Technology and Automation Revolutionizing Geoprofessional Practice

Dimitrios Zekkos, PhD, PE

Associate Professor

Berkeley UNIVERSITY OF CALIFORNIA

GBA SPRING CONFERENCE

San Diego, April 9 2022

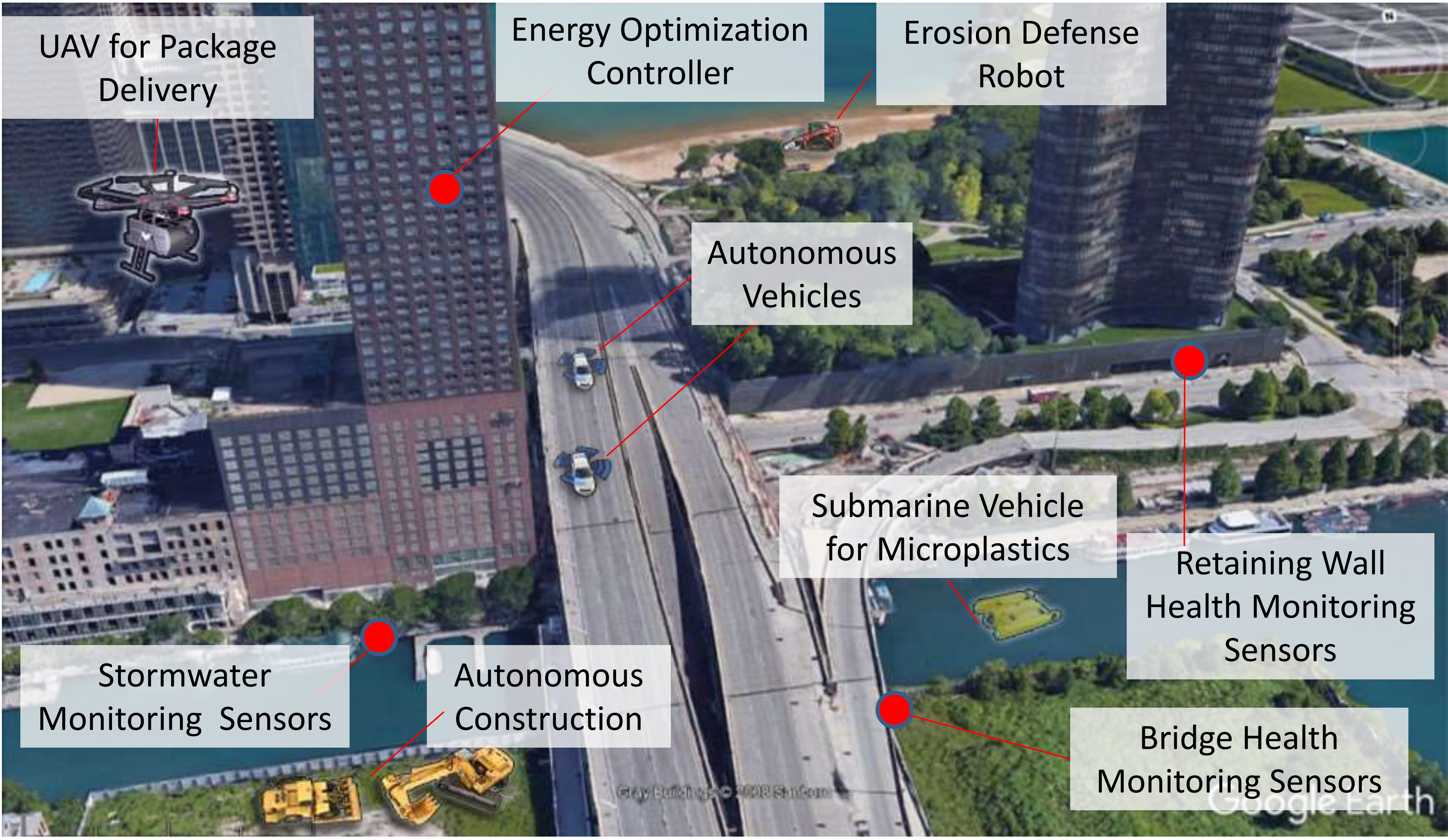
Outline

- Automation & Infrastructure
- Example applications of autonomy and decision-making across scales:
  - Satellite
  - **UAVs**
  - On-the-ground sensors
- Think Big Conclusions
- Act Bigger Recommendations

Berkeley
UNIVERSITY OF CALIFORNIA

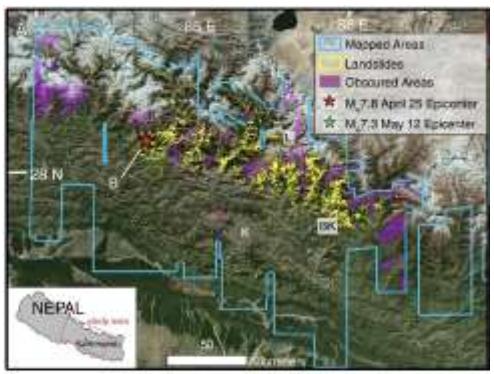
Autonomy for Infrastructure & the Environment

Advances in Autonomy (robotics, sensing and controls) will shape the way we protect the environment & design, build, monitor and operate our infrastructure

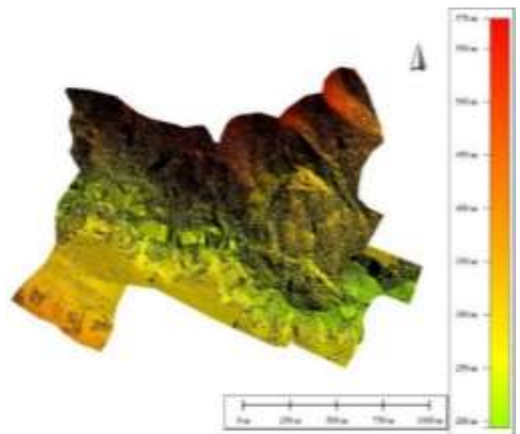


Multi-scale, multi-sensing monitoring frameworks can provide system-level resiliency

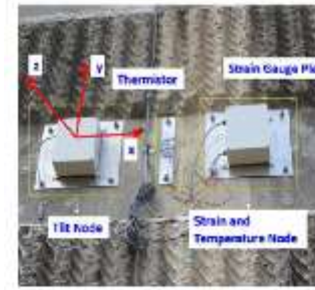
SATELLITES



UNMANNED AERIAL VEHICLES



WIRELESS SENSORS

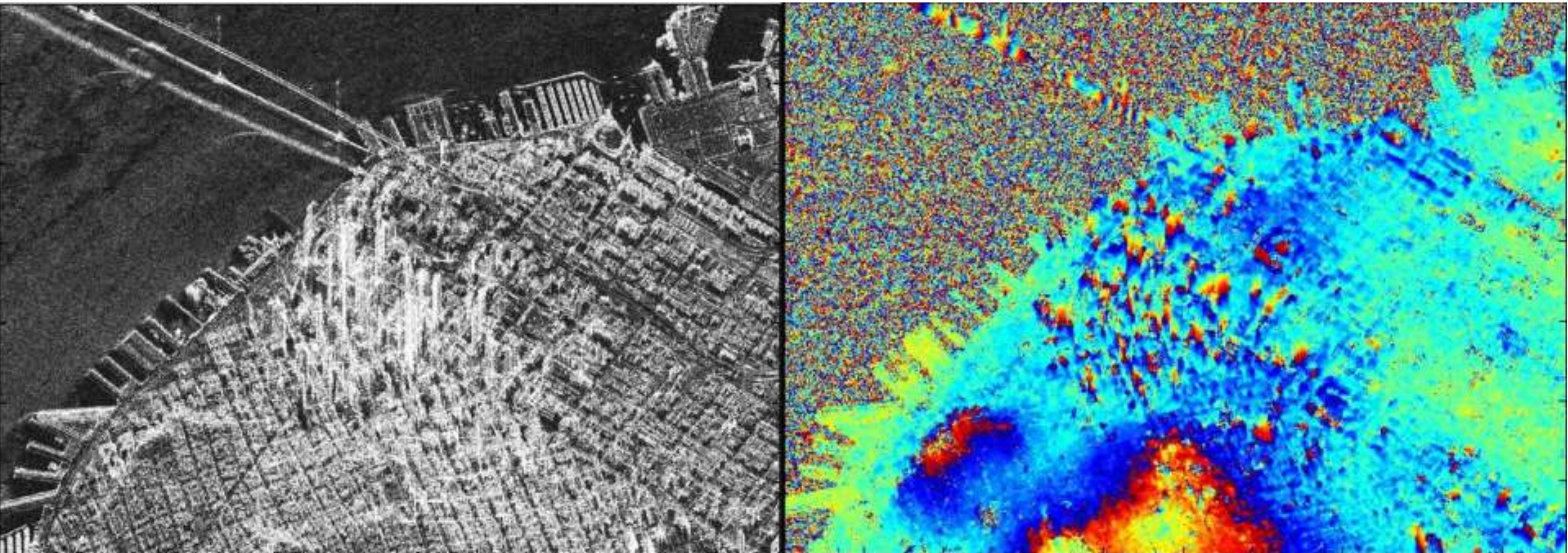


Coverage	>100 km²	1-100 km²	<1 km²
Data Resolution	>0.5 m	>1 cm	local
Data Frequency	days	hrs	sec
Sensors	Optical, Infrared, Radar	Optical, Infrared, and more	Wide range

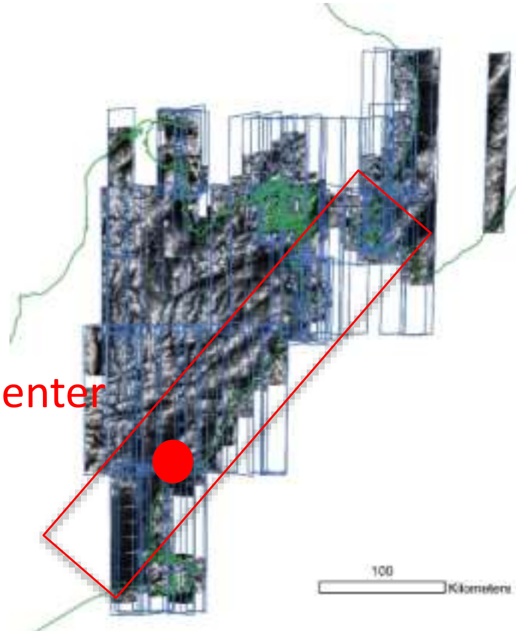
Satellite Monitoring Innovation

- Unprecedented investment on new satellite constellations with multiple sensors (optical, radar, infrared)
- Earth observation satellites in orbit:
  - 2008: 150 satellites
  - 2019: 768 satellites
- Improving data quality & data frequency collection

Worldview 3 – Digital Globe



Satellite-based Digital Surface Model DSM following 2016 Kaikoura Earthquake



Kaikoura M_w7.8 earthquake affected region

Based on open-access Surface Extraction with TIN-based Search-space minimization (SETSM) methodology.

Created DSM at 0.5 m and 2 m resolution
North part of South Island = 65,000 km^2
(Size of the State of South Carolina)

Berkeley
UNIVERSITY OF CALIFORNIA

Robots are an integral part of Autonomous Infrastructure

LAND-BASED

April©

SUBMARINE

Youcan©

AERIAL

DJI Matrice 600©

Photos of Robots used by our Research Group

Berkeley
UNIVERSITY OF CALIFORNIA

Why is UAV Technology changing the Geo-Infrastructure field?

- Inexpensive, yet powerful
- Mobile
- Safe(r)
- Multi-sensing capability
- Data acquisition platform
- Computational platform

UAVs introduce mobility in sensing!

Photos of UAVs at UC Berkeley

UAV Multi-Sensing Capabilities are key

The ability of UAVs to integrate with any type of sensor is empowering for characterizing infrastructure systems

Sensor to be used depends on project needs

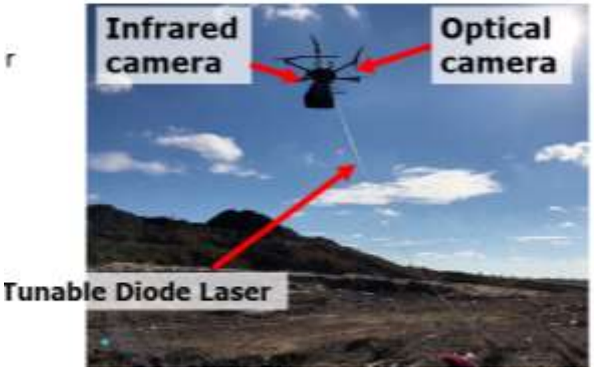
Optical Camera

Infrared Camera

Multi-Spectral Camera

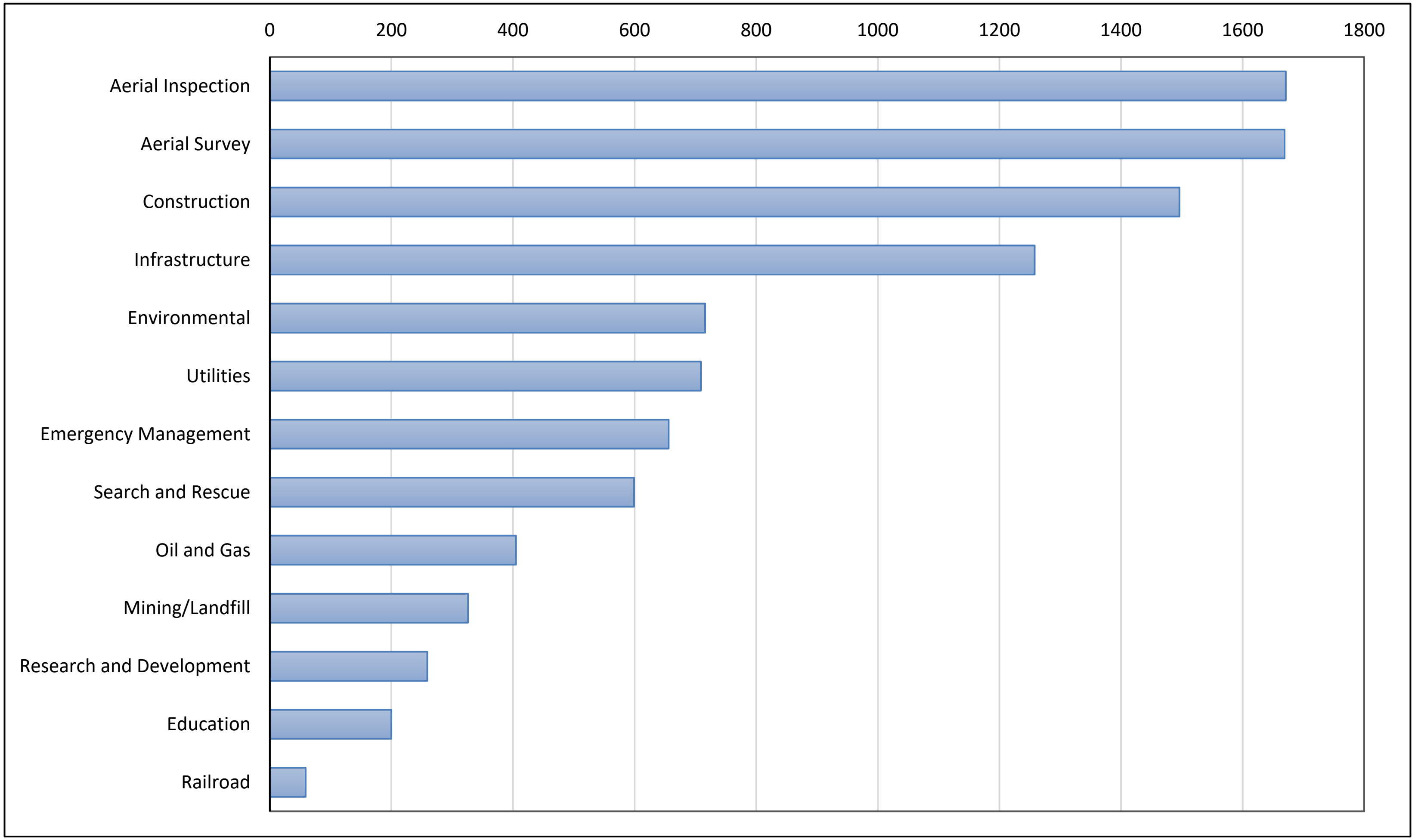
LIDAR

Geophysics



Laser + opt + infrared

Imagery Collection and Construction Sequence Monitoring



Number of civil engineering-related applications cited in FAA UAS exemption applications (Greenwood et al. 2019)

Mobility & Accessibility are key advantages of UAV-based imagery!

- November 17th 2015 Mw 6.4 Lefkada earthquake (Greece)

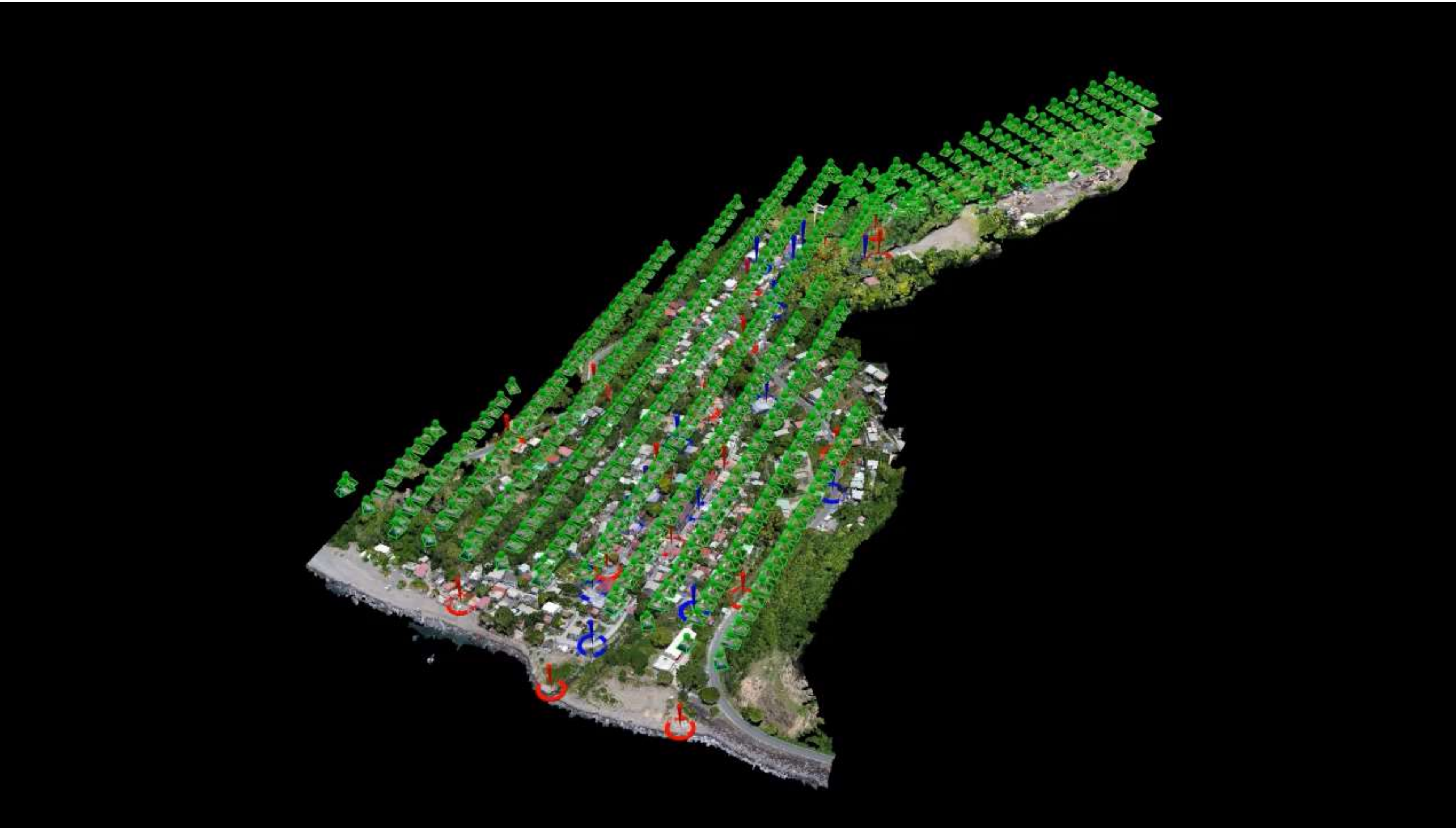
← November 19th 2015 (2 days later)

UAVs allow immediate access to field data that may be otherwise inaccessible by land or satellite

← April 12th 2016 (5 months later)

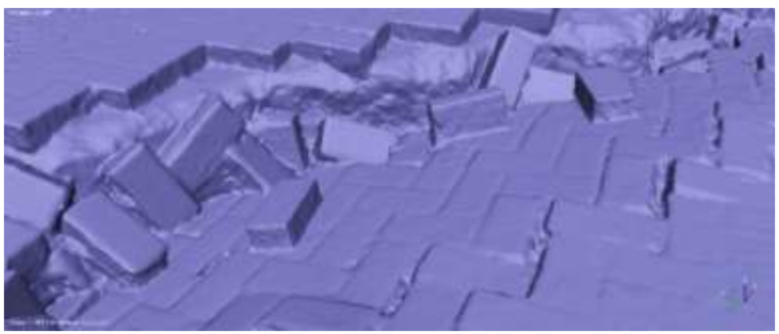
Creation of 3D Models using Optical Cameras

- Based on Structure-from-Motion (SfM) Photogrammetry using overlapping imagery
- 3D models may be 3D point clouds, 3D Surfaces (Meshes)

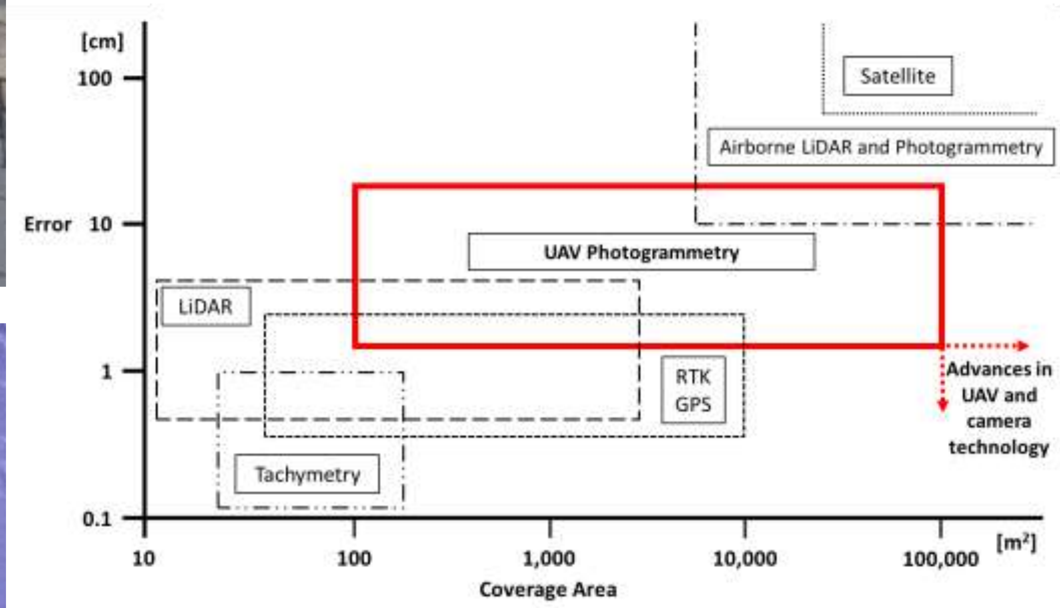


Island of Dominica, Caribbean sea

SfM is competitive in Accurately Mapping Large Areas at High Resolution



Resolution can be really high!
Ground Sampling Distance
GSD: 1.13 mm/pix
point density: 77.7 points/cm²



Extensive publication record on error/accuracy quantification

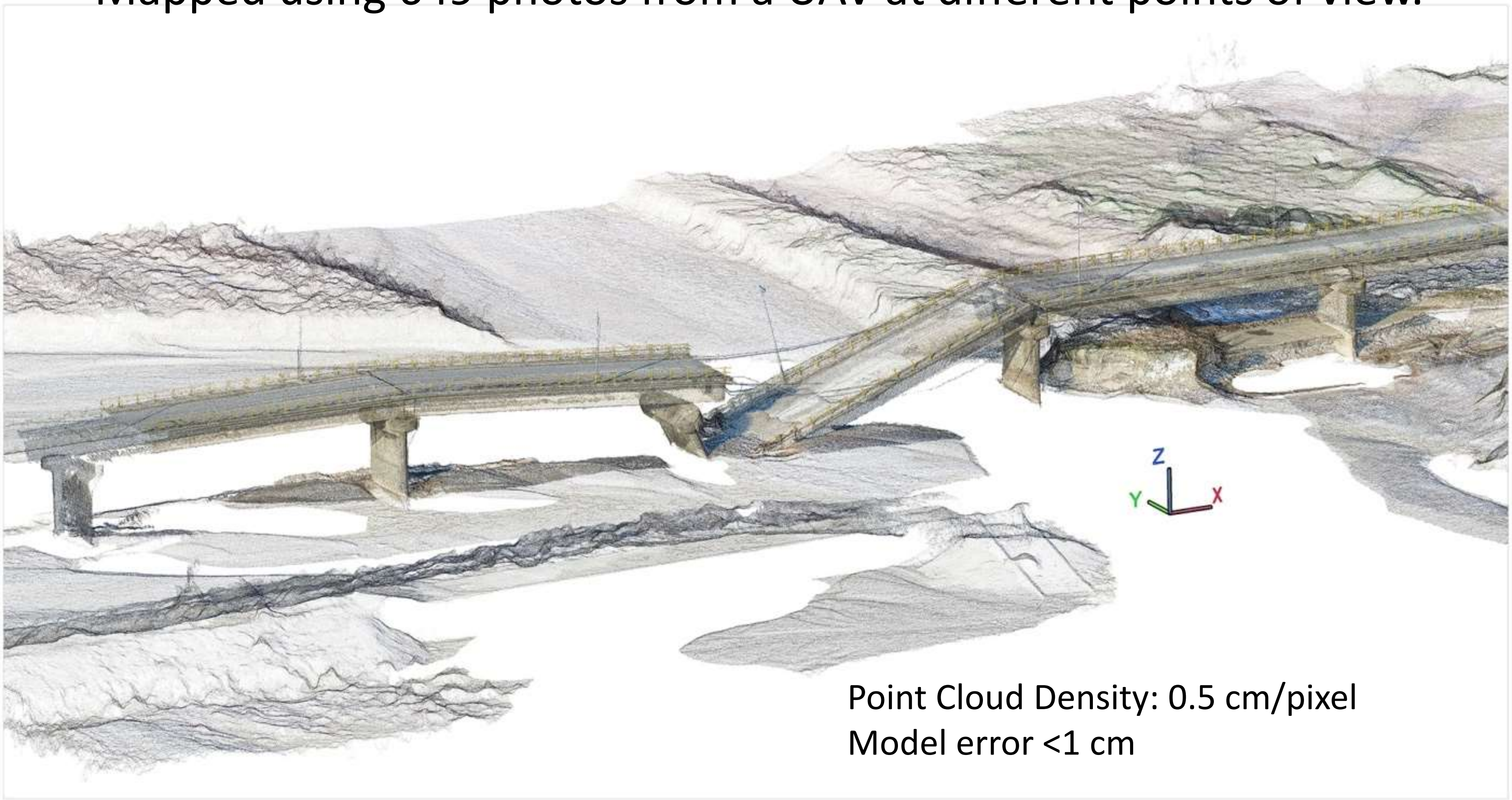
Greenwood, W. W., Lynch, J. P., & Zekkos, D. (2019). Applications of UAVs in civil infrastructure. *Journal of infrastructure systems*, *25*(2), 04019002.

Example Study #1: Remote Mapping of a Bridge Scour Failure

- Failure location was physically inaccessible due to river flooding & safety concerns by the owner
- 3-hr survey just 2 days after the failure. Analyzed using SfM

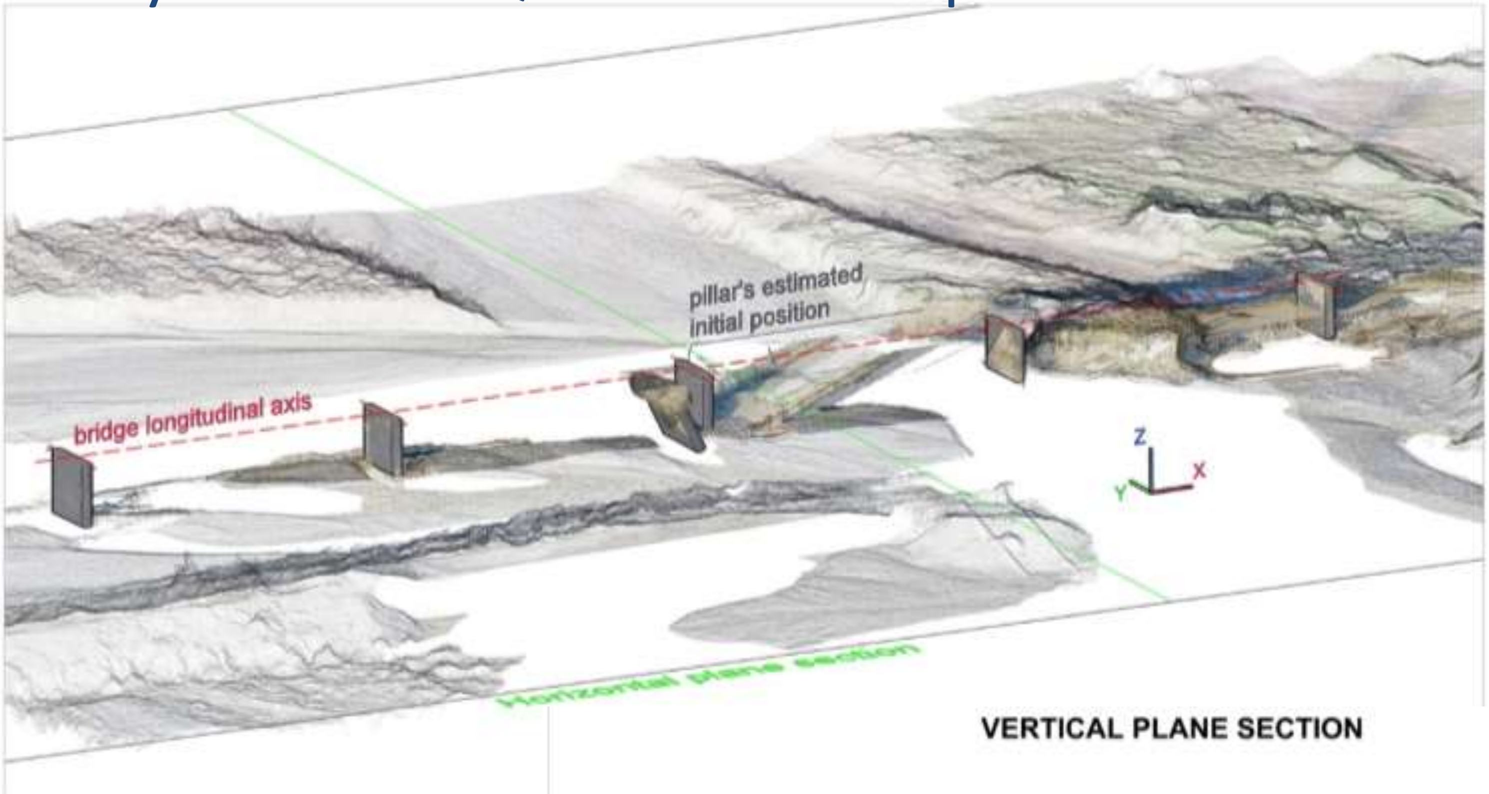
3D point cloud of the model

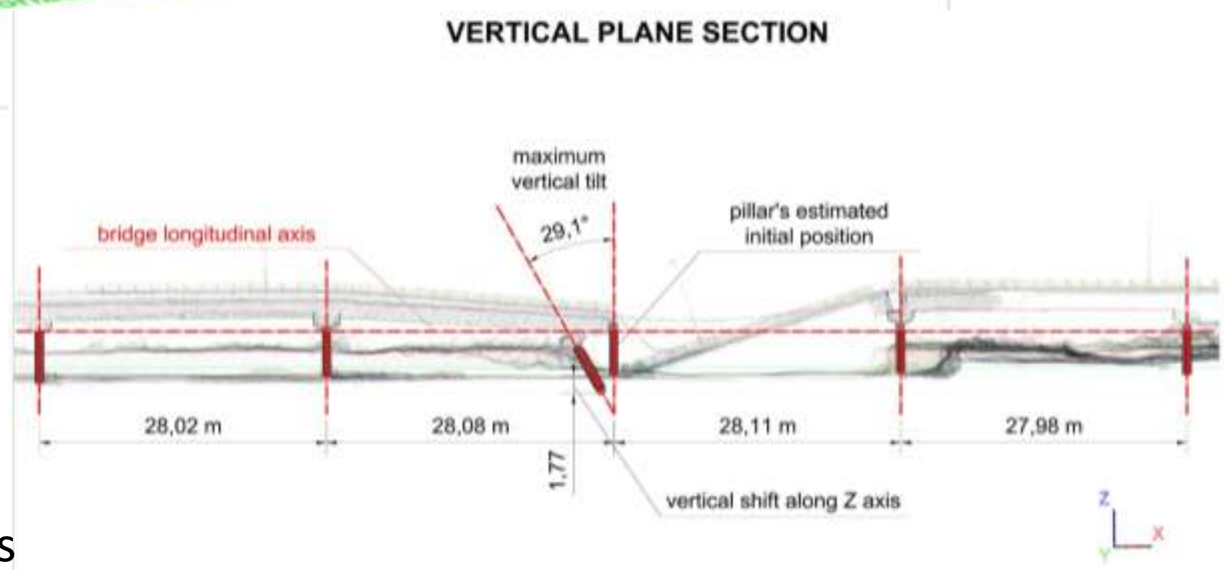
Mapped using 649 photos from a UAV at different points of view.



Zekkos, D., Manousakis, J., Greenwood, W., & Lynch, J. (2016, June). Immediate uav-enabled infrastructure reconnaissance following recent natural disasters: case histories from greece. In *International conference on natural hazards and infrastructure*.

Remotely-collected Quantitative Displacement Measurements





The bridge pier *displaced:*
1.38 m along bridge axis
0.91 m perpend. to axis
1.77 m vertically
The bridge pier *rotated*:
5.7 degrees horizontally
Vertical inclination 29.1 degrees

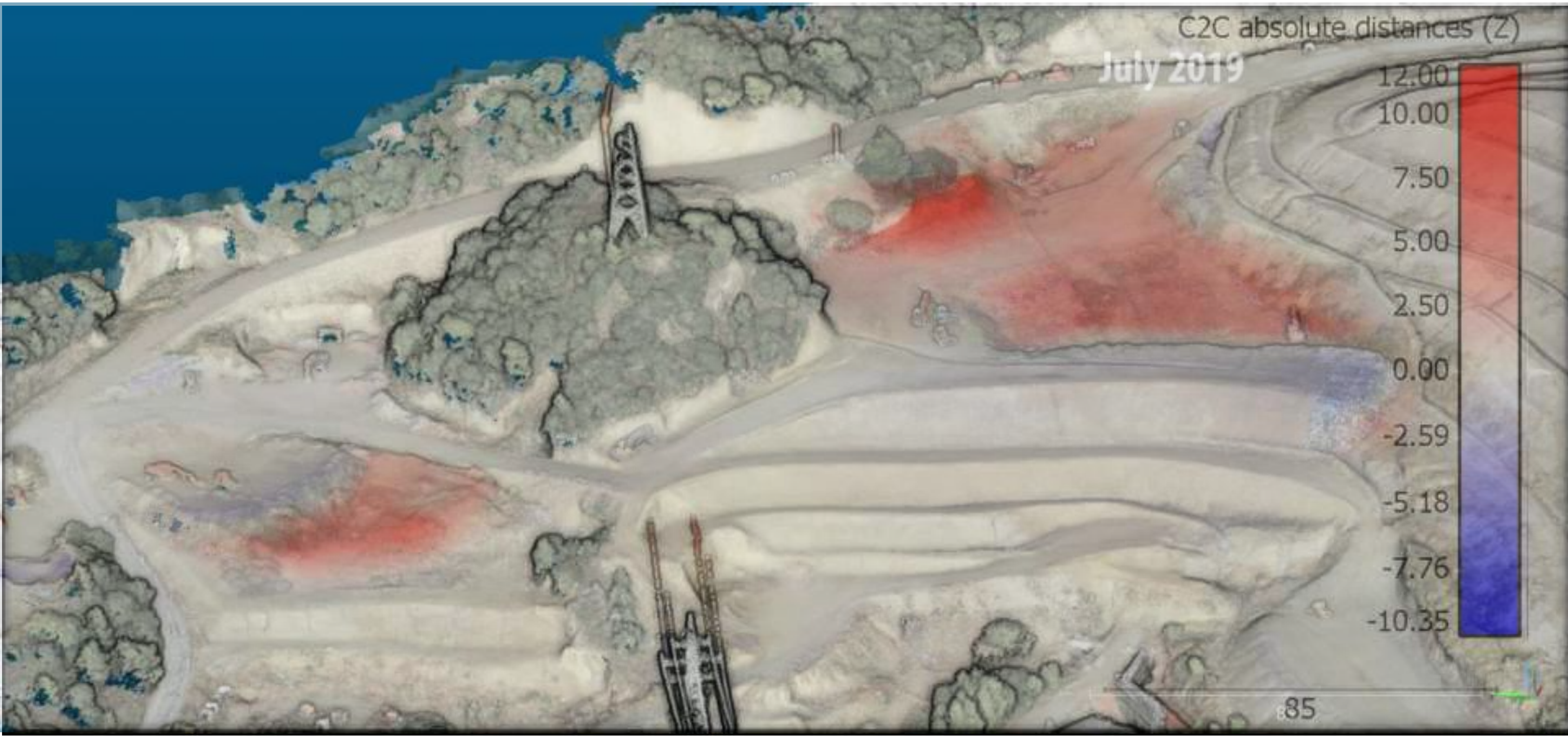
Example Study #2: Cut and Fill Volume Placement Calculation

Monitoring of operations at a landfill / construction site

July 30 2019

December 18 2019


July 2019
85

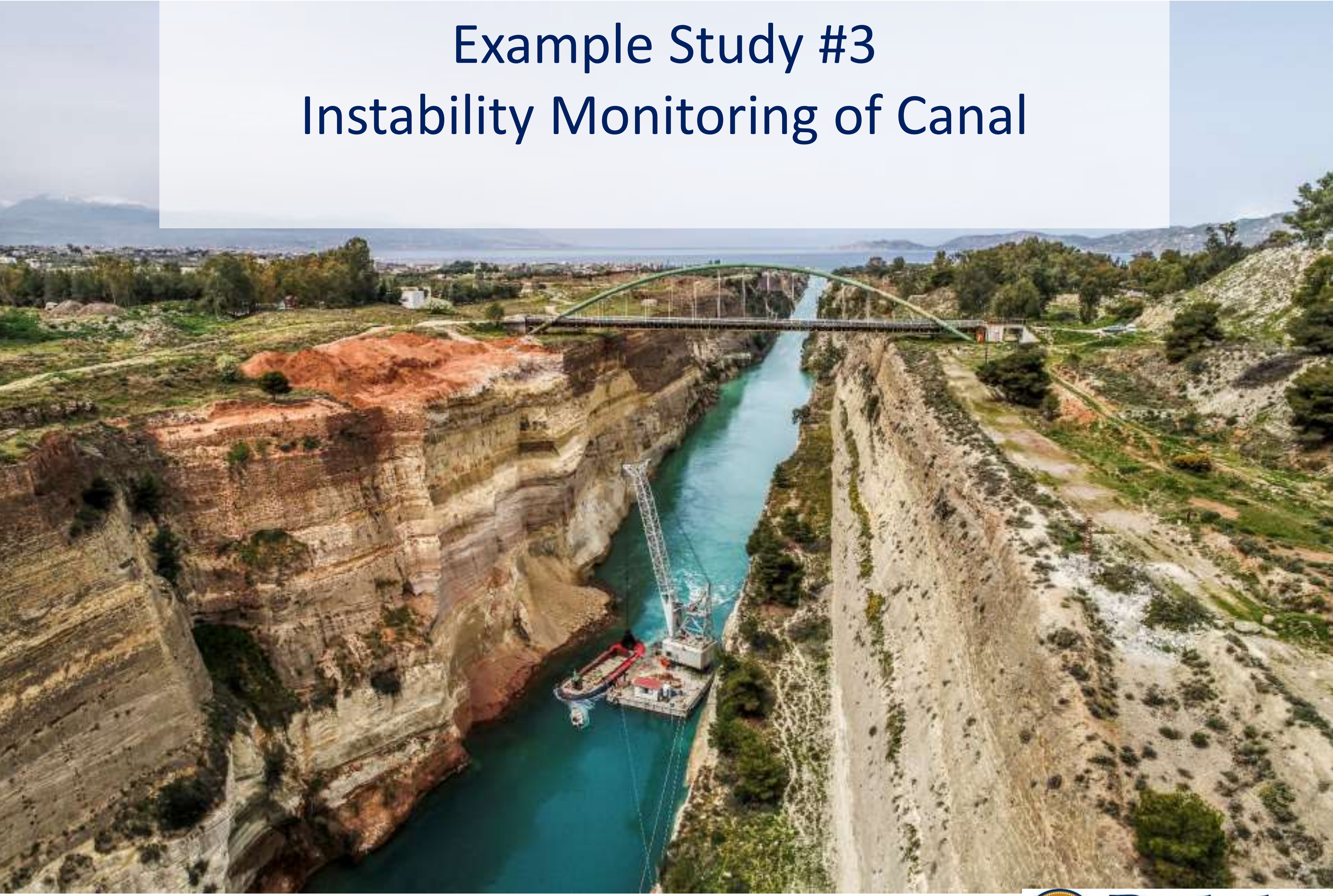


Volume of material placed between July 30 and December 18 2019: 53,200 m^3
Volume of material excavated between July 30 and December 18 2019 : 8,500 m^3

Height changes of a few cm can be measured

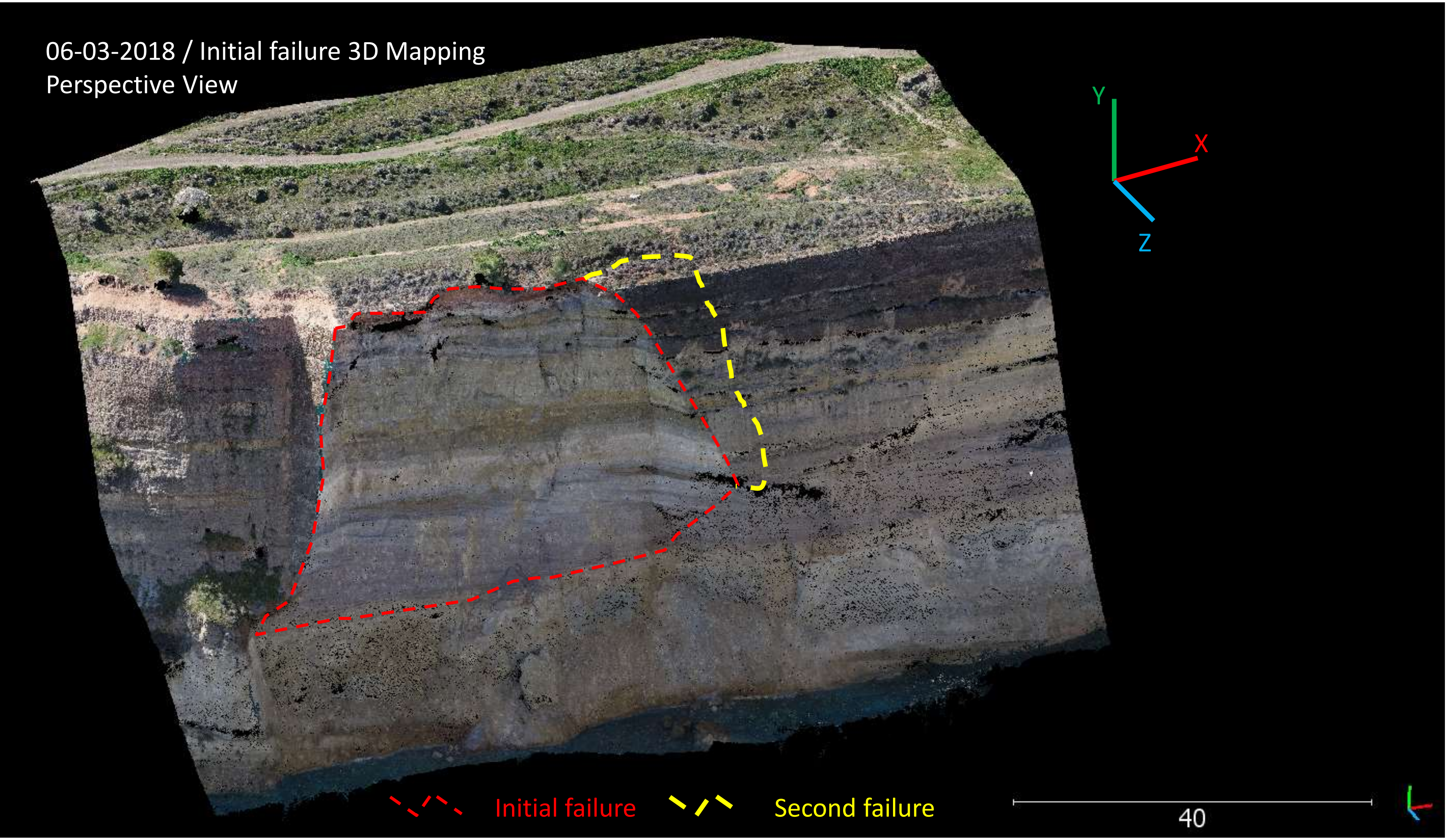
Berkeley
UNIVERSITY OF CALIFORNIA

Example Study #3
Instability Monitoring of Canal



The Corinth Canal, Greece

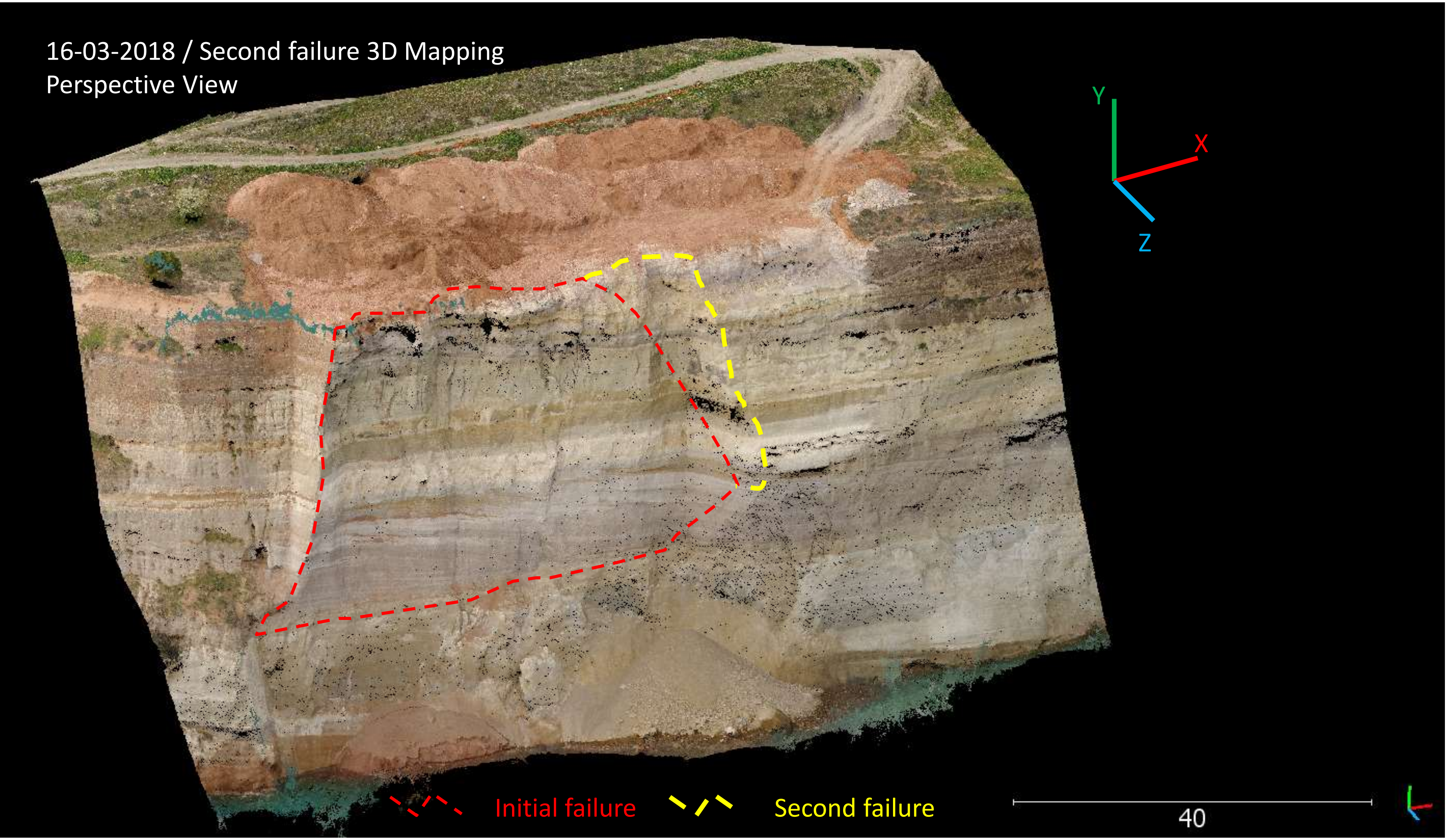
February 26 2018: First Failure



Volume Involved: 6000 m^3

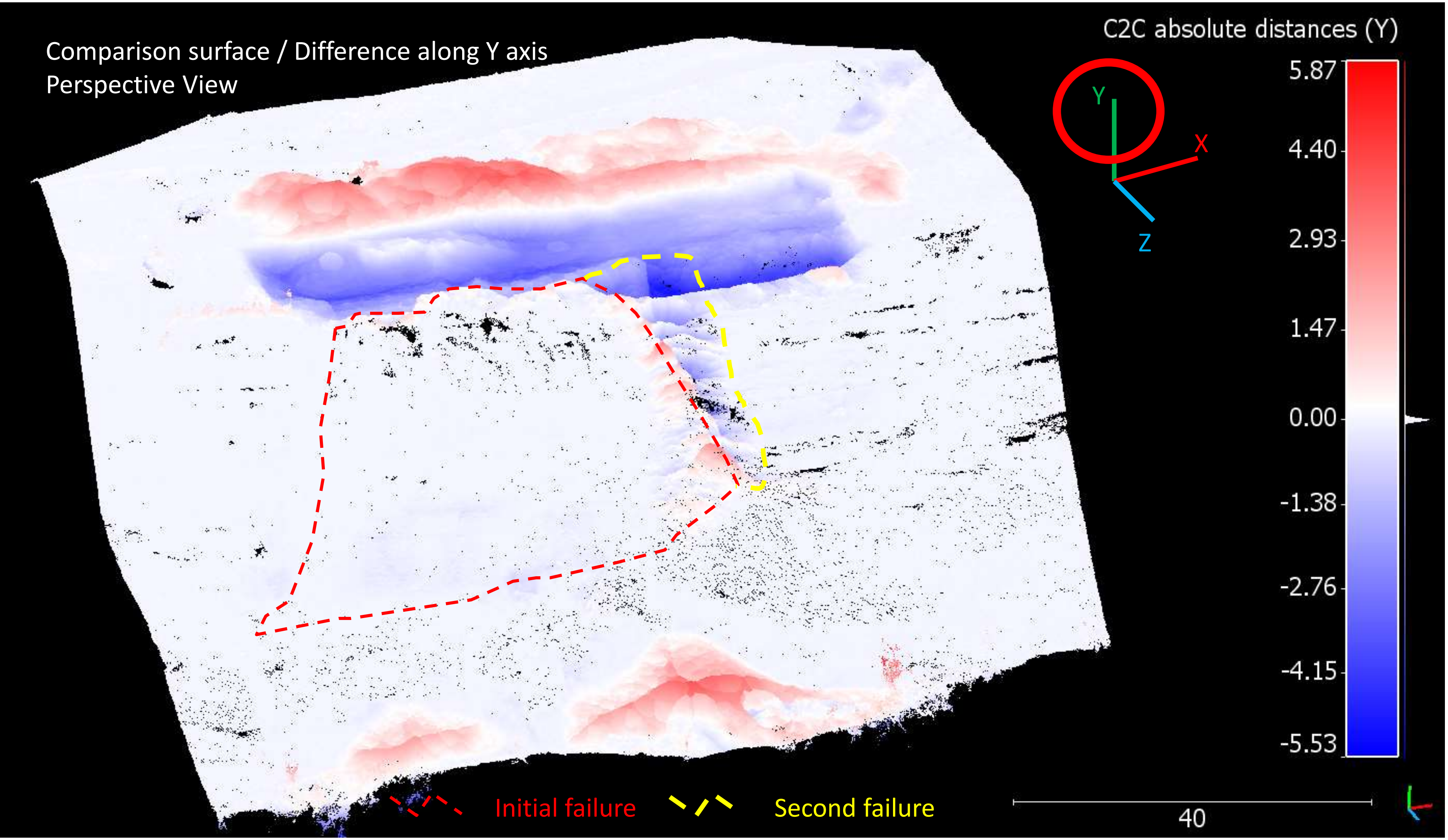
Berkeley
UNIVERSITY OF CALIFORNIA

March 9 2018: Second Failure



Volume Involved: 700 m^3

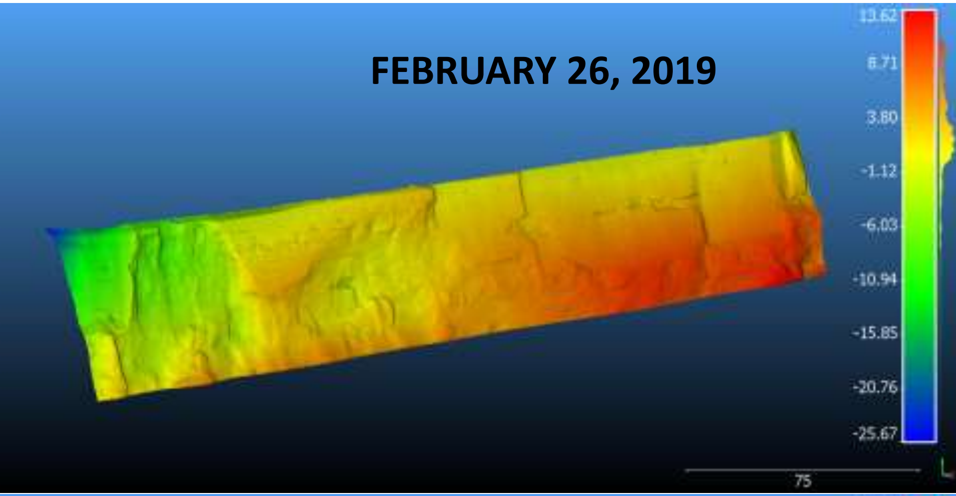
Berkeley
UNIVERSITY OF CALIFORNIA

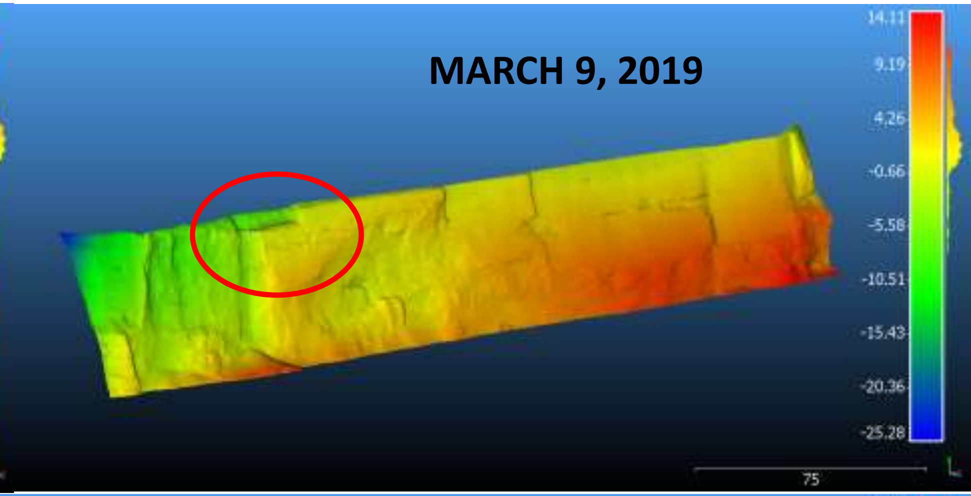


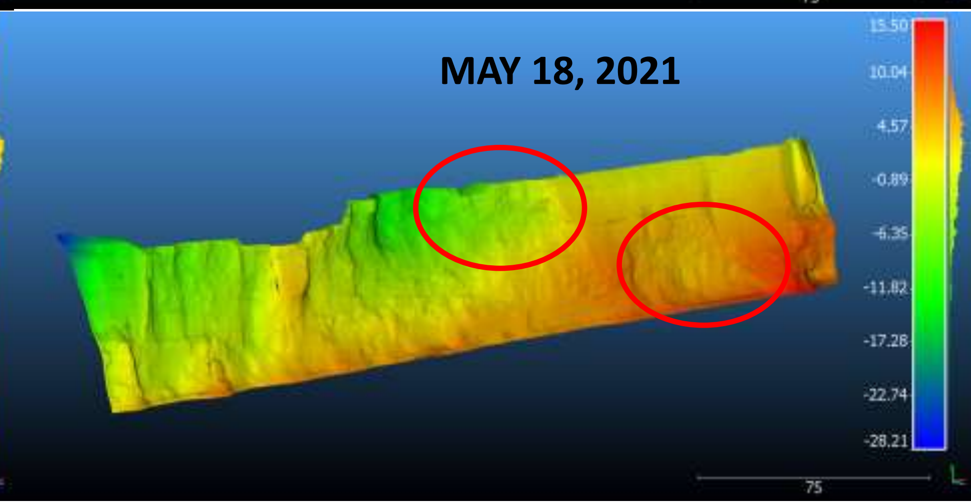
First failure: **6000 m^3.** Second failure: **700 m^3**

Berkeley
UNIVERSITY OF CALIFORNIA

SLOPE MONITORING





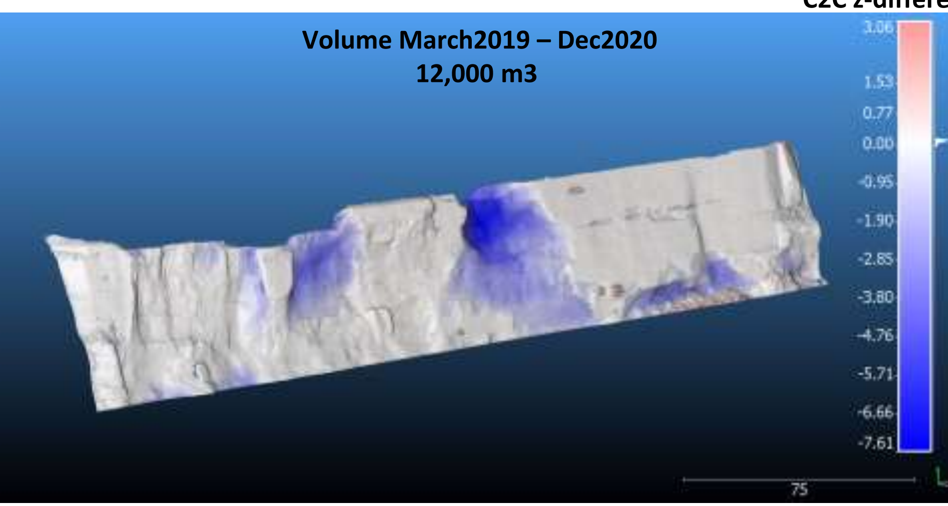


Berkeley
UNIVERSITY OF CALIFORNIA

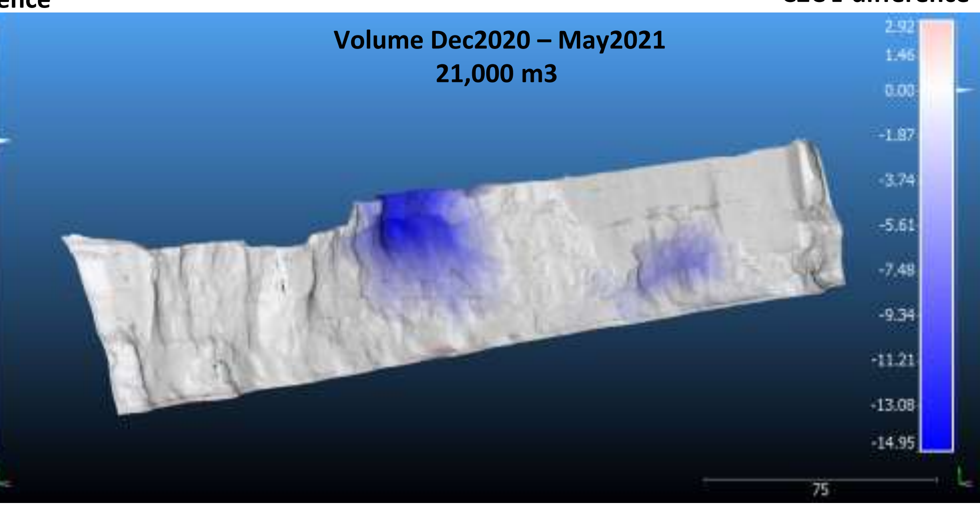
VOLUME CALCULATION

C2C z-difference

C2C z-difference



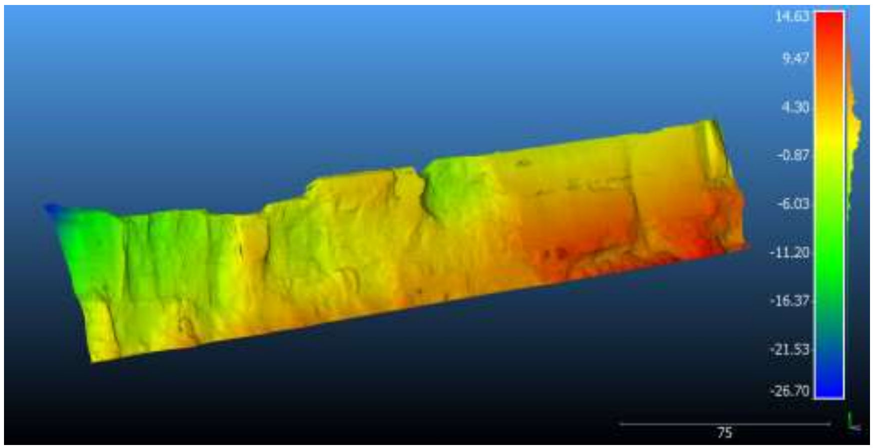
C2C z-difference



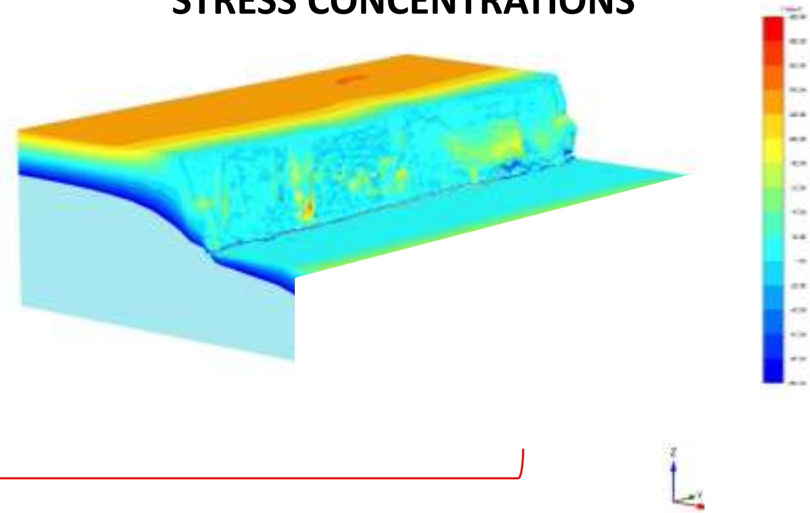
Berkeley
UNIVERSITY OF CALIFORNIA

Monitoring paired with Numerical Modeling Leads to Predictive Capabilities

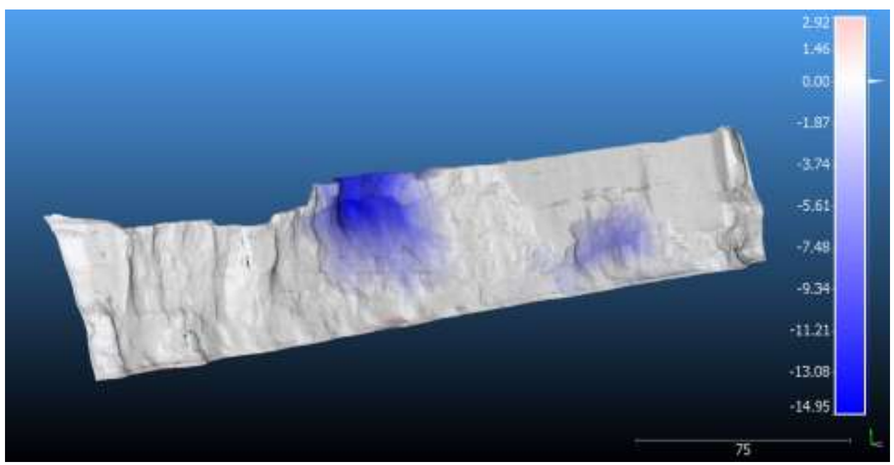
3D GEOMETRY ON DECEMBER 8, 2020



FINITE ELEMENT MODEL SIMULATION FOR STRESS CONCENTRATIONS



SLOPE RETREAT BY MAY 18 2021



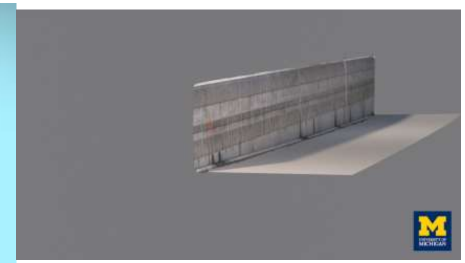
Berkeley
UNIVERSITY OF CALIFORNIA

Infrastructure 3D Modeling by our Research Group

Historical Structures

Cliffs / Cuts

Structural Damage



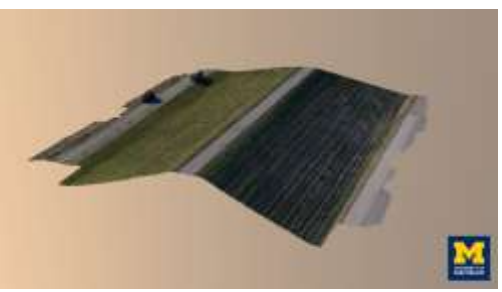
Retaining Walls

Canals

Quarries

Ports

Landfills



Roadway Embankments

Bridge Collapse

Dams & Levees

Landslides

Railroad

Rockfall

Airports

Rock masses

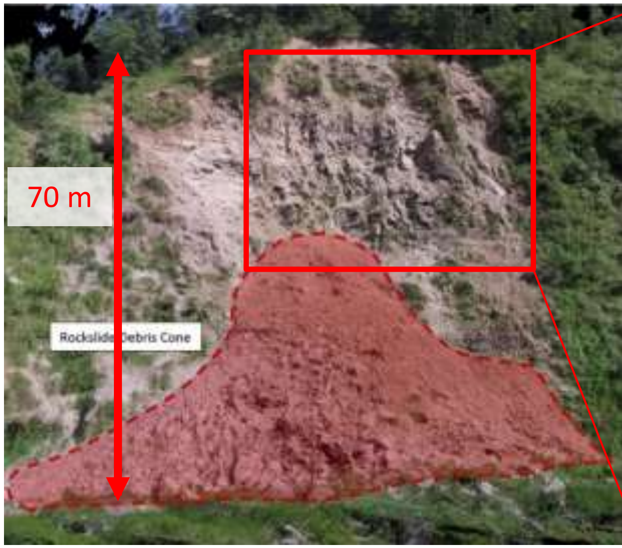
Community-Level Infrastructure Assessment Frameworks using Digital Twins

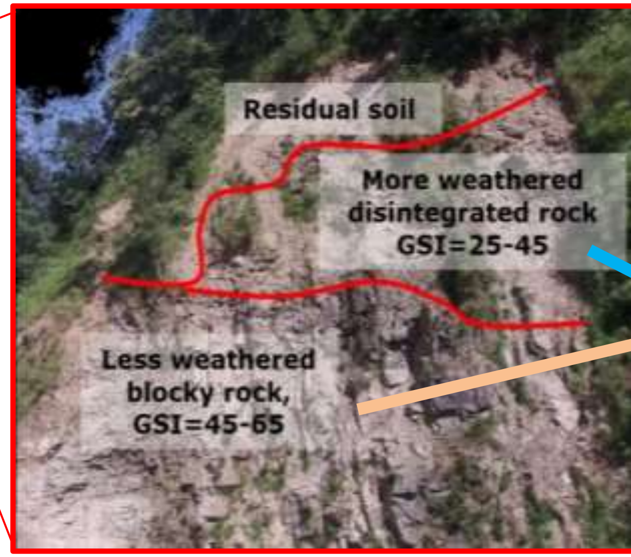
Data collected allows transition from infrastructure component to infrastructure system

Vrisa village, 12th June 2017 M_w 6.3 Lesvos earthquake, a week after the earthquake

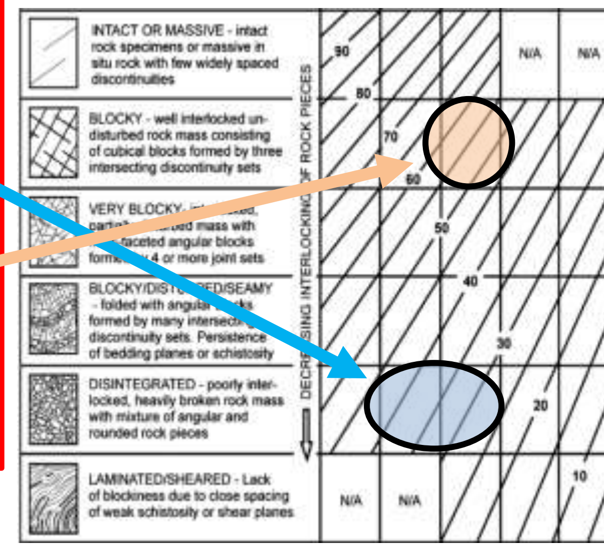
Enhancing Team and Client **Collaboration & Communication** of Engineering Results using Virtual Reality and Augmented Reality

Example 4: “Conventional” Rock Mass & Landslide Characterization

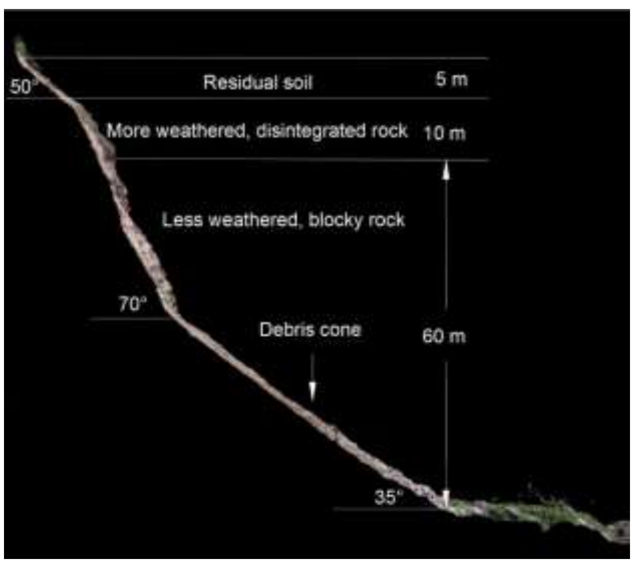




Geological Strength Index
Weathering condition of DISCONTINUITIES
good → bad



(Hoek et al. 2002)



Using 3D Digital Imagery Attributes, derive rock mass characteristics, e.g.,

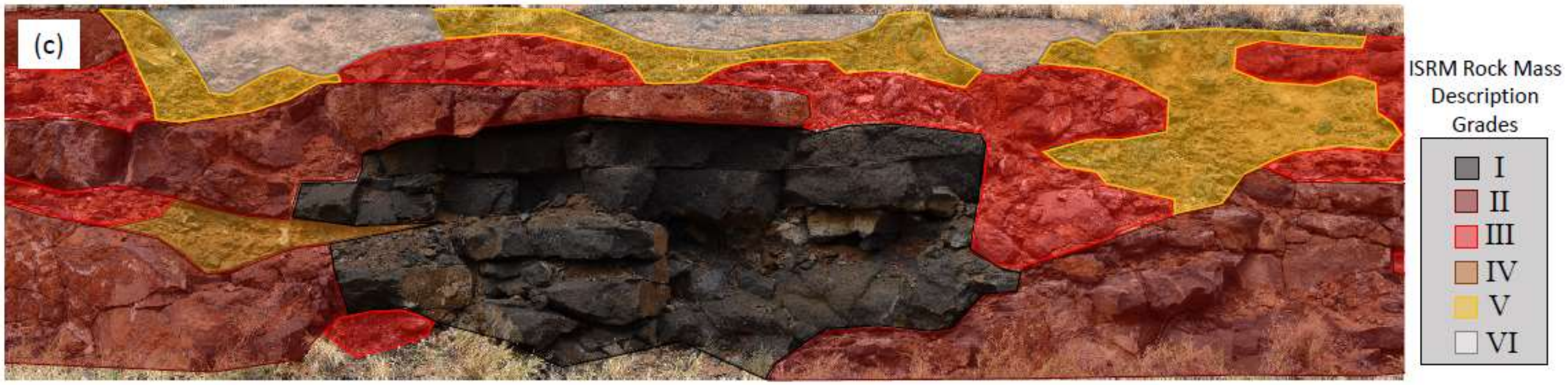
- Rock mass structure
- Rock mass weathering
- Rock mass strength

Zekkos, D., Clark, M., Whitworth, M., Greenwood, W., West, A. J., Roback, K., ... & Lynch, J. (2017). Observations of landslides caused by the April 2015 Gorkha, Nepal, earthquake based on land, UAV, and satellite reconnaissance. *Earthquake Spectra*, *33*(1_suppl), 95-114.

AI-based Digital "Image" Analyses of Rockmass 3D Model – Roadcut in Hawaii

3D Model

Manual Field Characterization

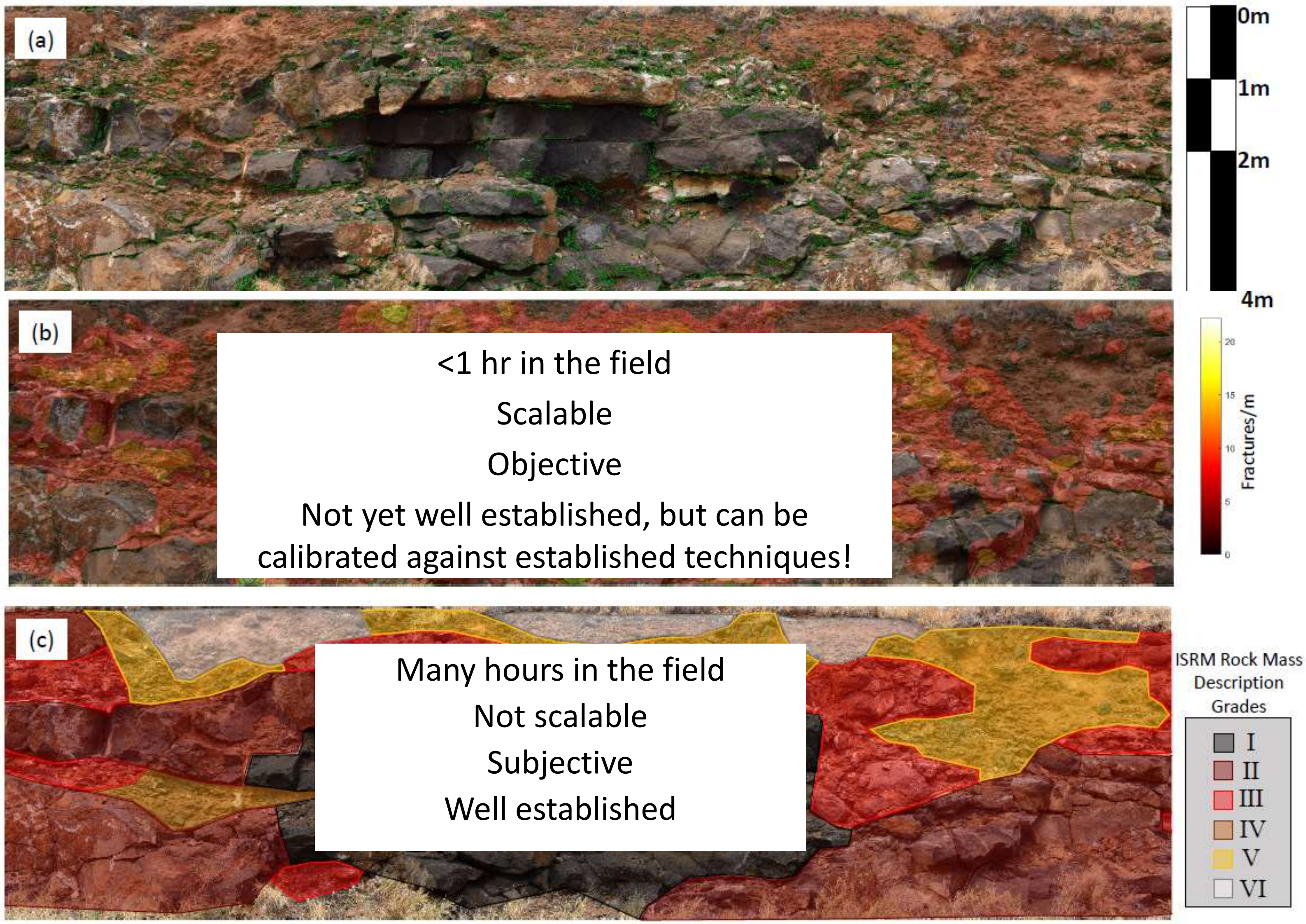


AI-based Digital "Image" Analyses of Rockmass 3D Model of Roadcut in Hawaii

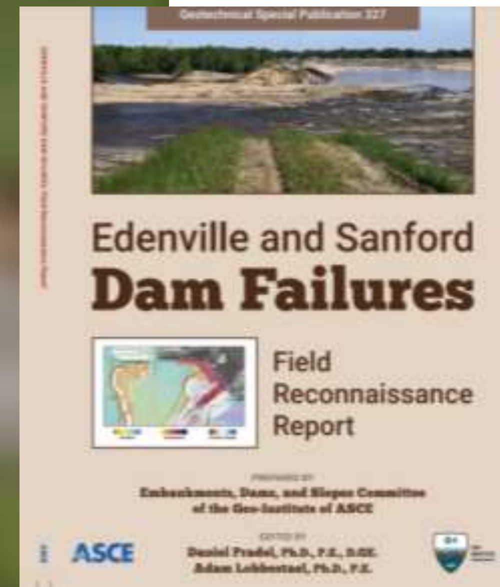
3D Model

AI-based Fracture Detection

Manual Field Characterization

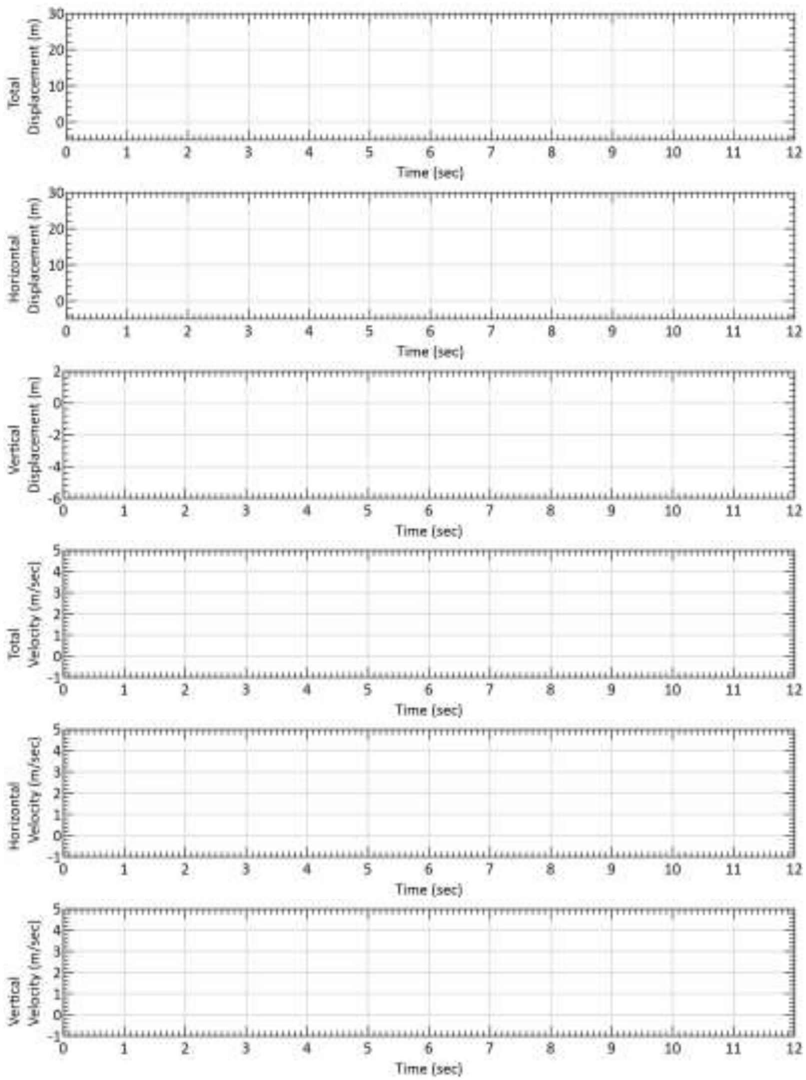


Example 5: UAV-enabled optical and infrared imagery fusion at Edenville Dam following May 19 2020 Failure



- Failure captured by by-stander
- Edenville Failure caused failure of Sanford dam and flooding to communities downstream

Forensic Investigation of the Kinematics Based on Digital Image Analysis

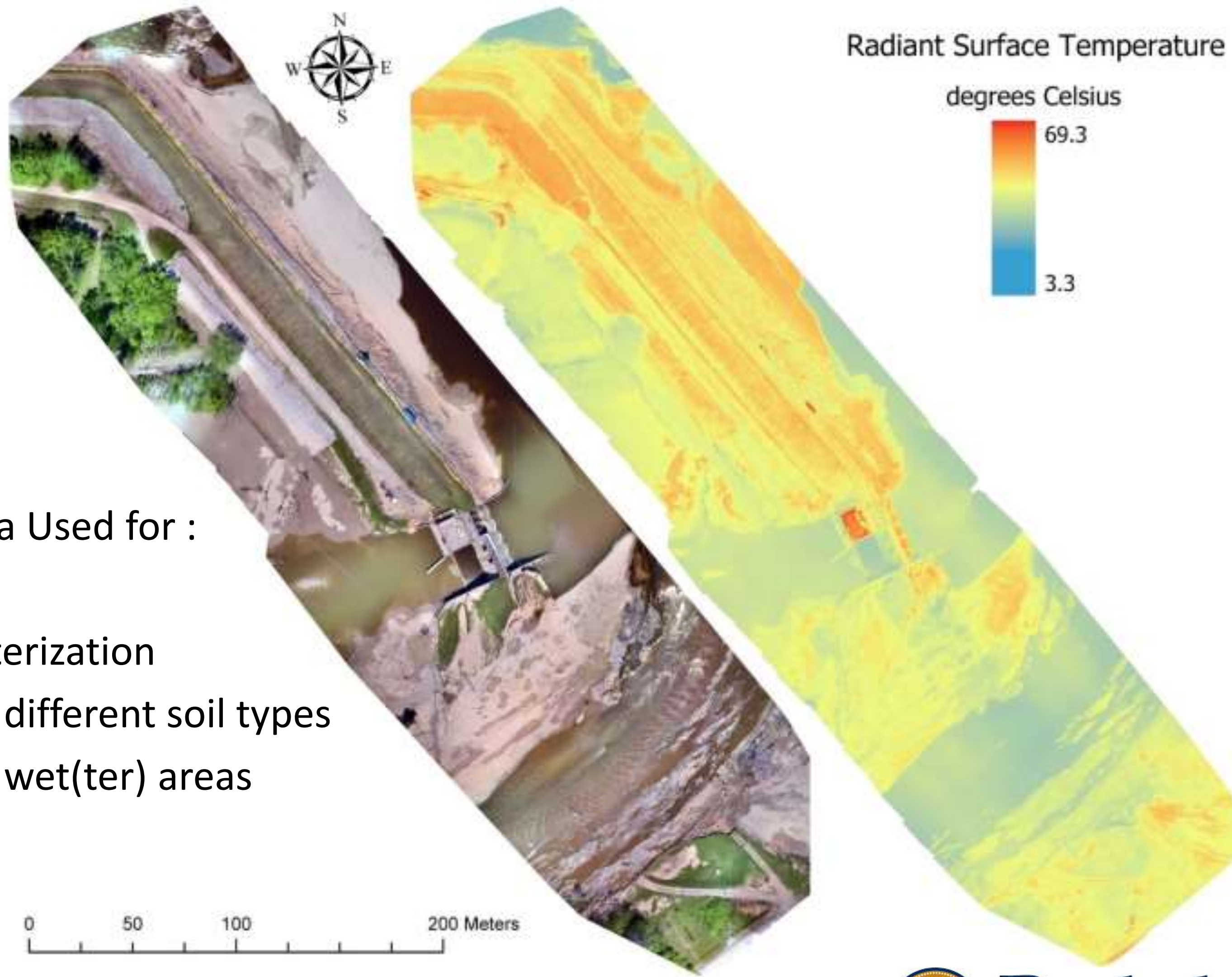


Using Image Stabilization algorithms and Pixel tracking algorithms

Berkeley
UNIVERSITY OF CALIFORNIA

3D Model from Optical Data

Optical and Infrared 3D Models of Edenville Dam

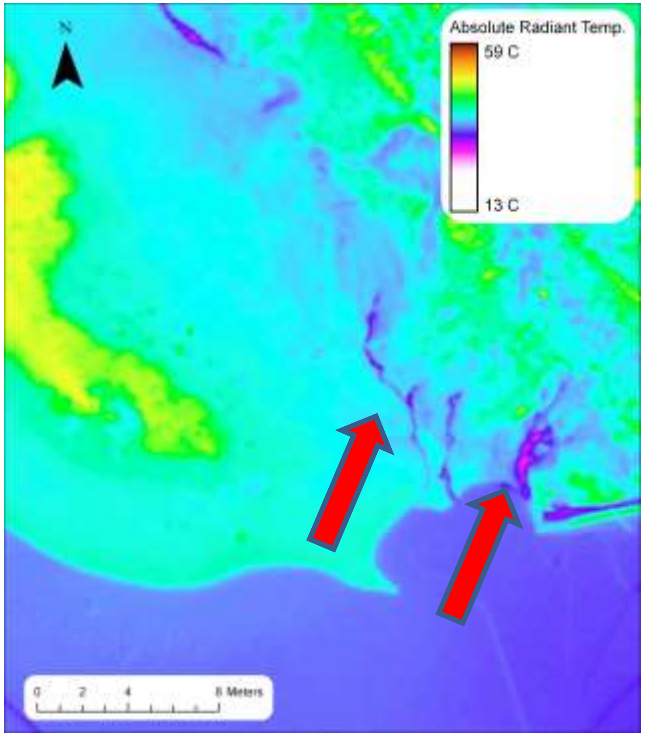


Optical and Infrared Data Used for :

- 3D modeling
- Material characterization
- Identification of different soil types
- Identification of wet(ter) areas

Infrared-based Identification of wet areas and seepage

Seepage is discerned as areas of lower temperature

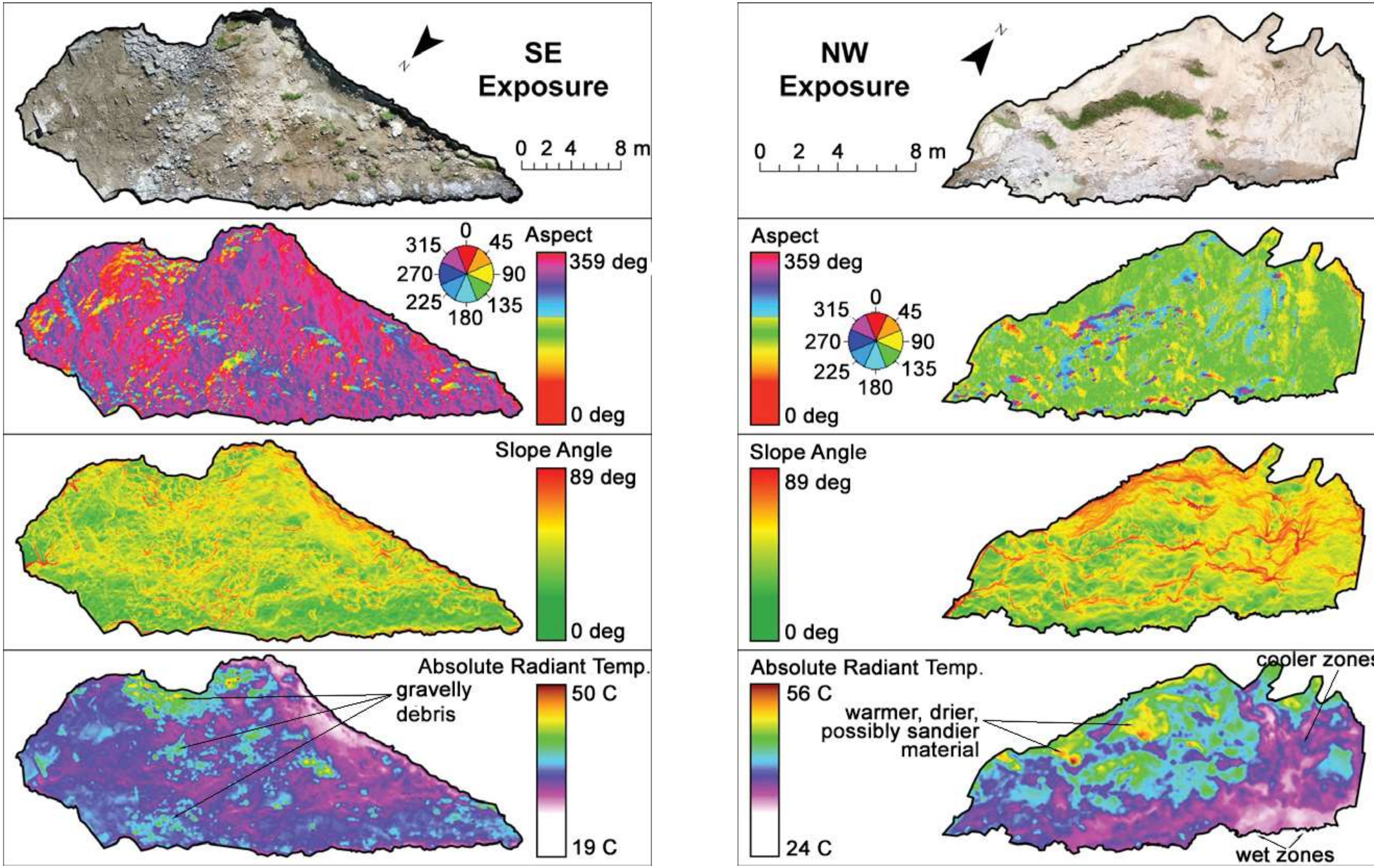


Even quantitative spatial estimates of moisture content are possible

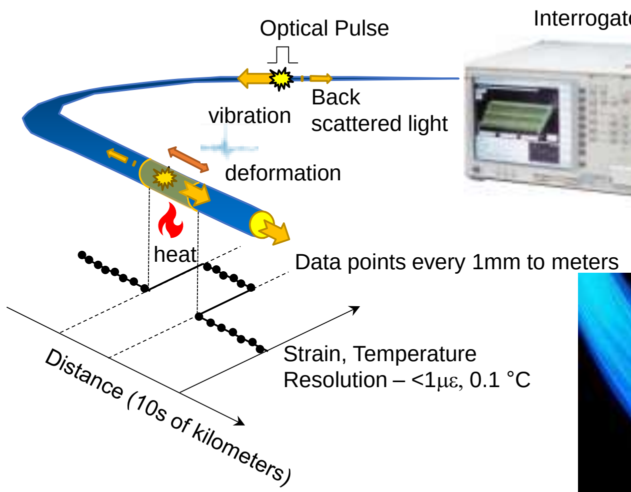
Zekkos, D., Champagne, C., Lynch, J., Manousakis, J., & Athanasopoulos-Zekkos, A. UAV-Enabled Coupled Infrared and Optical Characterization of the May 19, 2020, Edenville Dam Failure in Michigan. In *Geo-Congress 2022* (pp. 119-128).

Berkeley
UNIVERSITY OF CALIFORNIA

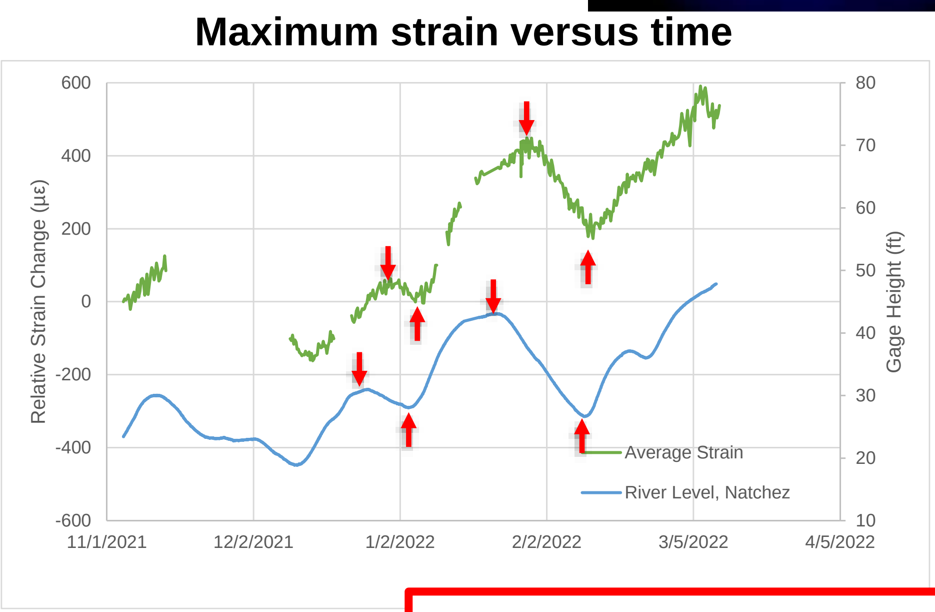
AI-based characterization of soil type and moisture content using Optical and Infrared Data

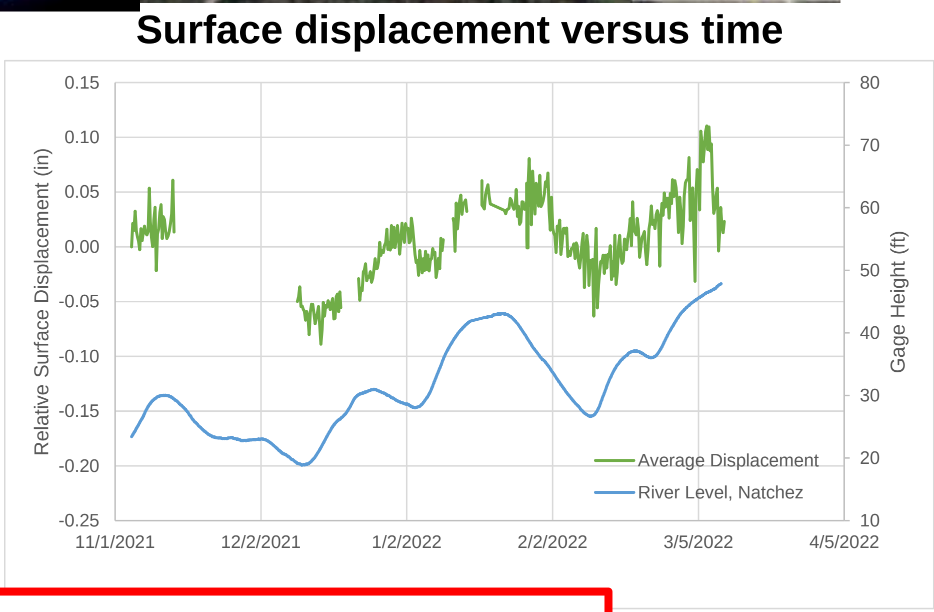


Continuous Levee Monitoring using Fiber Optics



Kenichi Soga



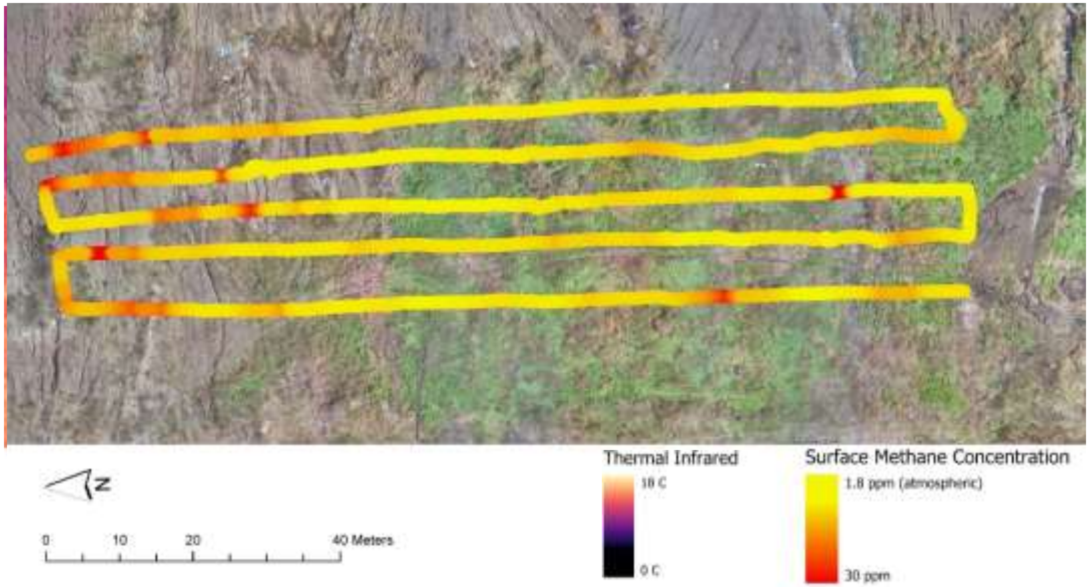


Monitoring the heartbeat of the levee?

AI-based Health Assessment of Landfills

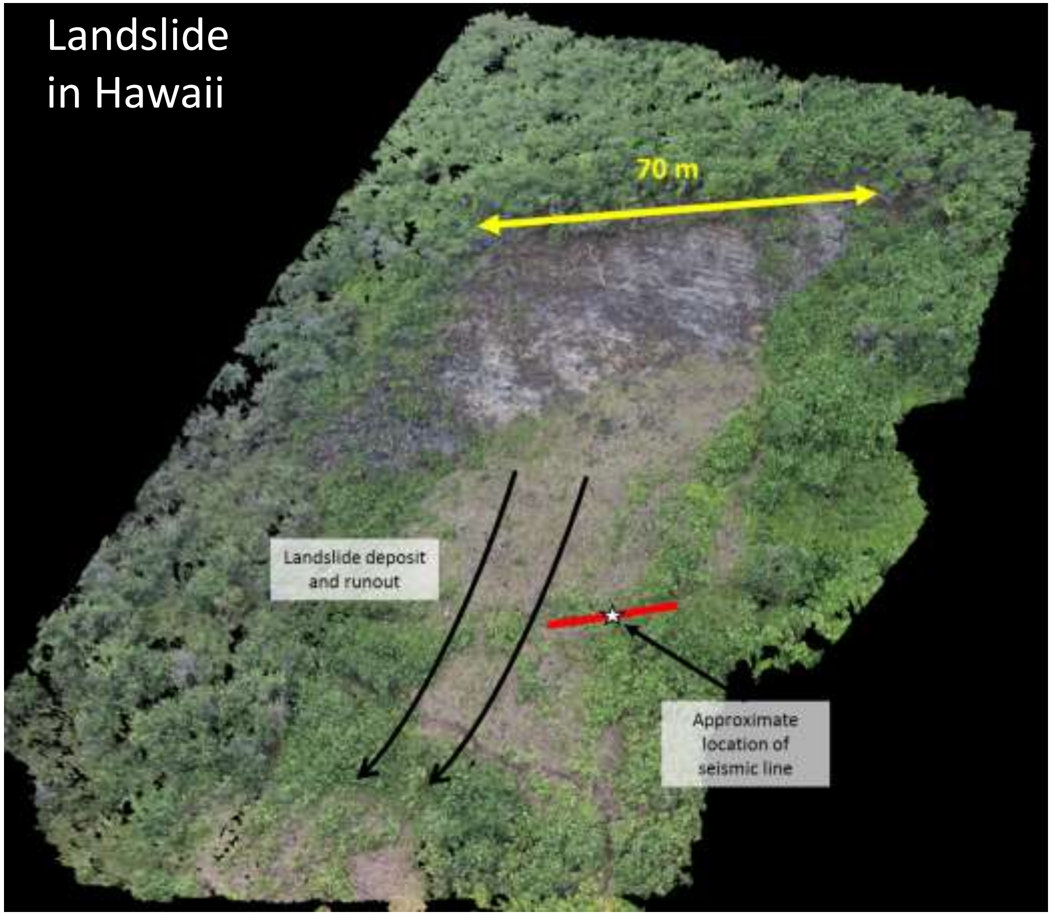
Approach used in landfills for:

- Finding thermal "hotspots"
- Classifying soil materials
- Methane leaks
- Ground cracks



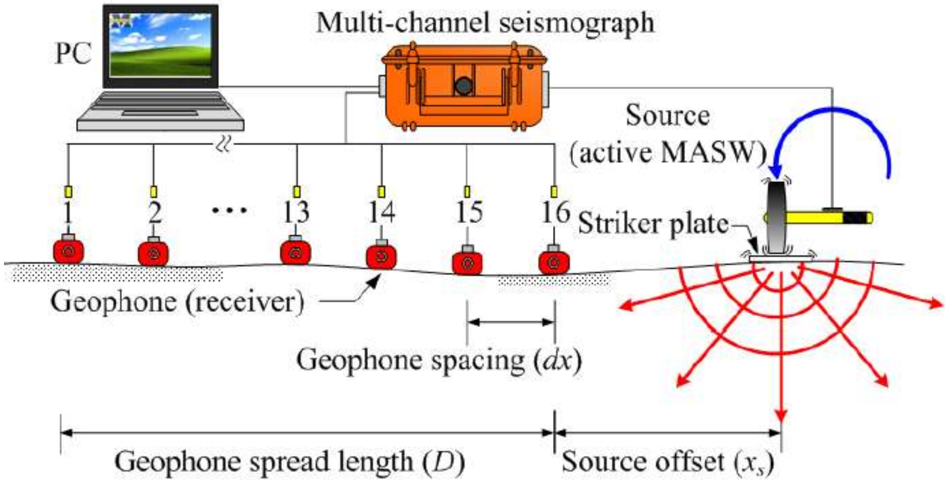
Berkeley
UNIVERSITY OF CALIFORNIA

Example #6: Fully Autonomous UAV Subsurface Characterization using Seismic Geophysics

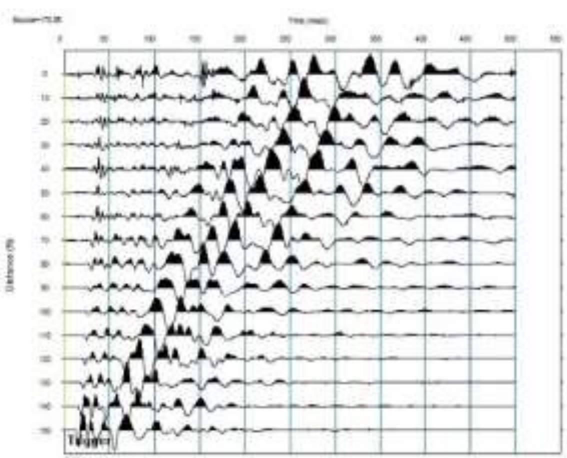


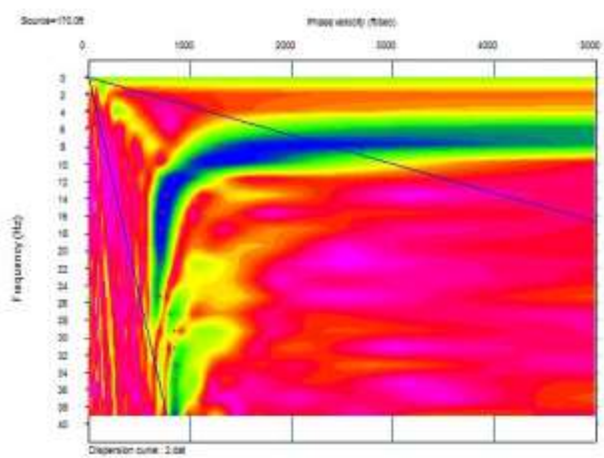
Fully autonomous UAV subsurface characterization will allow measurements in dangerous, remote sites and at reduced cost

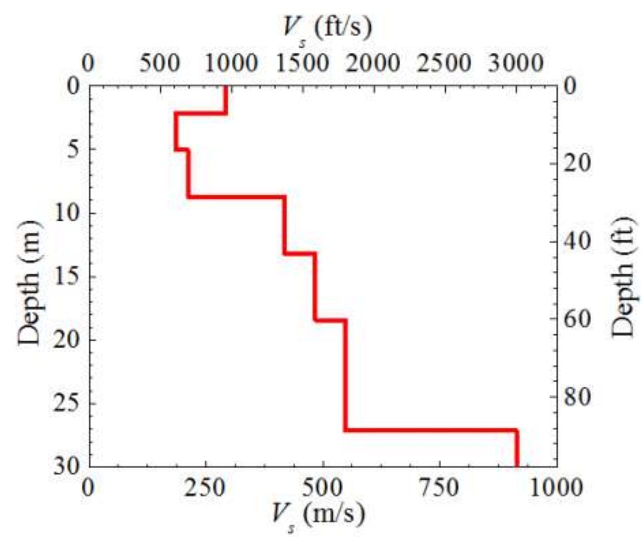
Multichannel Analysis of Surface Waves Analysis



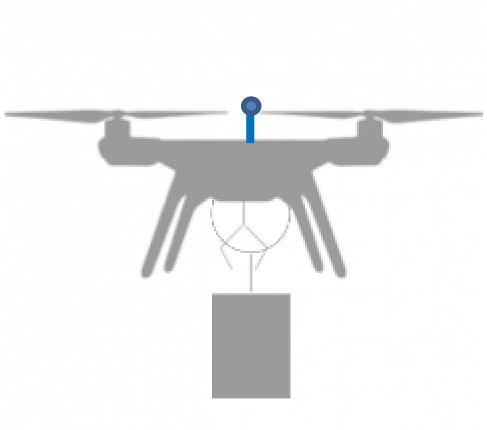
Data Collection → Dispersion Analysis → Inversion







Fully autonomous Seismic Surface Wave Measurements

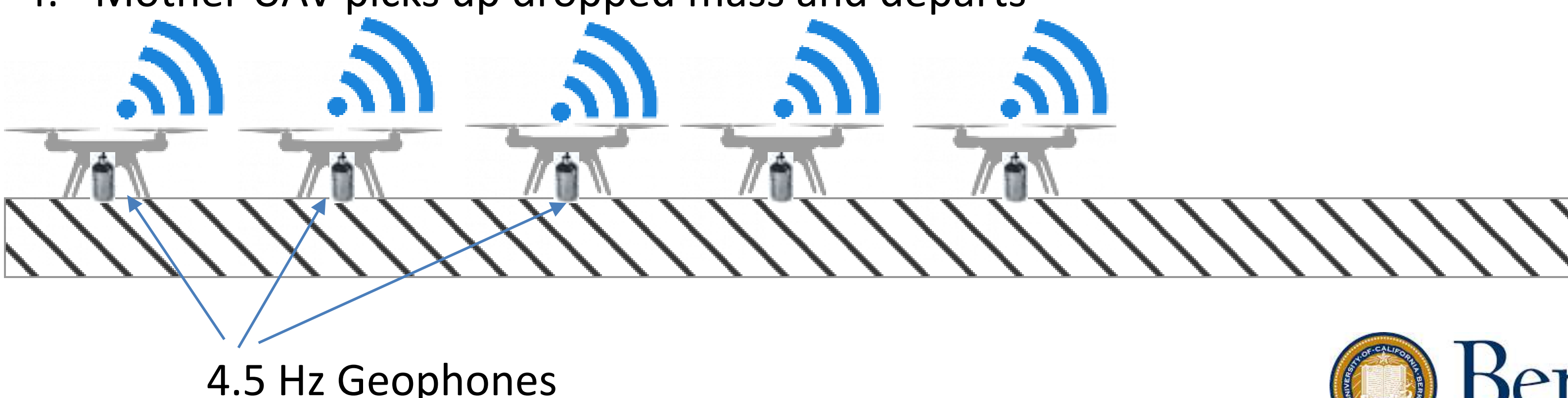


1. Small **UAV-geophones**, position themselves based on instruction from mother UAV and identifying previously positioned UAVs.

2. Mother UAV drops mass to generate stress wave, that is sensed by geophones.

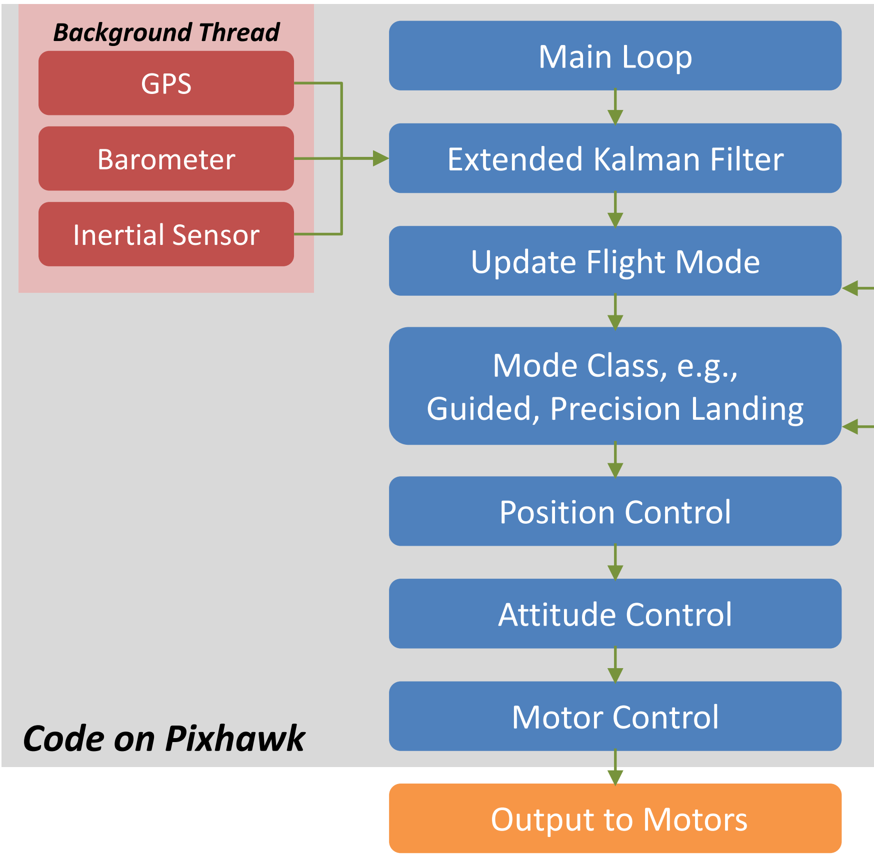
3. UAV swarm confirms data acquisition and data quality, transmits data to mother UAV and departs

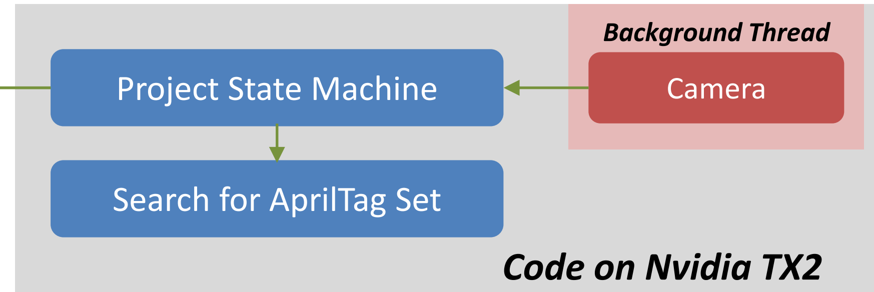
4. Mother UAV picks up dropped mass and departs

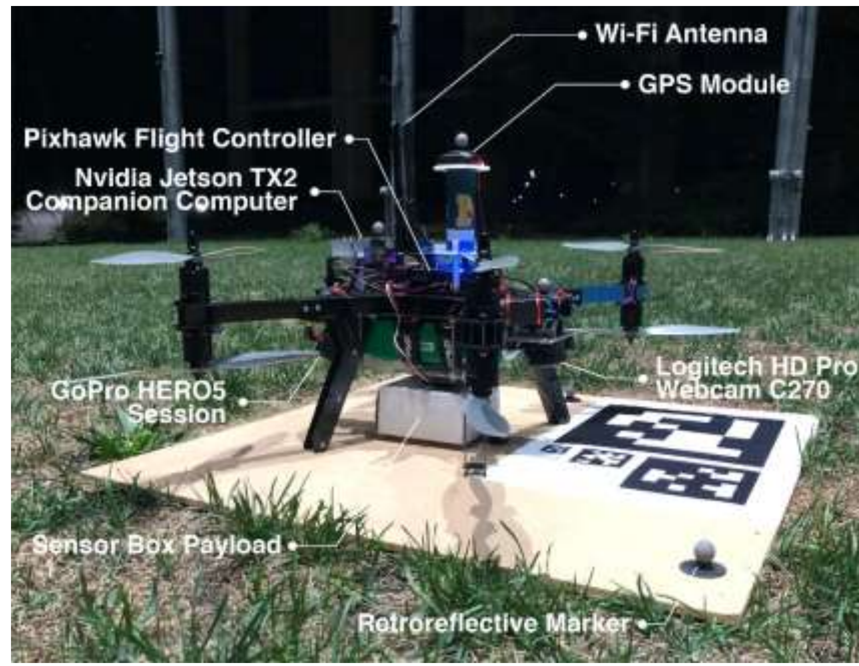


Berkeley
UNIVERSITY OF CALIFORNIA

UAV System Software Architecture

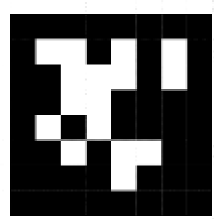






Base model: 3D Robotics X8+

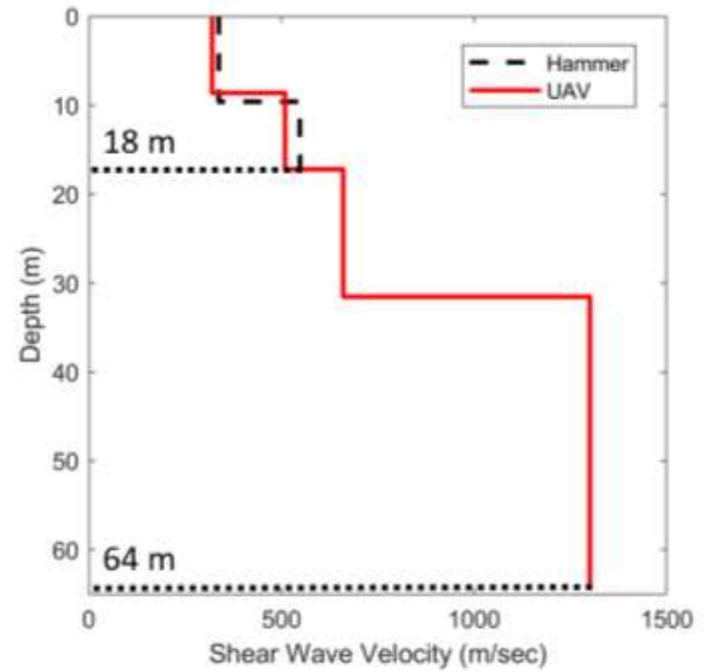
Hao Zhou



Fiducial marker employed in our experiments: AprilTag
(source: APRIL robotics lab, UMich)

Berkeley
UNIVERSITY OF CALIFORNIA

A new autonomous, portable, safer MASW for deep(er) site characterization

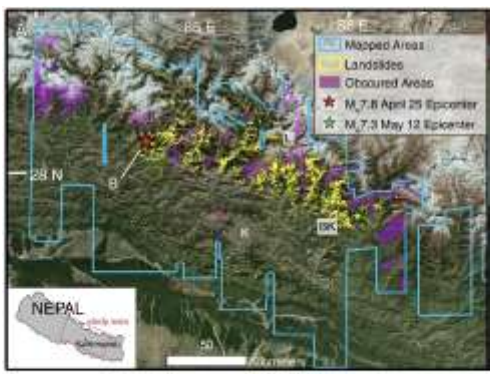


Greenwood, W. W., Zekkos, D., & Lynch, J. P. (2021). UAV-Enabled Subsurface Characterization Using Multichannel Analysis of Surface Waves. *Journal of Geotechnical and Geoenvironmental Engineering*, *147*(11), 04021120.

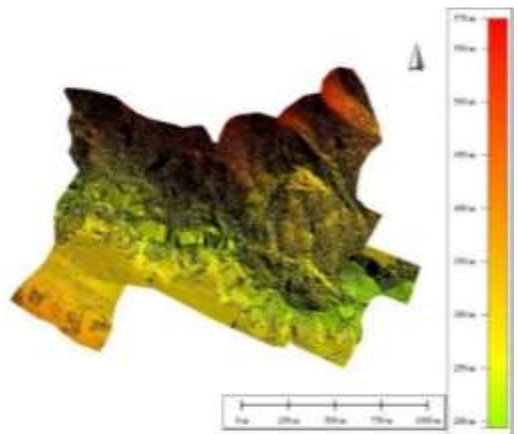
Zhou, H., Lynch, J., & Zekkos, D. (2022). Autonomous wireless sensor deployment with unmanned aerial vehicles for structural health monitoring applications. *Structural Control and Health Monitoring*, e2942.

For Distributed Systems, multi-scale, multi-sensing monitoring frameworks can provide system-level resiliency

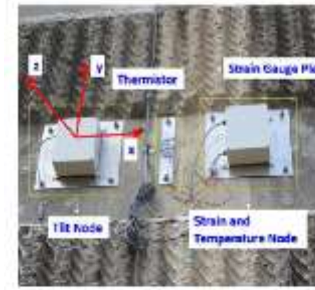
SATELLITES



UNMANNED AERIAL VEHICLES



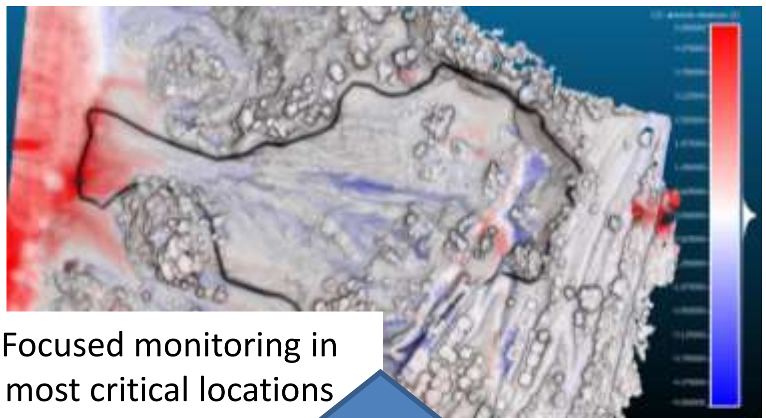
WIRELESS SENSORS



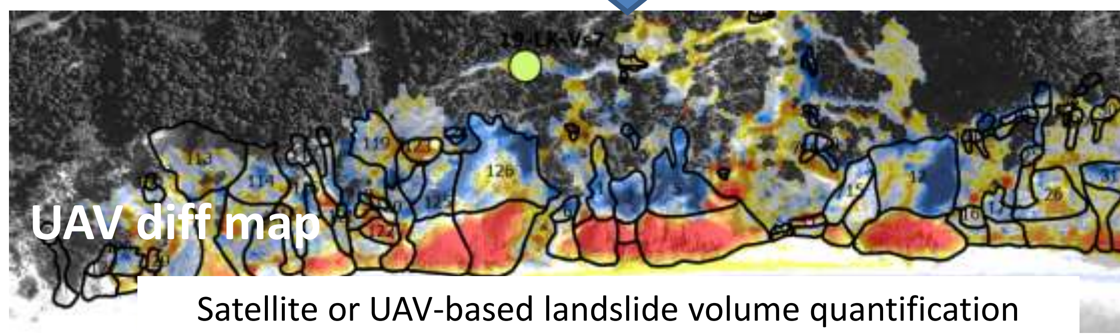
	Satellites	Unmanned Aerial Vehicles	Wireless Sensors
Coverage	>100 km^2	1-100 km^2	<1 km^2
Data Resolution	>0.5 m	>1 cm	local
Data Frequency	days	hrs	sec
Sensors	Optical, Infrared, Radar	Optical, Infrared, and more	Wide range

Coastal Instability Monitoring

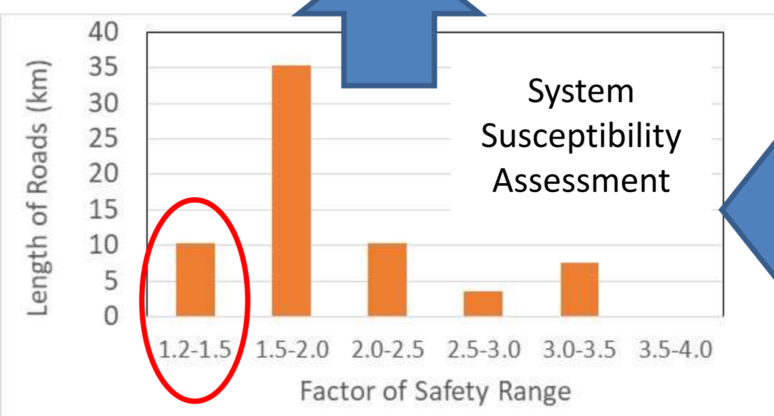
Satellite-based manual and ML-based landslide mapping



Focused monitoring in most critical locations

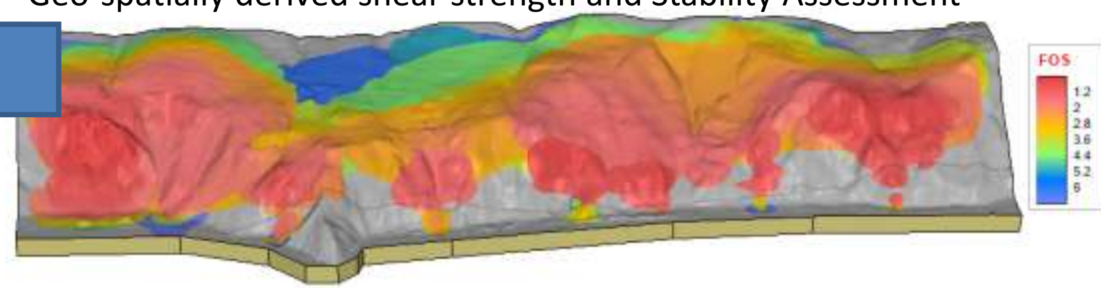


Satellite or UAV-based landslide volume quantification



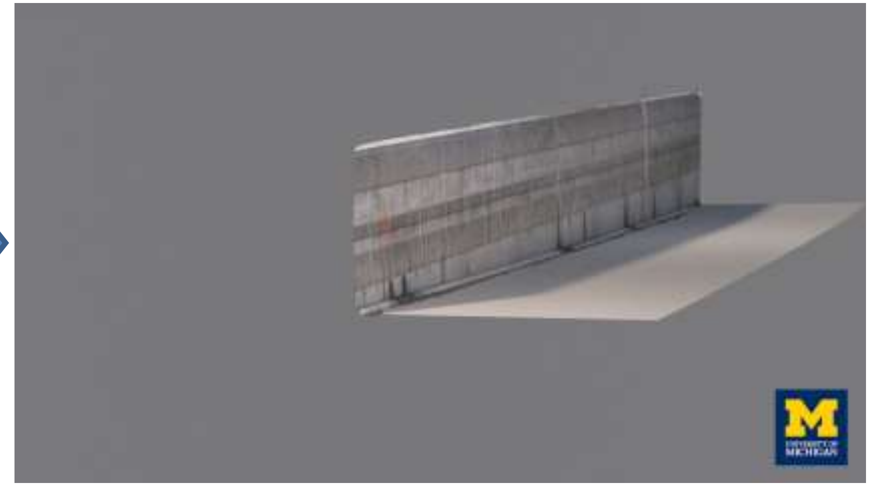
System Susceptibility Assessment

Geo-spatially derived shear strength and Stability Assessment



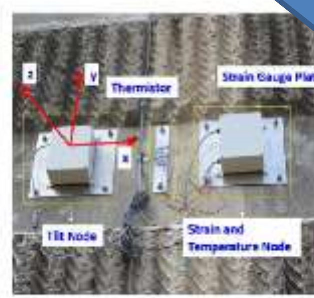
Highway Retaining Wall Condition Assessment

Optical-based inspection of Distributed Asset



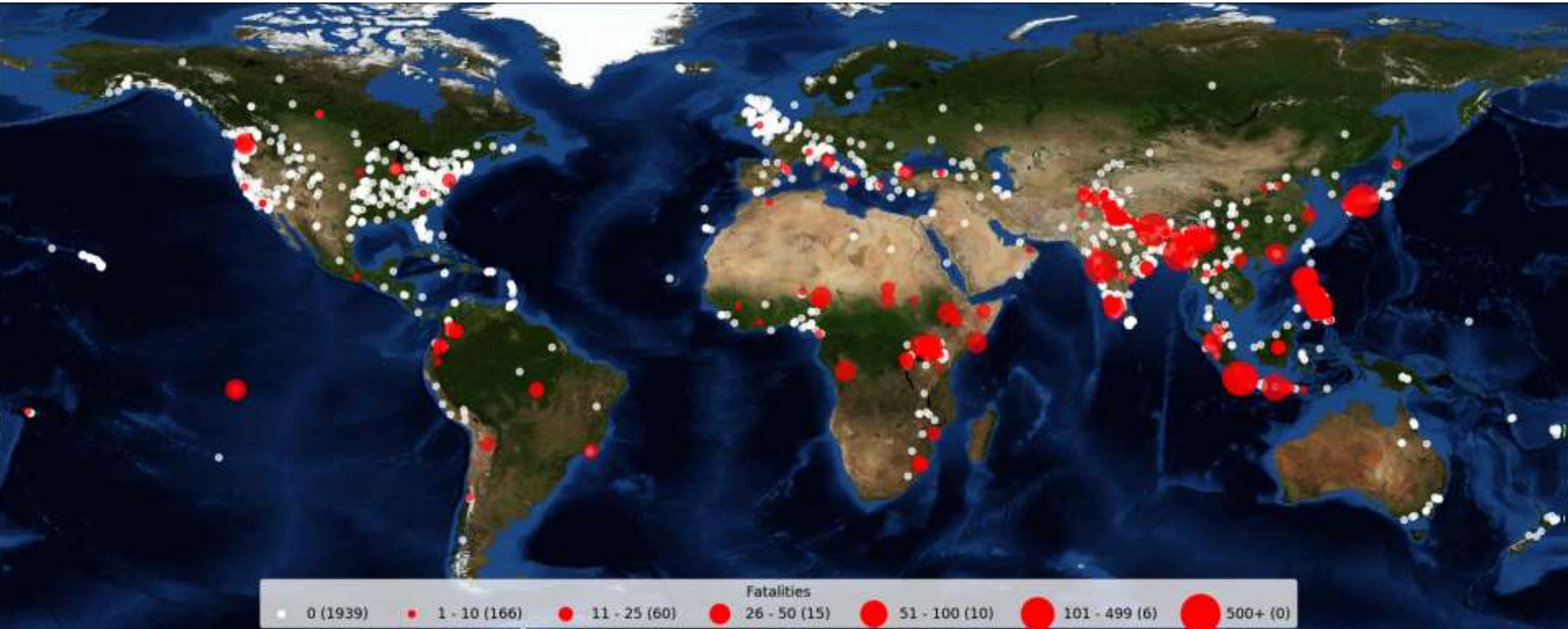
4D AI algorithms for moisture and geometry change detection

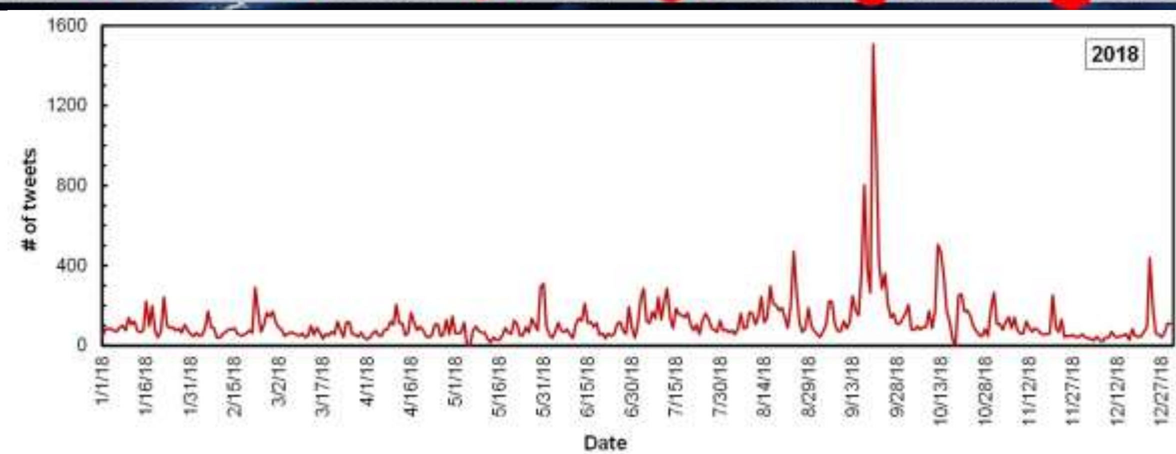
Michigan DOT's inspection procedures based on Risk-based Asset Management of Retaining Walls



Prioritization of critical locations for Self-powered Wireless Sensing

Tweeting People as Landslide Sensors






THINK BIG.
ACT BIGGER.

THINK BIG.

Automation in the Geo-Profession

- We are at the beginning of the Automation "revolution" in Civil Infrastructure. Autonomy revolutionizes the **quality**, **quantity** and **rate** by which we collect (**perishable) geo-data**;

- Approaches allow for an **unprecedented** level of infrastructure **monitoring;** key to that is the **mobility** and **multi-sensing** aspects

- Autonomy brings **Big Data Approaches using AI to the forefront**. Data collected highlight the need for **refined models** that better capture the true performance of infrastructure

- These approaches will **improve** decisions for **infrastructure assessment**, **asset management**, and **risk quantification**.

THINK BIG.

Automation in the Geo-Profession

- We are at the beginning of the Automation “revolution” in Civil Infrastructure. Autonomy revolutionizes the **quality**, **quantity** and **rate** by which we collect (**perishable) geo-data**;

- Approaches allow for an **unprecedented** level of infrastructure

The Automation “Revolution” does not threaten the geoprofessional community. It strengthens and expands it: In skills, portfolio, diversity of workers.

- Data collected highlight the need for **refined models** that better capture the true performance of infrastructure

- These approaches will **improve** decisions for **infrastructure assessment**, **asset management**, and **risk quantification**.

Berkeley
UNIVERSITY OF CALIFORNIA

ACT BIGGER. : Education at UC Berkeley

- CEE Students learn Python at undergraduate education
- New undergraduate courses on Smart Infrastructure Sensing and Modeling Course
- Technologies and frameworks introduced in graduate geo-curriculum
- Short course for training professionals


Kenichi Soga


Robert Kayen

http://geotechnical.berkeley.edu

ACT BIGGER.: Research

Berkeley
CENTER FOR
Smart Infrastructure

https://smartinfrastructure.berkeley.edu/

Director:
Kenichi Soga

Co-Director:
Matt Dejong

Co-Director:
Dimitrios Zekkos

The center **integrates research, the tech industry, consultants, contractors and infrastructure owners**

Develops and tests **emerging technologies** such as intelligent systems and networks, remote sensing and monitoring, and **data analytics for decision-making** to address major infrastructure and environmental problems

ACT BIGGER. : Geo-Industry (You)

- Diversify the staff that you are hiring in gender as well as in expertise:
  - Sensors / Electronics engineer
  - Remote Sensing professionals
  - Data Analyst; programmer

or collaborate with companies/groups that have this expertise

- We are seeing "the rise of geodata analyst", a new sub-discipline of geotechnical engineering and geology. A geo-data Analyst:
  - Understands geotechnical engineering
  - Has programing skills
  - Can manage and process geospatial and sensor big data
  - Can apply AI to this data

- Connect and partner with Universities to collaborate in new advances and focus research in the directions that matter to your organization

Berkeley
UNIVERSITY OF CALIFORNIA

Acknowledgements

Students

- William Greenwood
- Cassandra Champagne
- Hao Zhou
- Weibing Gong
- Jhih-Rou Huang
- Parker Blunts
- Drew Gomberg

Senior Collaborators

- Jerome Lynch, CEE, U. Michigan
- Marin Clark, EES, Univ. Michigan
- Adda Athanasopoulos-Zekkos, UCB
- Kenichi Soga, UCB
- Robert Kayen, UCB
- John Manousakis, ElxisGroup, Greece
- Alexandros Tsavalas, ElxisGroup, Greece

Funding Support

Thank you!

Dimitrios Zekkos
zekkos@berkeley.edu
Berkeley UNIVERSITY OF CALIFORNIA
https://dimitrioszekkos.org/