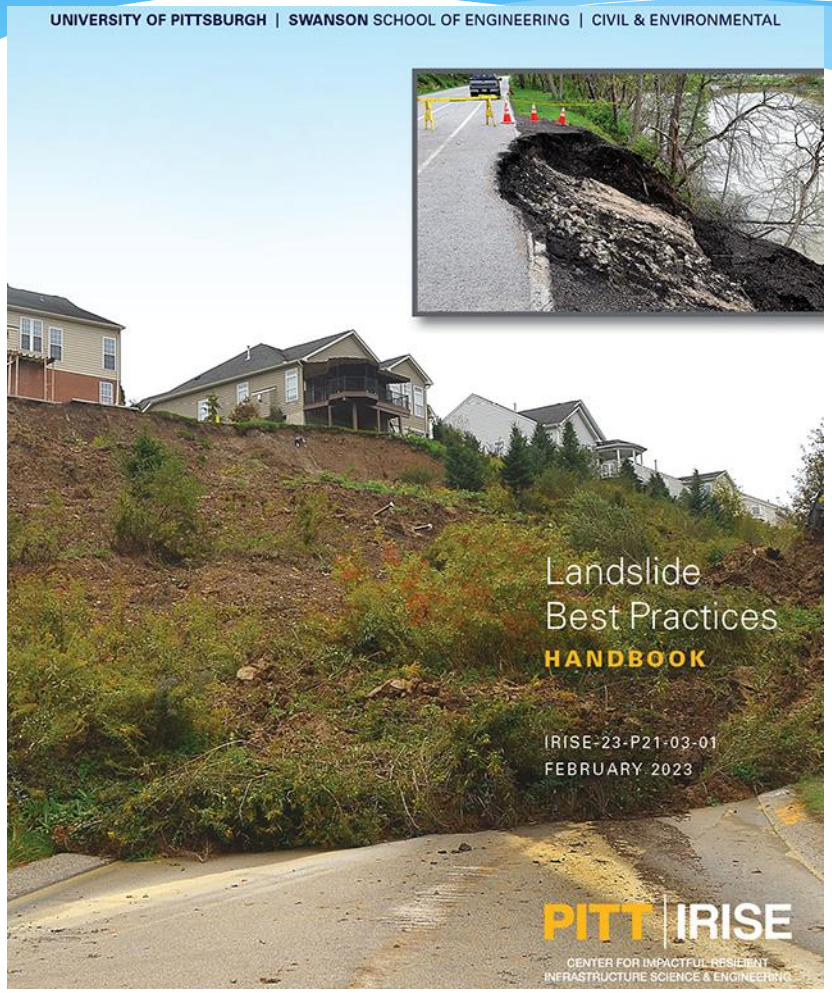
Landslide Best Practices Handbook



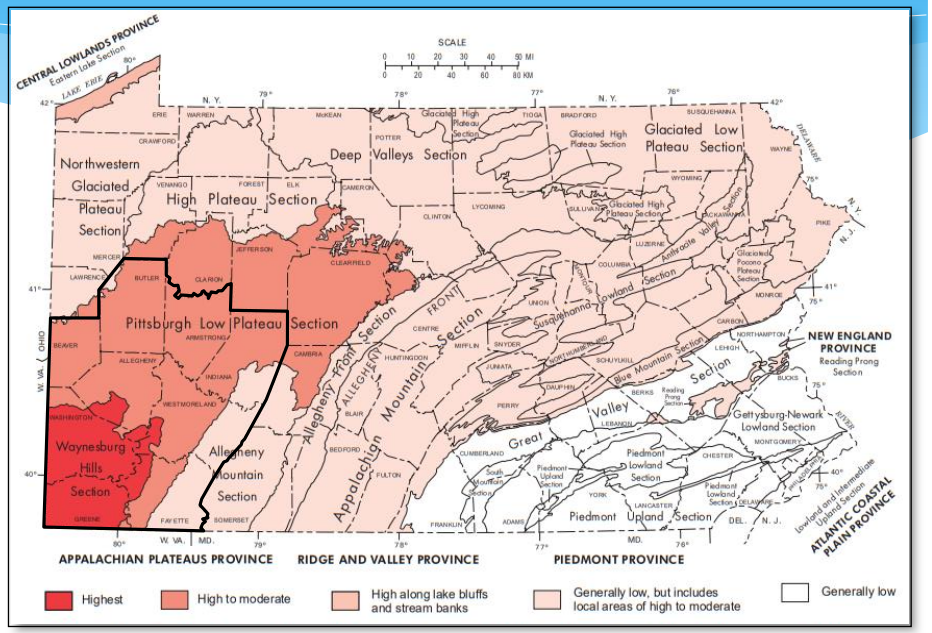
Fatma Ciloglu, Ph.D., P.E.

IRISE ANNUAL MEETING

MAY 17, 2023

Project Objectives

- Classify the type and form of landslide, based on typical landslide movement and hazards in southwestern Pennsylvania.
- Identify proven/long-term or reliable design approach(es) as well as innovative construction methods and materials that will provide a more resilient infrastructure system



(Delano and Wilshusen 2001)

- Bring forth emerging technology being used in other regions to mitigate landslides
- Assess/develop a hazard rating & establish a threat priority
- Differentiate between temporary and permanent mitigation response, including a rough cost comparison that can be used for planning use.

Project Approach

Identify/Track/Monitor Possible Movement – Global vs Local (Site Specific) Scale	• **Chapter 2, *Slope Movement Mechanisms*** • **Chapter 3, *Identification of Failure Prone Mechanisms*** • Chapter 9, *Slope Management Systems*
Investigate	• Chapter 4, *Landslide Investigation* • Chapter 5, *Problem Definition* • Chapter 6, *Instrumentation and Monitoring* • Chapter 7, *Laboratory Testing*
Assess / Design	• Chapter 10, *Stabilization and Repair Methods* • Chapter 11, *Economics of Repair Methods*
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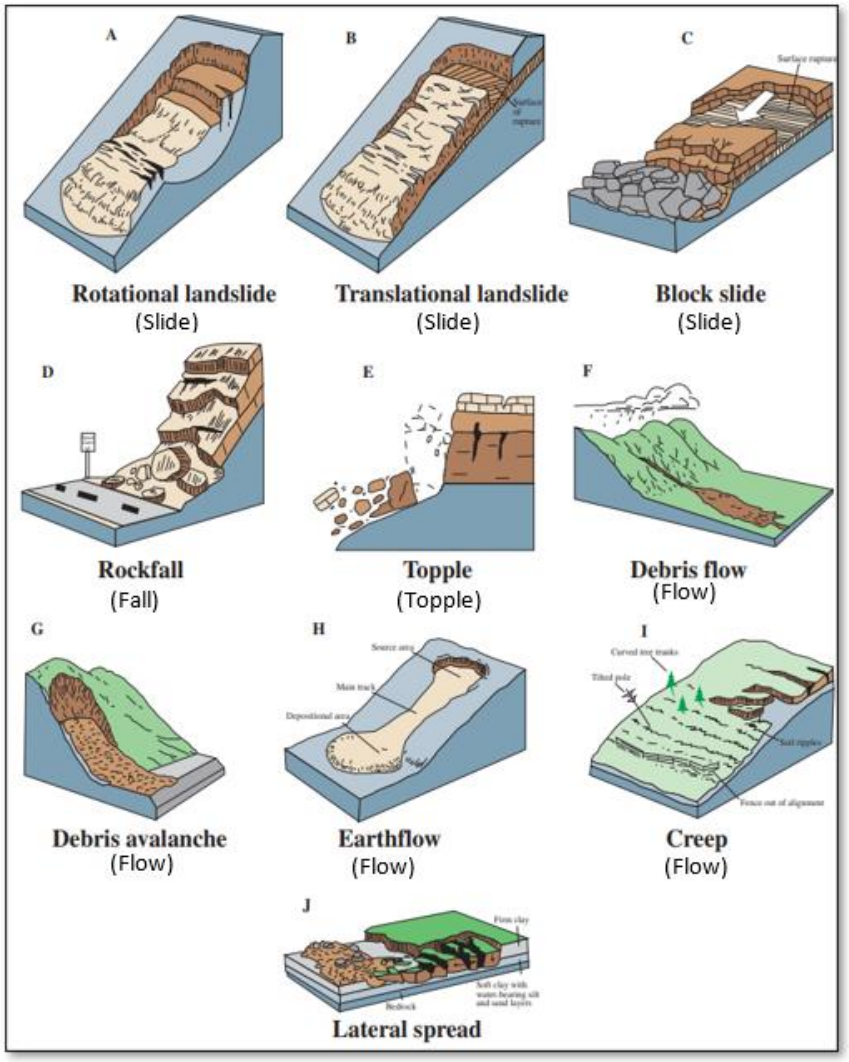
Post Action (verification) - Confirm Success	• Chapter 6, *Instrumentation and Monitoring*

Slope Movements Mechanisms



Schematics of Landslide Movement Categories (Highland, L. and Johnson, M., 2004. *Landslide Types and Processes*: United States Geological Survey)

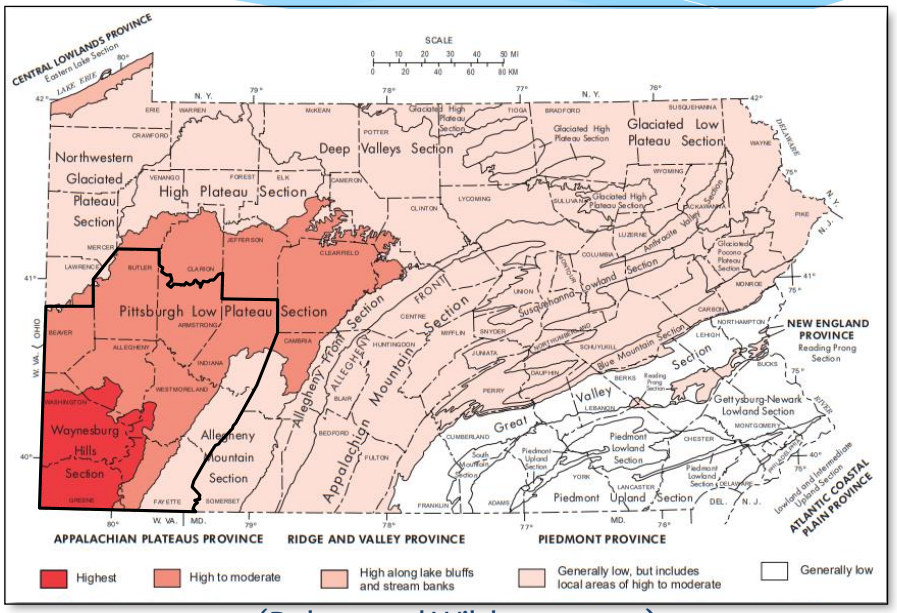
Landslide

The movement of a mass of rock, debris, or earth down a slope

- Classification of Landslides
- Definition of Landslide Features
- Causes of Landslides
- Triggering Mechanisms

Landslide Susceptibility

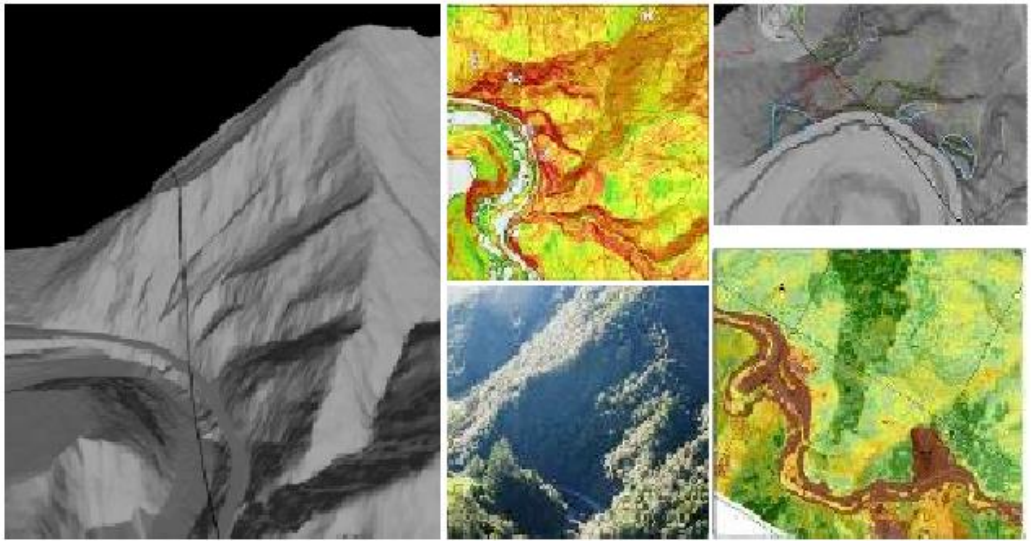
Geologic Formation	Soil Units and Geologic Members Prone to Landslides	General Remarks
--	Alluvial and Glacial Terrace Deposits (on Parker Strath)	Up to 80 ft thick; high plasticity
--	Upland Silt Loams	Comprised of silty loam soils and perched water tables found on hillslopes and valleys.
--	Colluvial Deposits	Soils are indicative of historic slides (i.e., unstable slopes); soils exhibit very low shear strength due to previous shearing; residual strength values shall be assigned to this material
--	Strip Mine Spoils	Soils typically end dumped and heterogenous; these soils will likely exhibit low shear strengths and perched water tables.
Dunkard Group; Washington and Waynesburg Formations	Dunkard Group	Variable claystone interbeds; known for "carpet slides"
Conemaugh Group; Casselman Formation	Pittsburgh Limestone	Includes up to nine separate limestone beds: potential water-bearing formation
	Upper Clarksburg limestone underlain by the Clarksburg Redbeds	Shaley redbeds with clayey shale interbeds
	Duquesne Coal and limestone underlain by the Grafton sandstone and deeper Schenley (Birmingham) Redbeds	Pale red to greenish claystone and shale
Conemaugh Group; Casselman and Glenshaw Formations	Unnamed Redbeds underlain by the Ames limestone and the Pittsburgh Redbeds	Marine limestone distinguishable by an abundance of marine fossils including crinoid stems between pale green and pale red interbedded claystones and shales



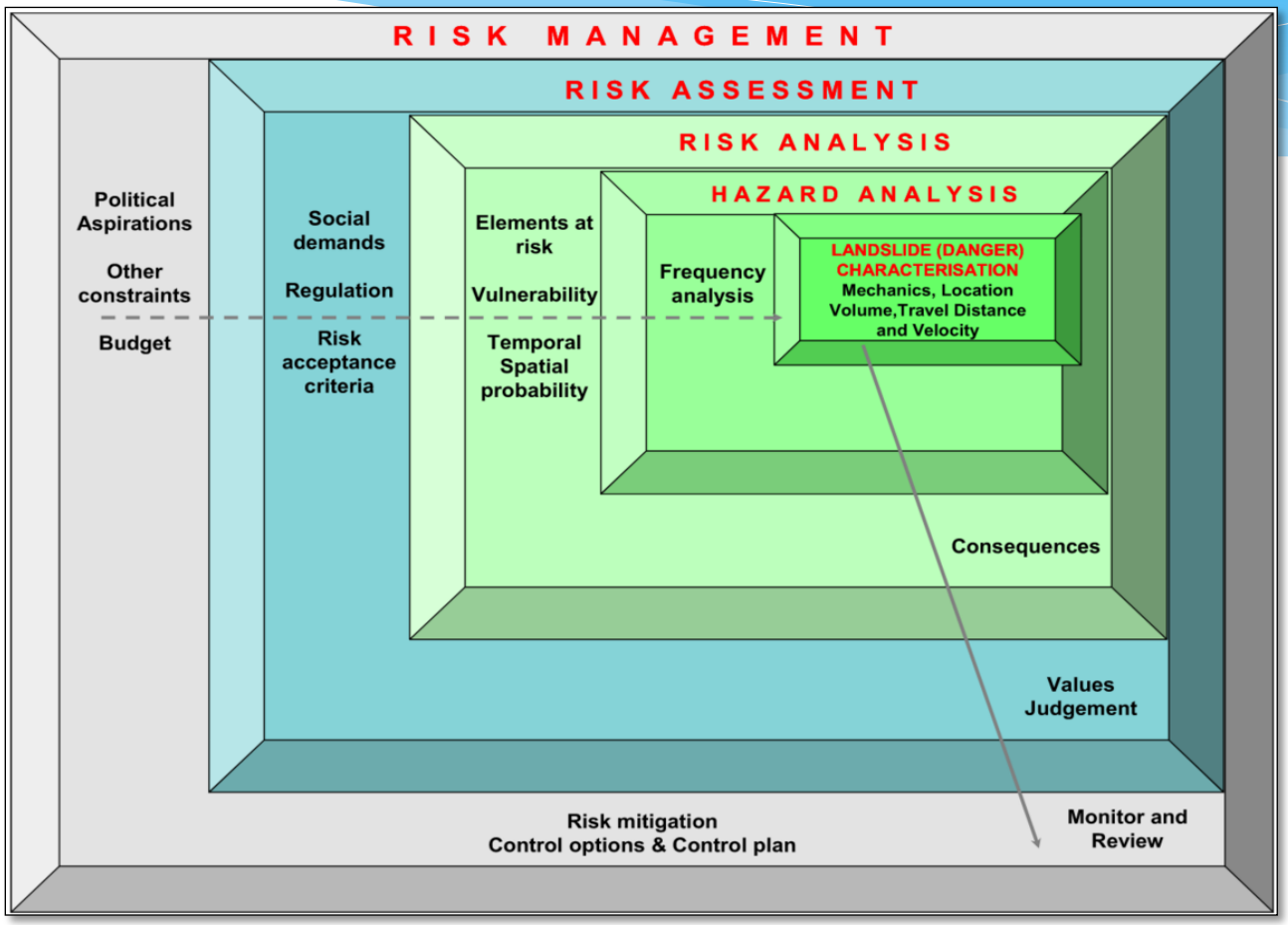
(Delano and Wilshusen 2001)

Slope Management System

- Characterize Hazard, Vulnerability, & Risk
- Slope Hazard Rating
- Landslide Inventory(ies)
- Data Management
- Decision Making Matrix
- Risk Reduction (knowledge-based action)
- Emergency Response vs. Planned Improvement



Slope Management System



Slope Management System

Best Practice Stability Rating (BPSR)

17.2 30.0 42.0 70.9

Best Practice Hazard Rating (BPHR)

	Minimum	Maximum
Rating Point (Consequence) =	44	640

Hazard Rating		= Rating Point * Net RF
44	640	

Best Practice – Remedial Options

1. Bypass & reduce consequence (avoidance)
2. Monitor + install warning system
3. Slope Inventory & Management System
4. Make capital improvement & reduce risk of failure

10 15 20 25 30 40 50 60 70 80 90

Project Flow

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Landslide Mitigation Flowchart

Unstable Slope is Identified – Time to Respond

Site Reconnaissance

CHAPTER 2, 4, & 5

- Complete Field Checklist
- Identify scope and urgency of project
- Identify key geologic and topographic features
- Identify existing drainage features and potential issues
- Identify site constraints such as existing infrastructure, utilities, proximity to ROW/property line, etc.
- Determine likely mode of failure

Desktop Study

CHAPTER 3, 4, & 5

- Review available geologic, historic, landslide, mining, flood history and topographic information
- Identify any presence of problematic geologic units (e.g. redbeds, etc.) or colluvium (historic slides)
- Review historic aerial photographs to document history of slope movement
- Request maintenance records if available
- Identify sensitive features in proximity to slide (e.g., utilities, structures, roadway, etc.)

Subsurface Investigation

CHAPTER 4, 5, 6, & 7

- Prepare/execute an Exploration Plan
- Drill test borings and excavate test pits to characterize subsurface conditions and assess the extent of the slide
- Perform a laboratory investigation to aid in classification of soils encountered and determine engineering properties for analysis and design

Instrumentation and Monitoring

CHAPTER 6

- Depending on the urgency or impact of the unstable slope, this may be performed prior to the subsurface investigation
- Install instrumentation to monitor piezometric conditions and/or slope movement

Analysis and Design

CHAPTERS 5, 10, & 12

- Use data obtained to develop subsurface section(s), define the extent of the slide mass and mode of instability, and assess rate and magnitude of movement
- Perform engineering analyses and conduct a detailed alternatives analysis
- Complete design and prepare construction documents

Identify Preferred Solution(s)

CHAPTERS 10 & 11

- Select the preferred alternative to repair/stabilize the slope with the client considering:
  - Effectiveness;
  - Acceptable Risk;
  - Economic Constraints;
  - Impact to the public and environment; and
  - Time constraints (e.g., urgency)

Construction

CHAPTERS 6, 8 & 12

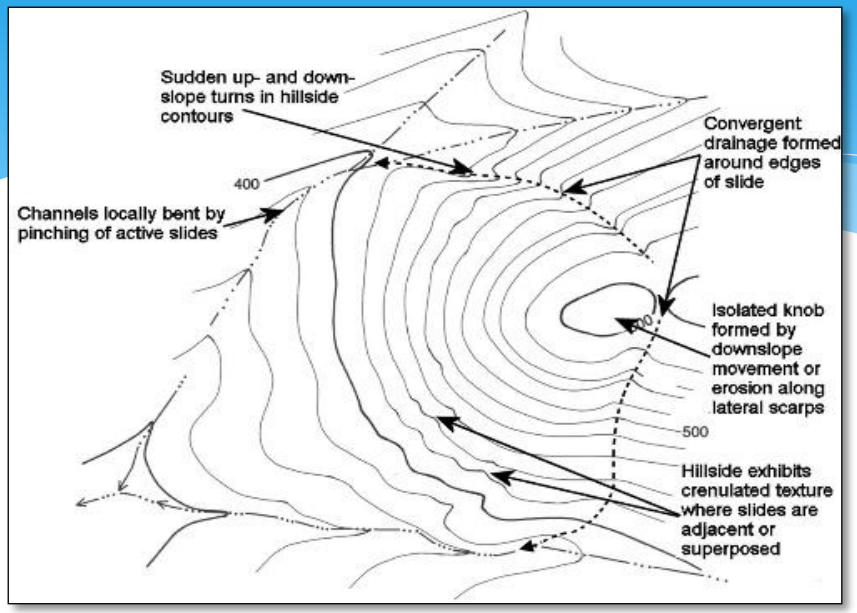
- Execute plans to mitigate/repair/stabilize landslide
- Monitor the site closely to ensure construction activities are not triggering additional slope movement
- Ensure surface water and groundwater are managed during construction

Post Construction Monitoring

CHAPTER 6

- Use instrumentation and/or regular site visits to verify successful execution to stabilize slope
- Confirm implemented mitigation, stabilization or repair is performing as designed

Landslide Investigation



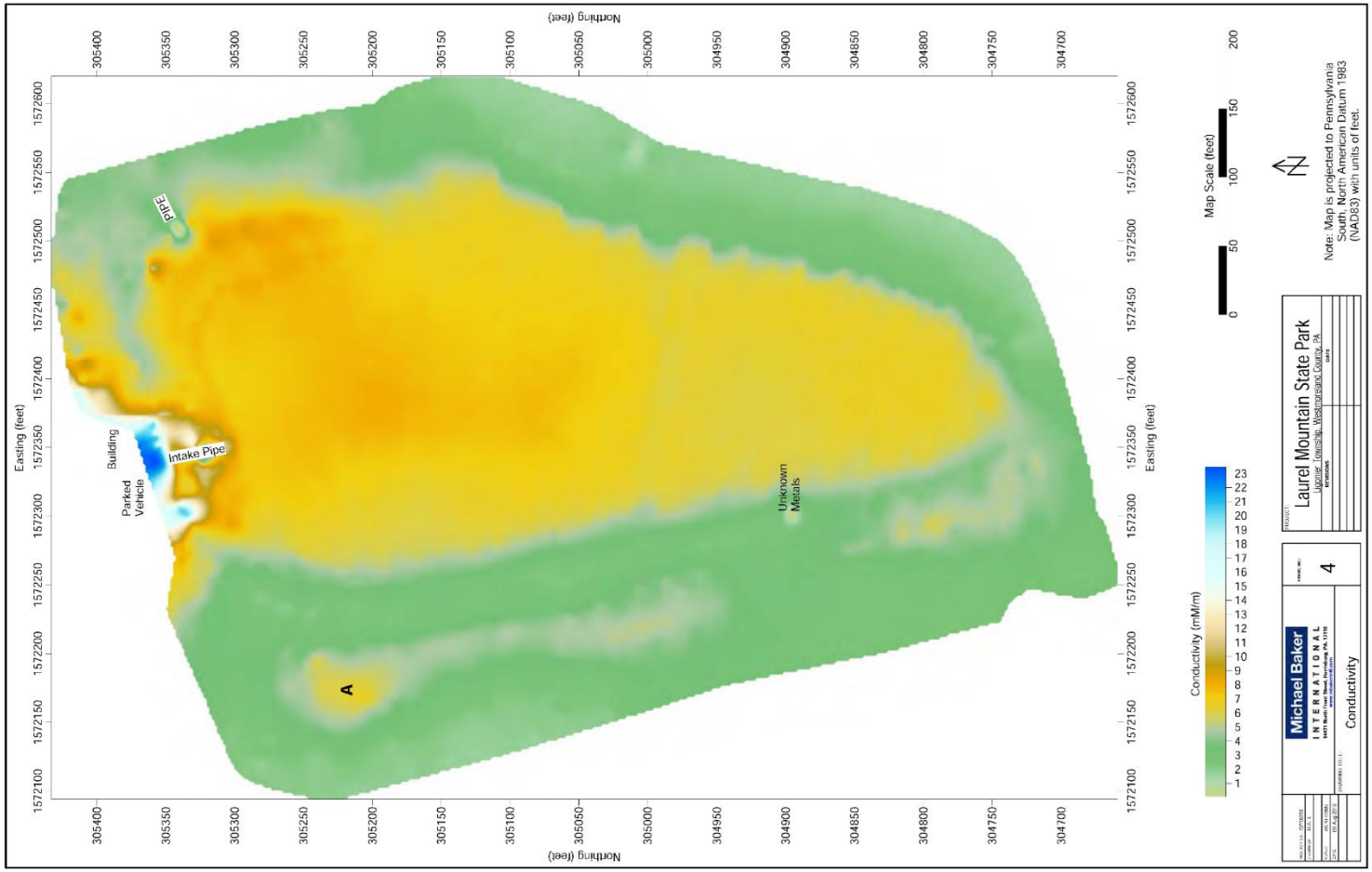
Desktop Study / Site Reconnaissance

- Review of available data and mapping in the region to identify landslide prone areas
- Use site reconnaissance data to develop potential triggers or modes of failure

Landslide Investigation

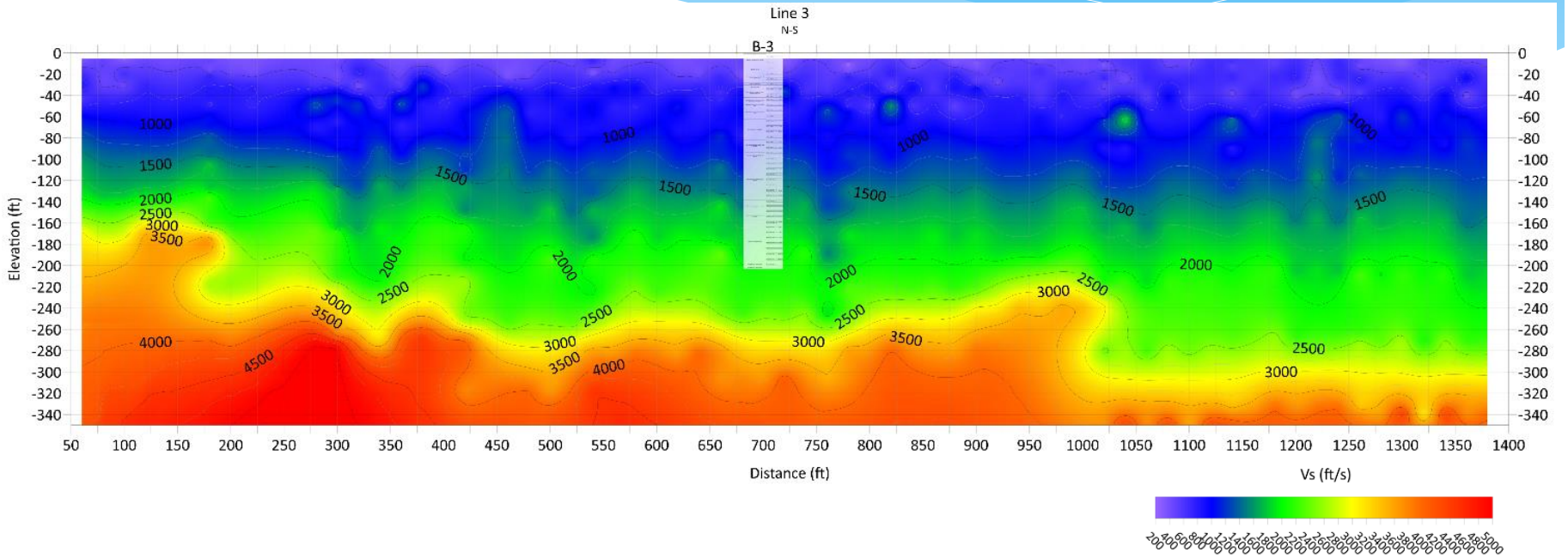
- Perform a purpose driven subsurface investigation; samples for laboratory testing, water level readings, and any instrument will be installed during the investigation
- Develop detailed subsurface sections to serve as the basis of design

Landslide Investigation



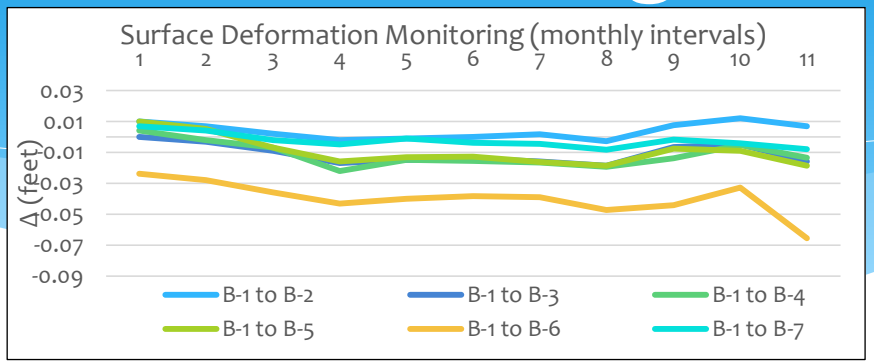
- Geophysical Electromagnetic Conductivity to detect changes in lithology, zones of saturation

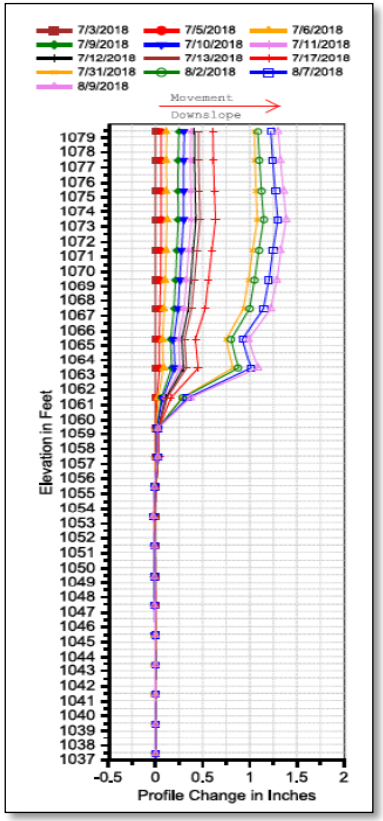
Landslide Investigation



- Seismic Surface Wave Method (MASW) - Detect Irregular Bedrock Surface

Instrumentation & Monitoring

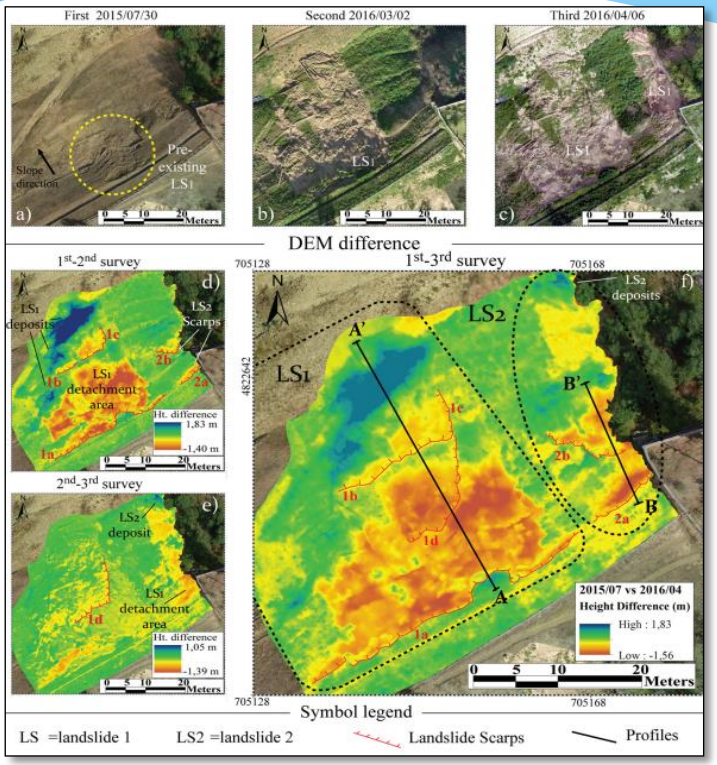




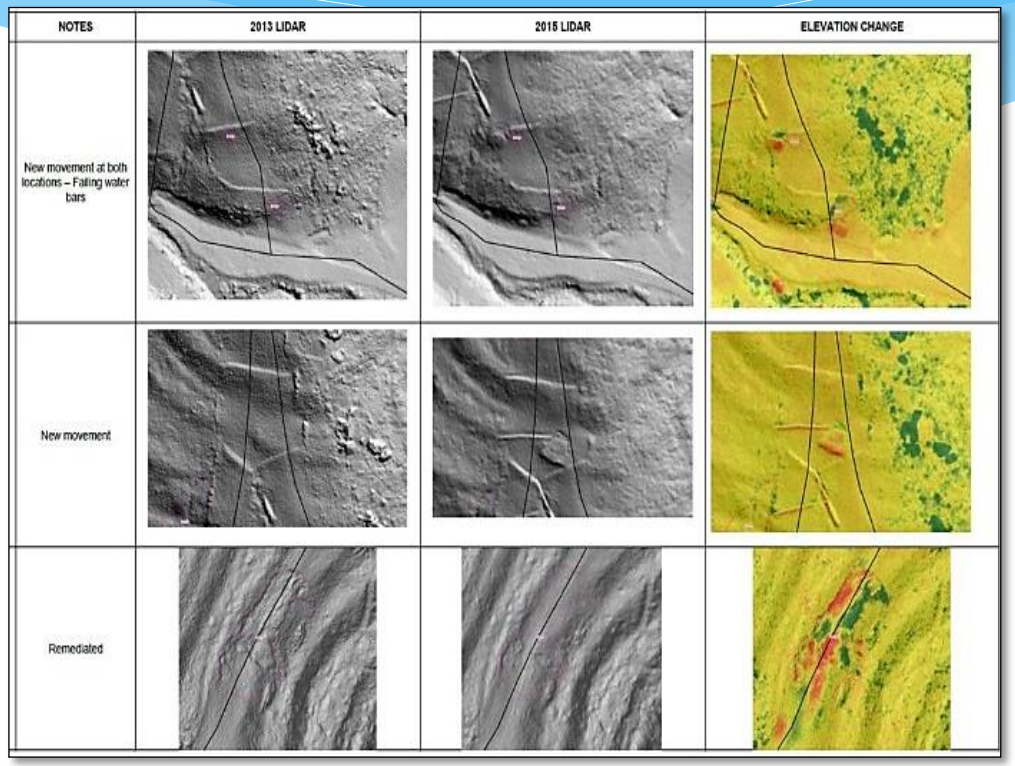
- Overview of common instrumentation for landslide monitoring including:
  - ❖ Surface Monitoring via conventional survey
  - ❖ Inclinometers
  - ❖ Tiltmeters
  - ❖ Crack Gauges
  - ❖ Piezometers
- Description, use, costs, and installation considerations
- Data Reduction and Forecasting

Instrumentation & Monitoring

- Emerging technology including LiDAR and UAV's



(Rossi, 2018)



- Emerging technology for remote satellite monitoring including inSAR

Laboratory Testing

Shear Strength based on Correlation with Index Properties and Published Values

- Empirical correlations using standard tables and figures
- Published data for similar materials
- Local experience

Shear Strength based on Site-Specific In Situ Tests and Strength Testing in Laboratory

- Select relevant test results that best represent the mode of failure
- Assess influence of test and design conditions
- Calibrate (e.g., back-analysis) to relate parameters to actual design condition
- Local experience

Shear Strength Parameters Selected for Analysis

Cautious estimate of parameters taking into account:

- Number of Test Results,
- Variability of subsurface conditions,
- Data scatter,
- Limit state of concern and volume of landside mass involved, and
- Risk and consequence

Shear Strength Parameters Selected for Design

- Overview of index property and shear strength testing to inform parameter development
- Coworking relationship between practitioner and laboratory
- Data verification

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Landslide Stabilization and Repair Elimination Methods

- Relocation
- Removal

- Bridging

Landslide Stabilization and Repair Control Methods

- Retaining Structures
  - Buttresses
  - Slope surface enhancements
  - Shoulder Back-Up and Moment Sl
  - Single-Face Barriers
  - Gravity Walls
  - Cantilevered Pile Walls
  - Tieback (Ground) Anchors
  - Soil Nails
  - Geosynthetic Reinforced Soil (GRS)

Landslide Stabilization and Repair Control Methods

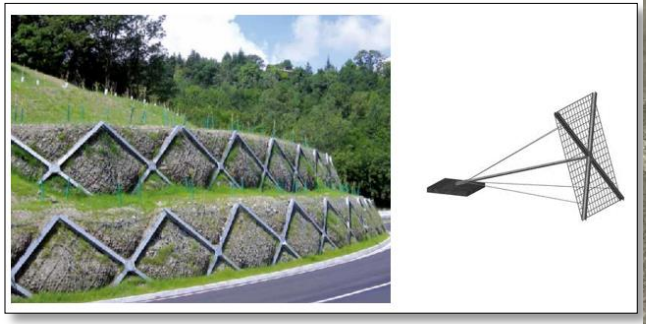
- Rebalance Ration Between Mobilized Resistance and Driving Force(s)
  - Surface Drainage Improvement
  - Subsurface Drainage Improvement
  - Lightweight Fill (to replace part of the landslide mass)
  - Partial Unloading (at top of slide mass)
  - Slope Flattening
  - Removal and Replacement (of slide mass)

Landslide Stabilization and Repair Elimination Methods

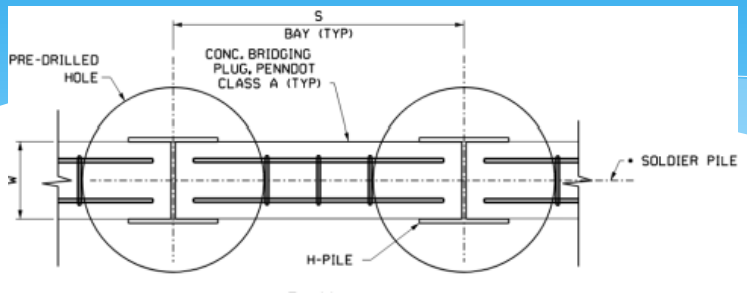
- Emerging Technology
  - Soil Nails and Grillage
  - Cruciform Structure with Anchor Slab
  - Debris-Flow Fence
  - Deep Polymer Injection
  - Bio-Remediation

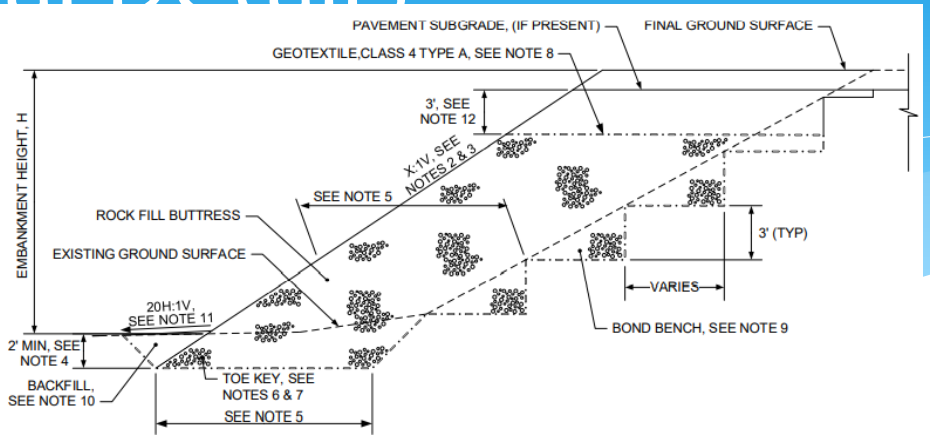

(a) Construction of soil nails and grillage.

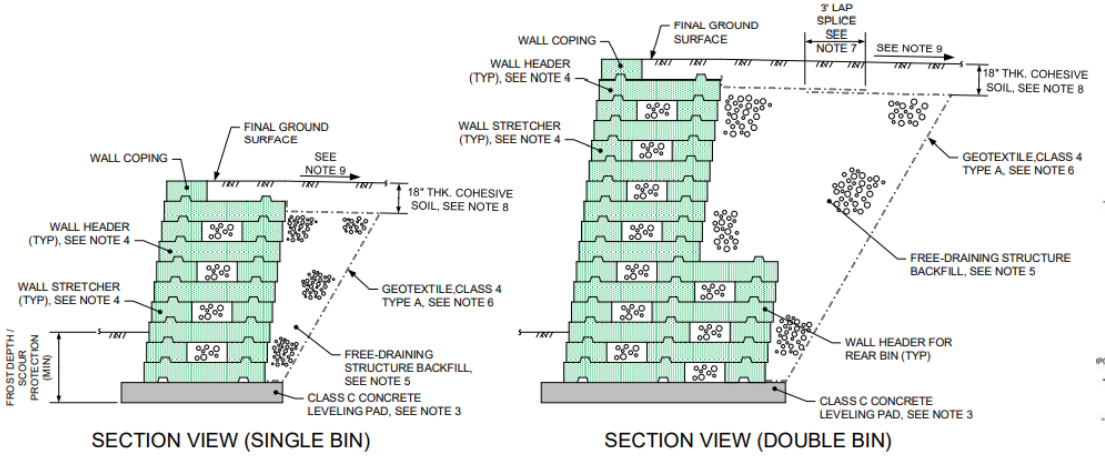
(b) Completion of soil nails and grillage construction.



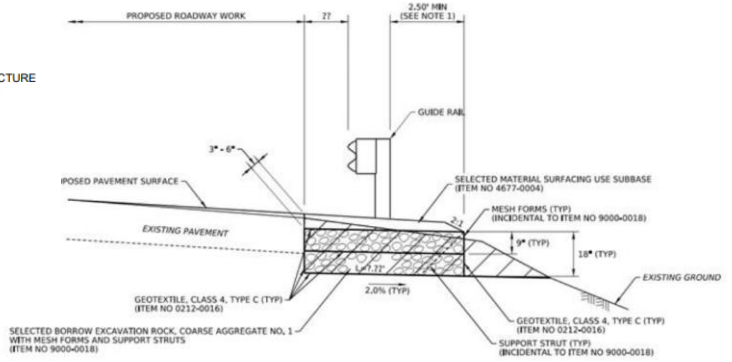
Typical Details







TYPICAL DETAIL – CRIB WALL



Forms / Design Example

SLOPE MOVEMENT FIELD VISIT CHECKLIST

* Refer to measurement and terminology "References" for consistency/clarity.

CLIENT & PROJECT NAME: _____

COUNTY: _____ MUNICIPALITY (IES): _____

ADDRESS: _____

LATITUDE: _____ LONGITUDE: _____

DATE OF FIELD VISIT: _____ WEATHER: _____

INSPECTOR: _____

PROJECT DESCRIPTION: _____

_____

_____

1 Site Visit Preparation

1.1 Site Visit Preparation Checklist

Did you review all relevant literature materials? _____
- Site history
- Geologic setting
- Hydrogeologic setting
- Available aerial photography

Do you have equipment to help document and inspect the site? _____
- Tape Measure/Ruler
- Measuring Wheel
- Camera
- Notepad

Do you have a device to record GPS coordinates and elevations of observed features? _____

SLOPE MAINTENANCE CHECKLIST

CLIENT & PROJECT NAME: _____

COUNTY: _____ MUNICIPALITY (IES): _____

ADDRESS/ROADWAY: _____

LATITUDE: _____ LONGITUDE: _____

DATE OF SITE VISIT: _____ WEATHER: _____

INSPECTOR: _____

FIELD OR REMOTE INSPECTION: _____

NOTE ANY SIGNIFICANT PRECIPITATION EVENTS IN THE PAST WEEK: _____

_____

REVIEW OBSERVATIONS AND RECORD DATE OF LAST SITE VISIT: _____

1 CONCLUSIONS

RECOMMENDATIONS FOR IMMEDIATE RESPONSE OR INCREASE INSPECTION FREQUENCY BASED ON OBSERVATIONS MADE: _____

_____

_____

RECOMMENDED MAINTENANCE AND URGENCY OF NEED:

_____

THANK YOU!

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Matthew Geary, DLC

Questions and Answers