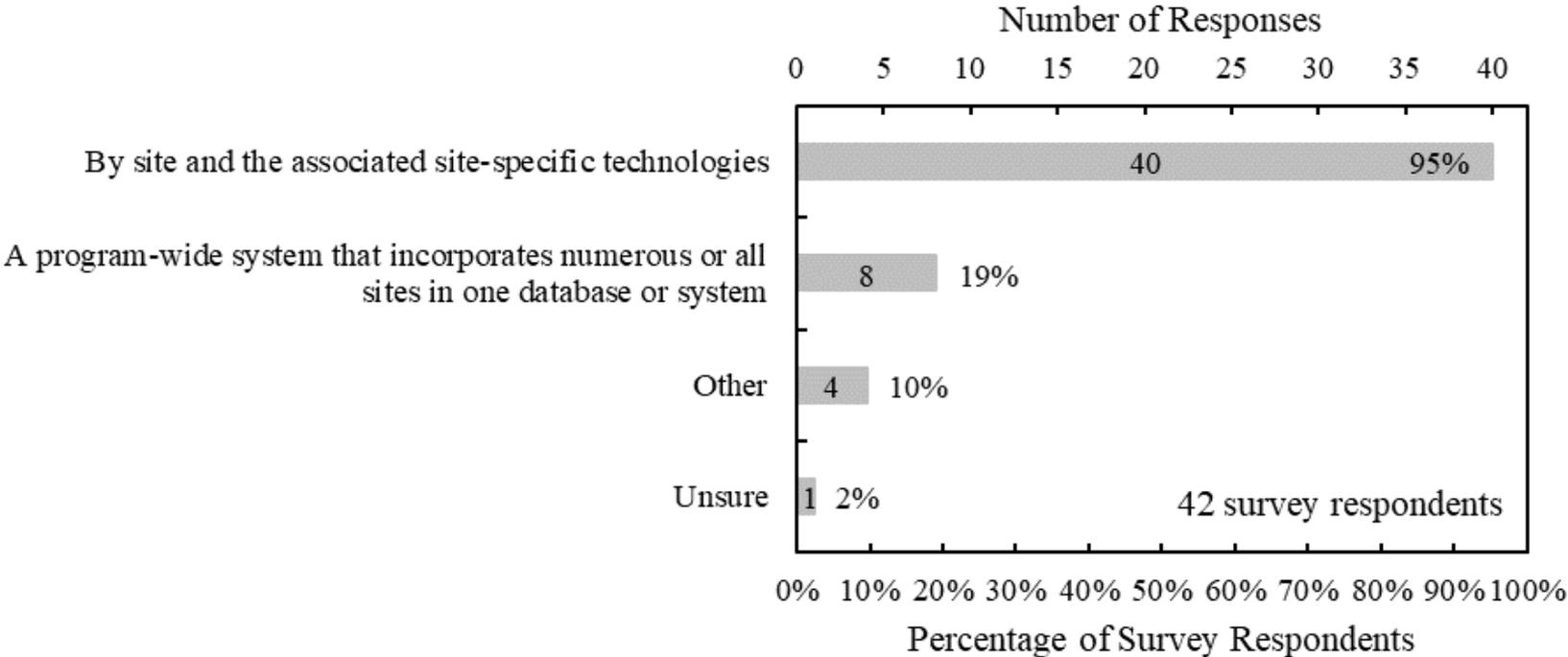


# Understanding Data Management for I&M

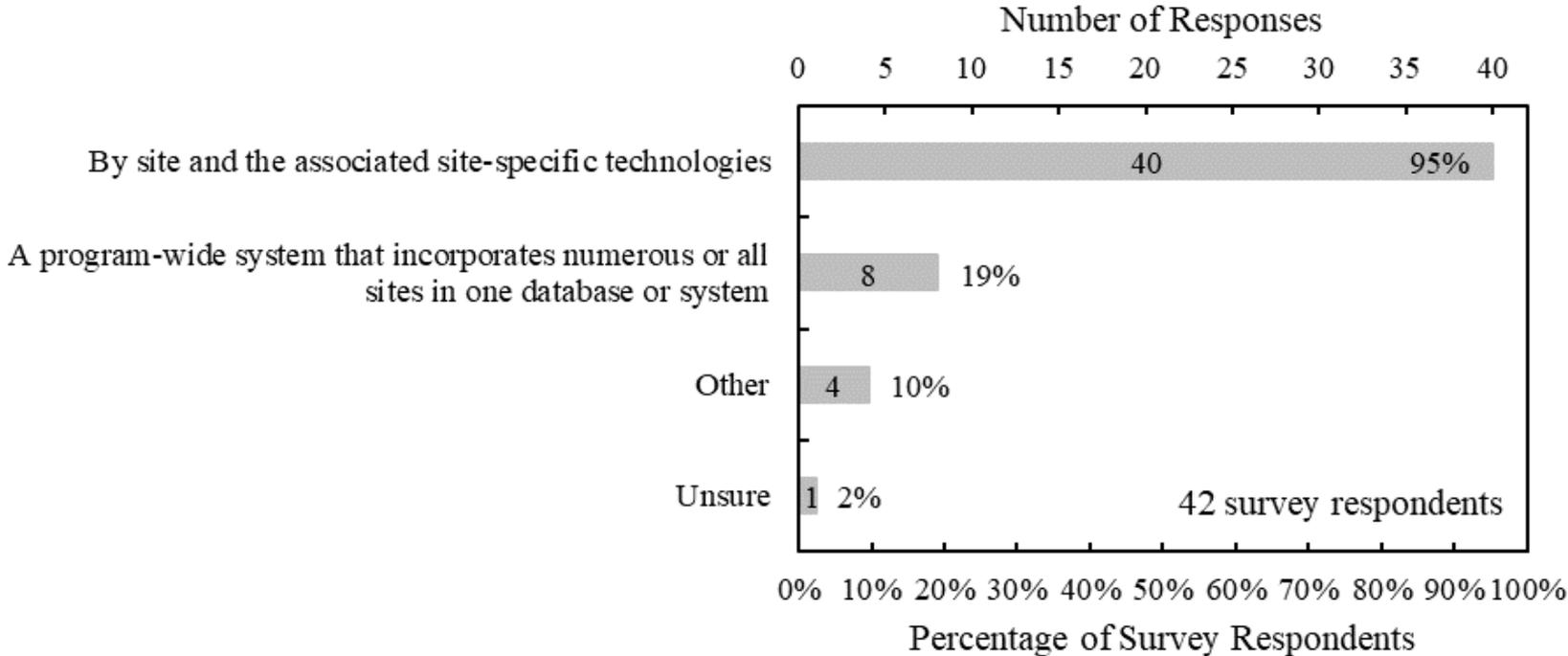
# How often are data used



# Is data management a site or program level activity?

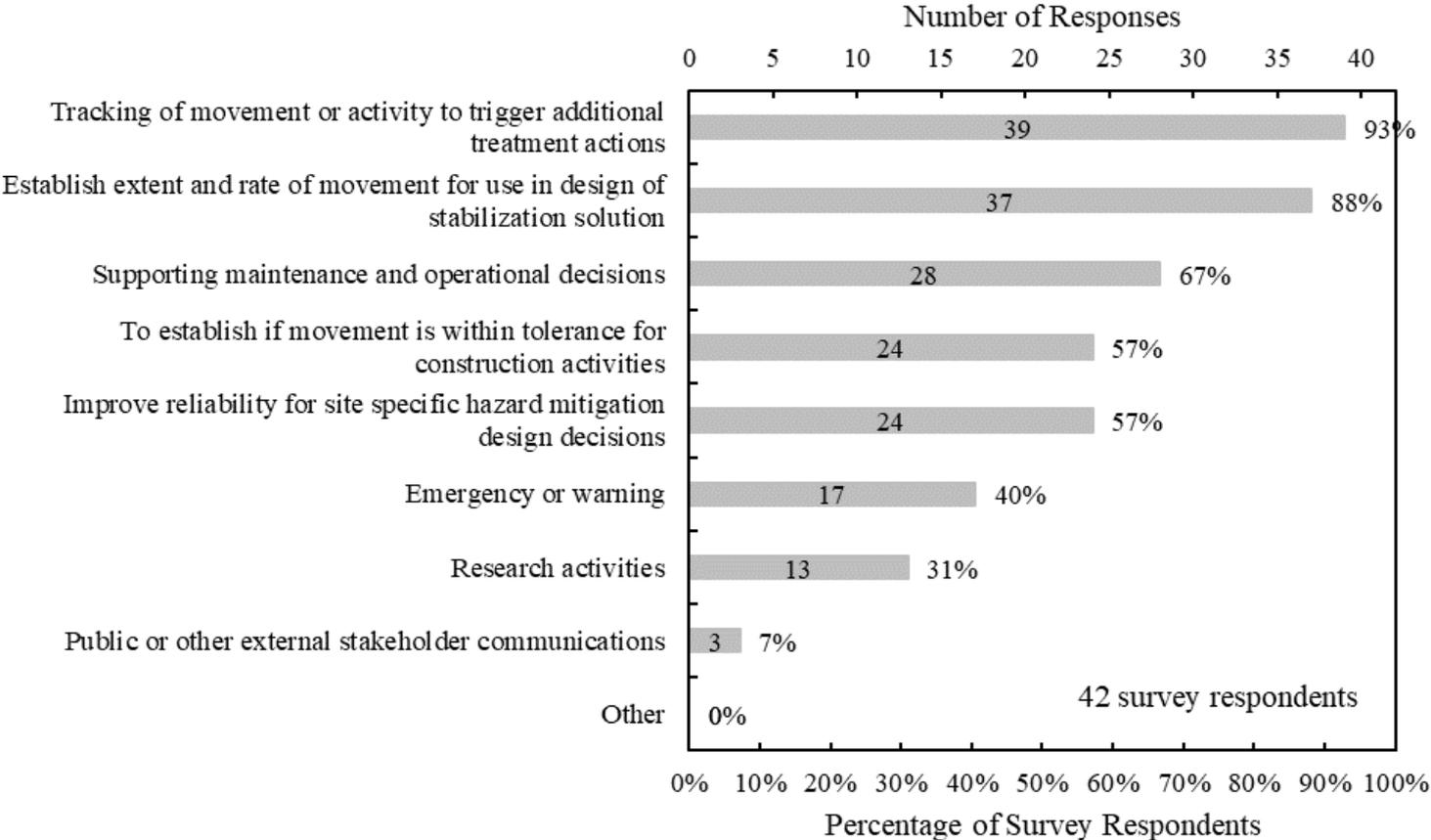


# Is data management a site or program level activity?

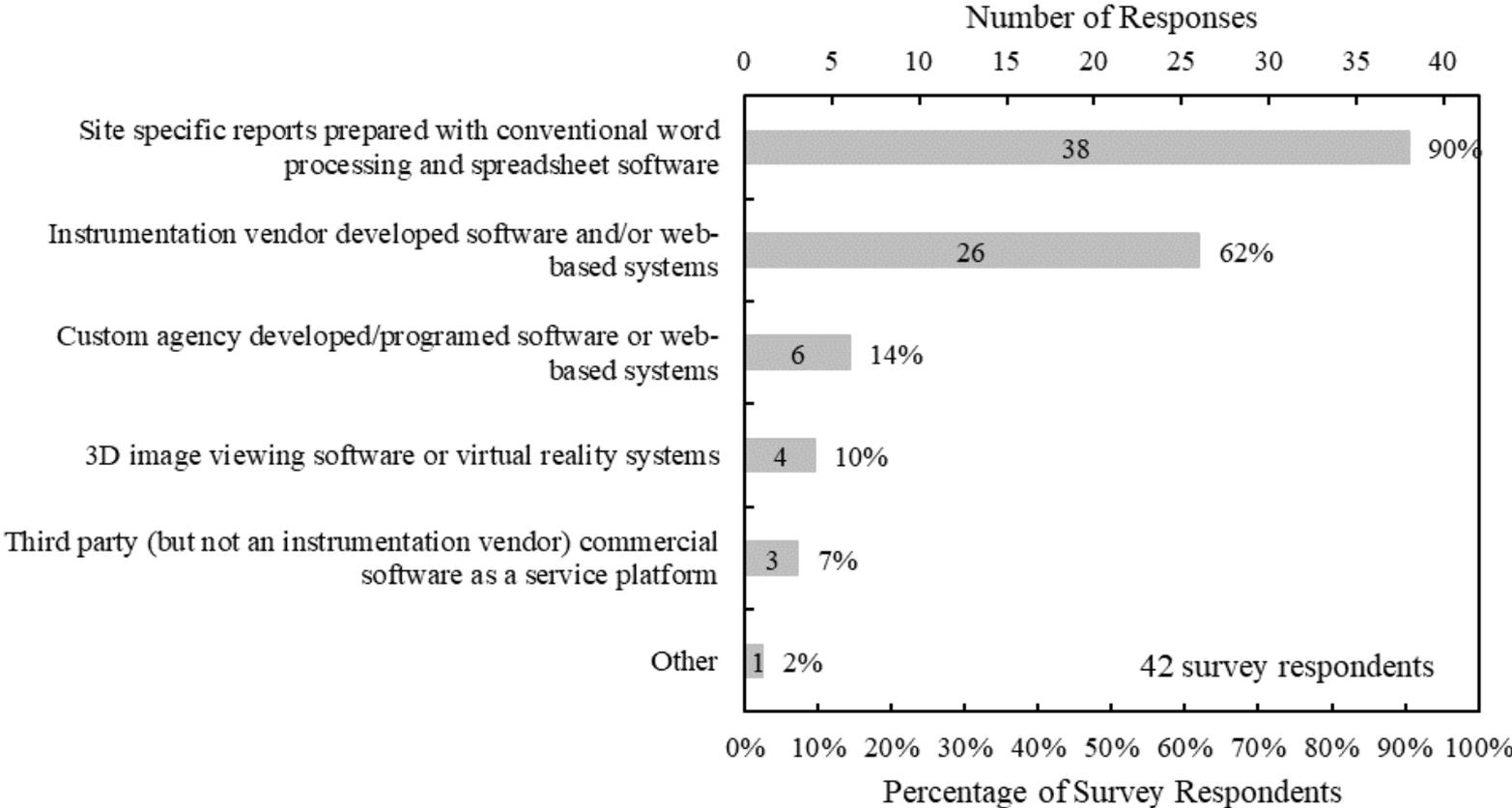


# Understanding how I&M data are used by state DOTs

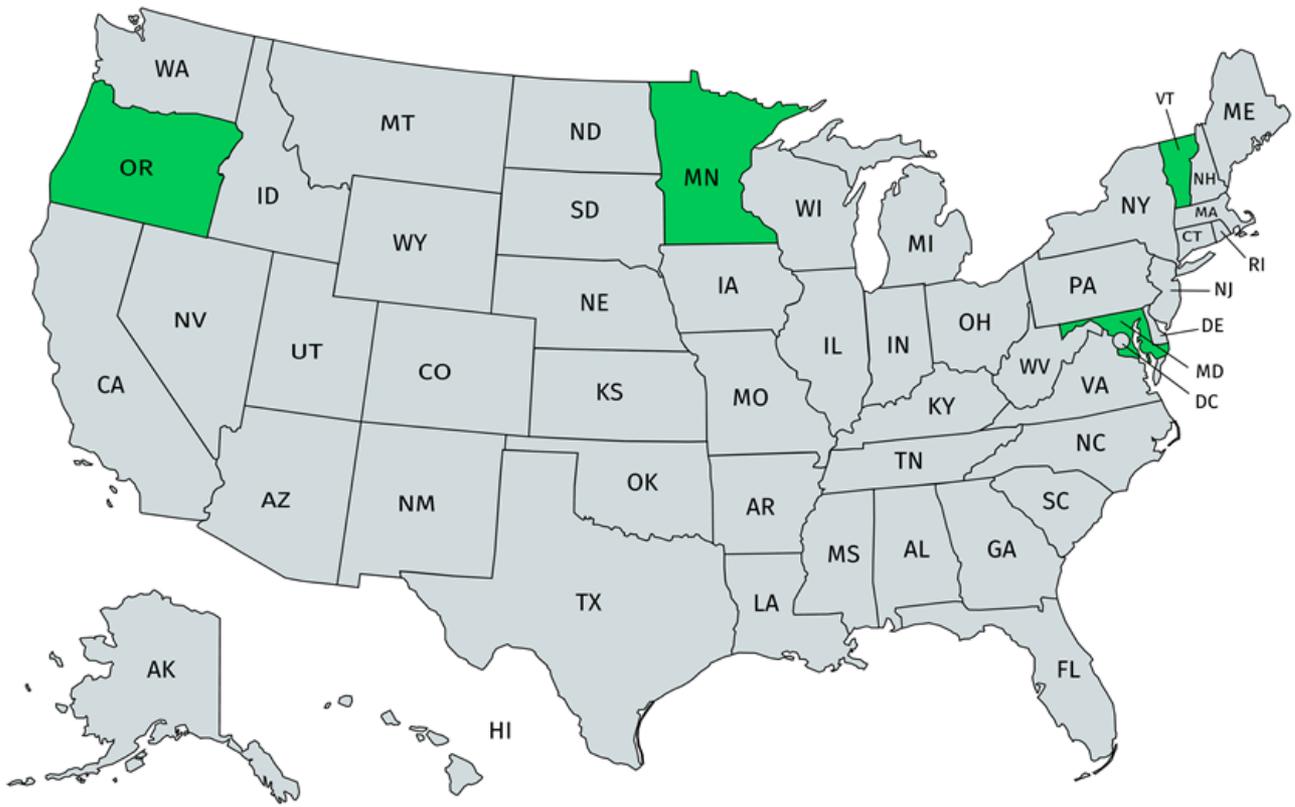
# Uses of the data



# Communication and Visualization



# State DOT Case Examples



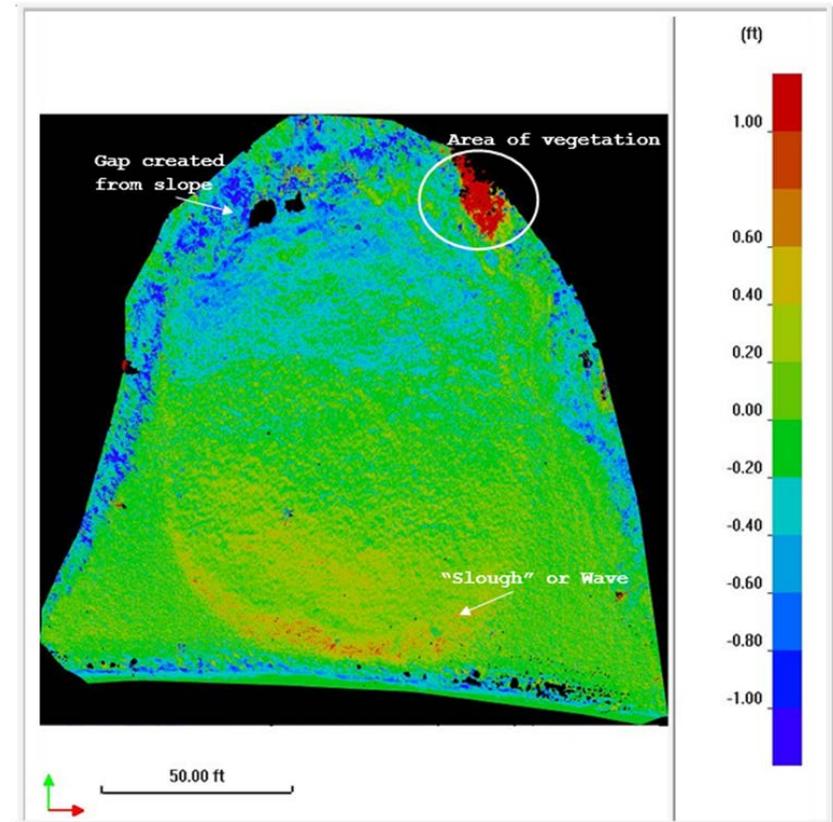
# Case studies of DOTs advancing I&M for their unstable slopes

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<b>State</b>	<b>Case Example</b>
Vermont	Recurring LiDAR Surveys for Slope Monitoring
Minnesota	Cost-Benefit of Instrumentation and Monitoring
Maryland	Implementing UAVs and New Software
Oregon	Evidence-Based Long-Term Planning

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# Vermont – LiDAR for Slopes



# Minnesota – Justifying the cost-benefit

Quantifying the benefits to gain support for  
I&M investments

# Maryland – Implementation of drone-base aerial photogrammetry

Building an inventory of slope assets through  
aerial photogrammetry and digital data  
management

# Oregon – Measuring change over long-term periods

Ground and aerial-based LiDAR for rock  
slopes and coastal bluff retreat

# Coastal Erosion and Coastal Landslide Monitoring Using Ground-Based LiDAR

Using Technology to Detect, Monitor,  
and Visualize Geomorphic Changes to  
Inform Policy, Planning, and Project  
Selection with respect to Climate  
Change and Seismic Events

*Michael Olsen, OSU; Ben Leshchinsky, OSU; Curran Mohnney, ODOT*

## Terrestrial LiDAR

### Mobile and Static Acquisition

- Supplemented by Color (RGB) assignment to individual pixels
- Point Cloud Generation and Comparison for Change Detection
- Total Station Survey of “Fixed” Objects



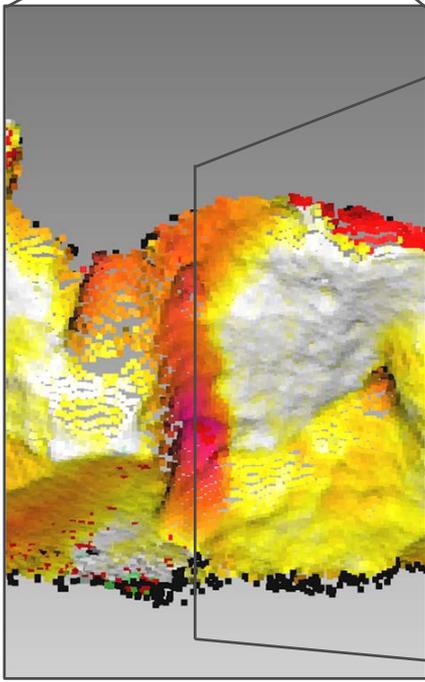
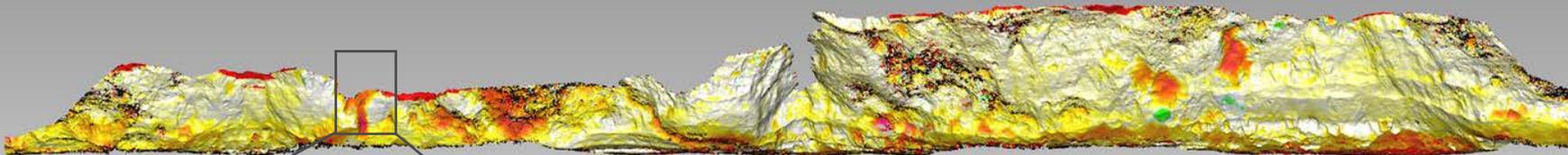
# Synthesis Report 554 Advances in Unstable Slope Instrumentation and Monitoring

Introduction

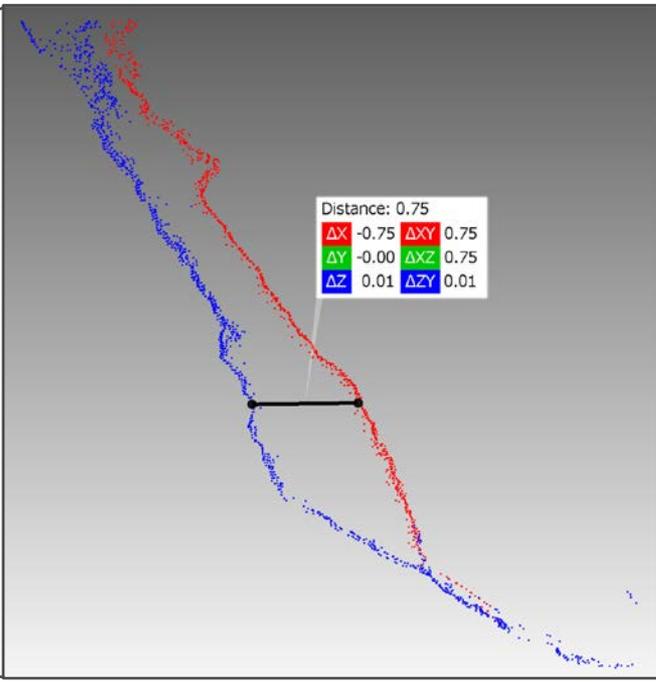
State of Practice

Practice Examples

Conclusions



4 metres

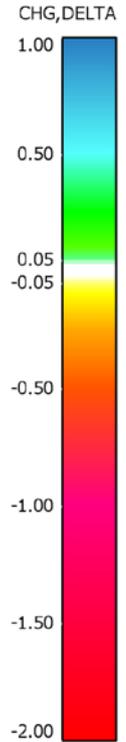


Distance: 0.75

$\Delta X$	-0.75	$\Delta XY$	0.75
$\Delta Y$	-0.00	$\Delta XZ$	0.75
$\Delta Z$	0.01	$\Delta ZY$	0.01

metres

4.2



# Synthesis Report 554 Advances in Unstable Slope Instrumentation and Monitoring

Introduction

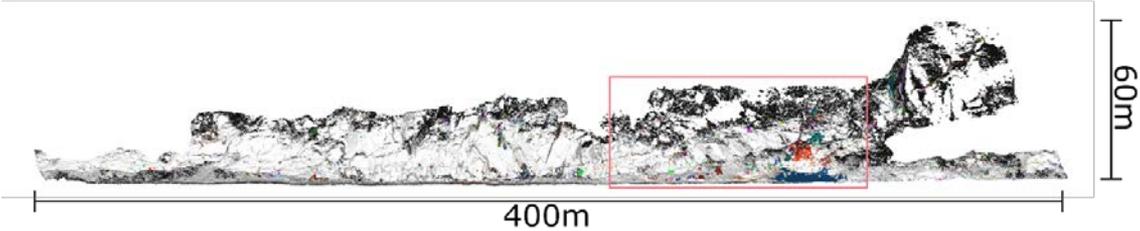
State of Practice

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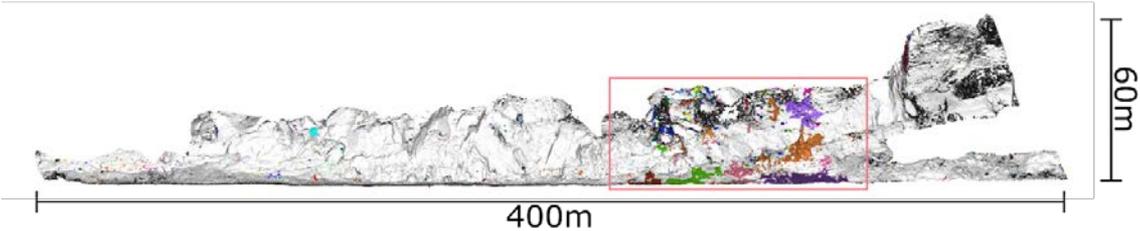
Conclusions

**SPR 809 – Rockfall  
Activity Index (RAI)**

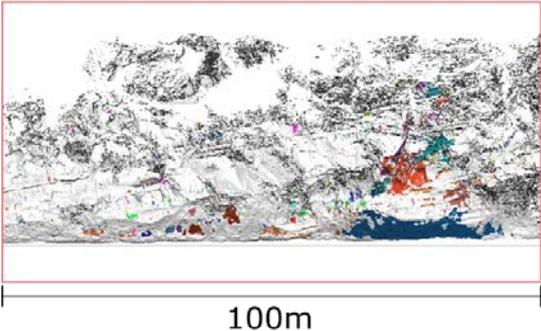
A). Mobile lidar ~ 3 passes



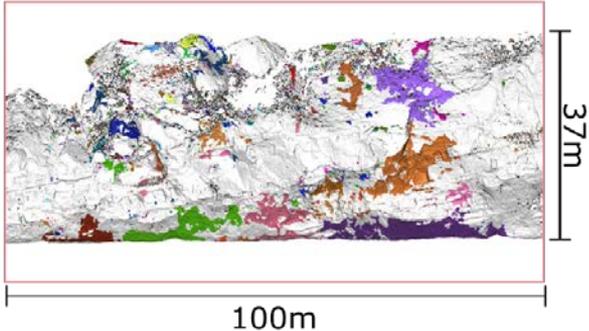
B). Terrestrial lidar



A). Mobile lidar ~ 3 passes



B). Terrestrial lidar



## Instruments:

### MEMS or Shape Accelerometer Array (SAA)

- ½ to 1 meter sensor lengths
- Capable of 360° readings on all axes
- Automated Readings along the full length of the borehole
- Remote output
- VW Piezometers attached



# Synthesis Report 554 Advances in Unstable Slope Instrumentation and Monitoring

Introduction

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Practice Examples

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Installing the MEMS in the hole



MEMS and VWP ready to install

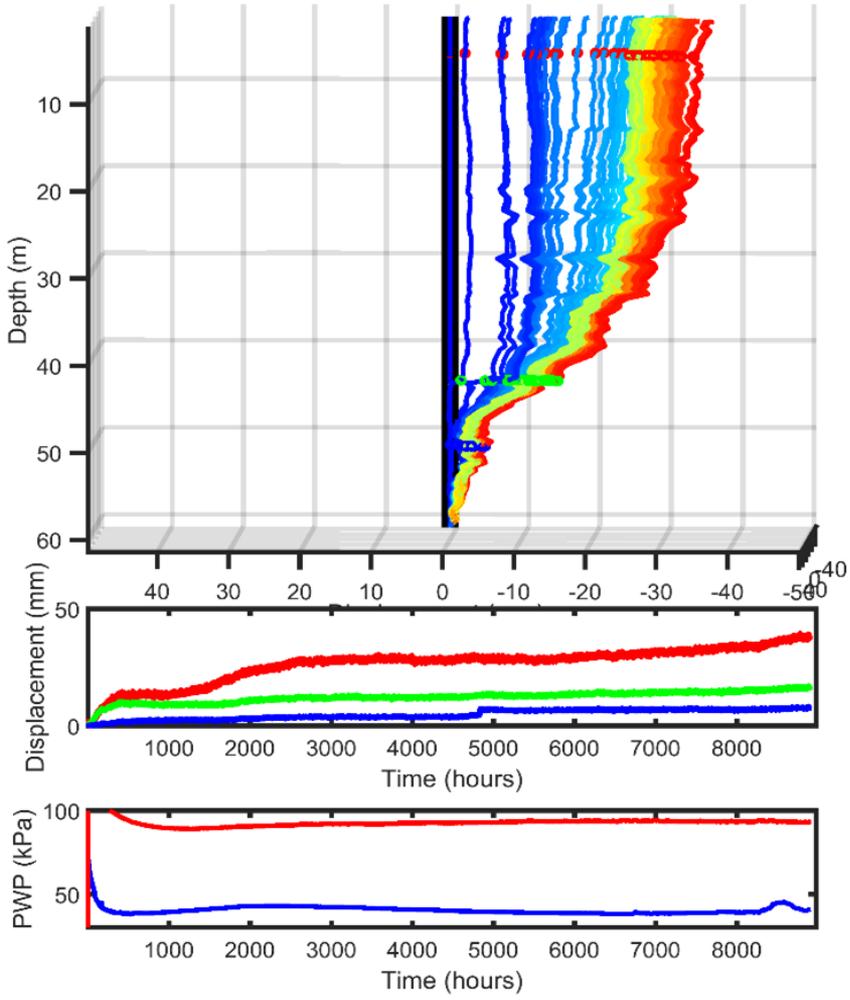
# Synthesis Report 554 Advances in Unstable Slope Instrumentation and Monitoring

Introduction

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Conclusions



SAA results

# Conclusions and Opportunities

# Synthesis Conclusions

- Unstable slopes impact almost every DOT
- Instrumentation and monitoring are across the life-cycle for:
  - Tracking slope movements
  - Informing hazard treatment decisions
  - Reducing uncertainty in design
  - Supporting maintenance and operations
  - Verifying performance is within expectations

# Synthesis Conclusions

Approximately 1/3 of the DOTs rely on instrumentation and monitoring for warning or emergency action work on unstable slopes

# Synthesis Conclusions

## Advancements in I&M

- Remote sensing has the greatest increase in use
- Ground-based and aerial LiDAR are the most common remote sensing methods for state DOTs

# Synthesis Conclusions

## Advancements in I&M

- Ground-based I&M advancements are related to technology improvements to established instrumentation types
- Electronic-based data management and visualization systems are an I&M technology showing increased use within last 10 years

# Opportunities

The synthesis suggests that existing and well proven instrumentation technology is underutilized

# Opportunities

Most states would benefit from training, additional staff resources, and additional funds to enable greater use of I&M

# Opportunities

An objective basis is needed for determining the need for I&M and communicating the benefit and cost-effectiveness of implementing existing and new technology

## Future Research Needs

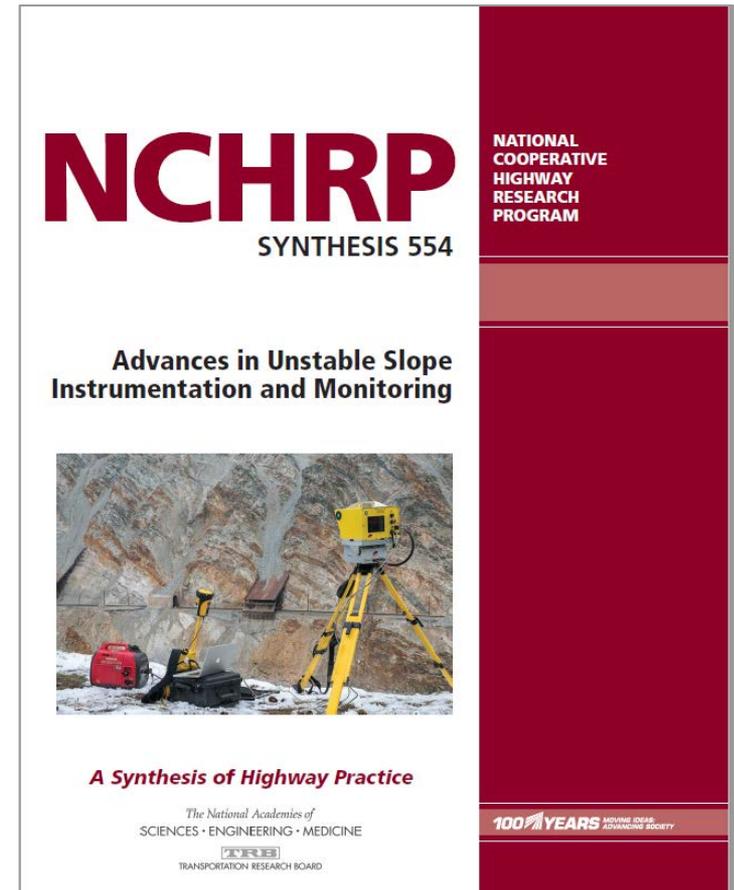
- Frameworks to match the application of technology to the unstable slope need
- Cost and benefit guidance for the business case of I&M
- Training and tools for implementation of specific I&M technologies

## Where to learn more

### NCHRP Synthesis 554: Advances in Unstable Slope Instrumentation and Monitoring

- On the web at:

<https://www.nap.edu/catalog/25897/advances-in-unstable-slope-instrumentation-and-monitoring>



# Today's Panel

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- Moderator: Derrick Dassenbrock, *Federal Highway Administration*
- Mark Vessely, *BGC Engineering*
- Scott Anderson, *BGC Engineering*
- Cole Christiansen, *BGC Engineering*

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# TRB's Annual Meeting Registration is Open!

- 100<sup>th</sup> TRB Annual Meeting is fully virtual in January 2021
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- [Registration](#) is open!
- Check our [website](#) for more information

