Assessing Slope Instabilities

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Slope Stability and Landslides

- Today's Presentation: Slope instability and landslide terms will be used interchangeably
- Landslide: downward and outward movement of slope-forming materials composed of natural rocks, soils, or combination of these materials
- Landslides can be further classified by types of movement
- Landslides are under the influence of geologic, topographic, or climatic factors

SR 60. Clark County, Indiana

Landslide Project Costs

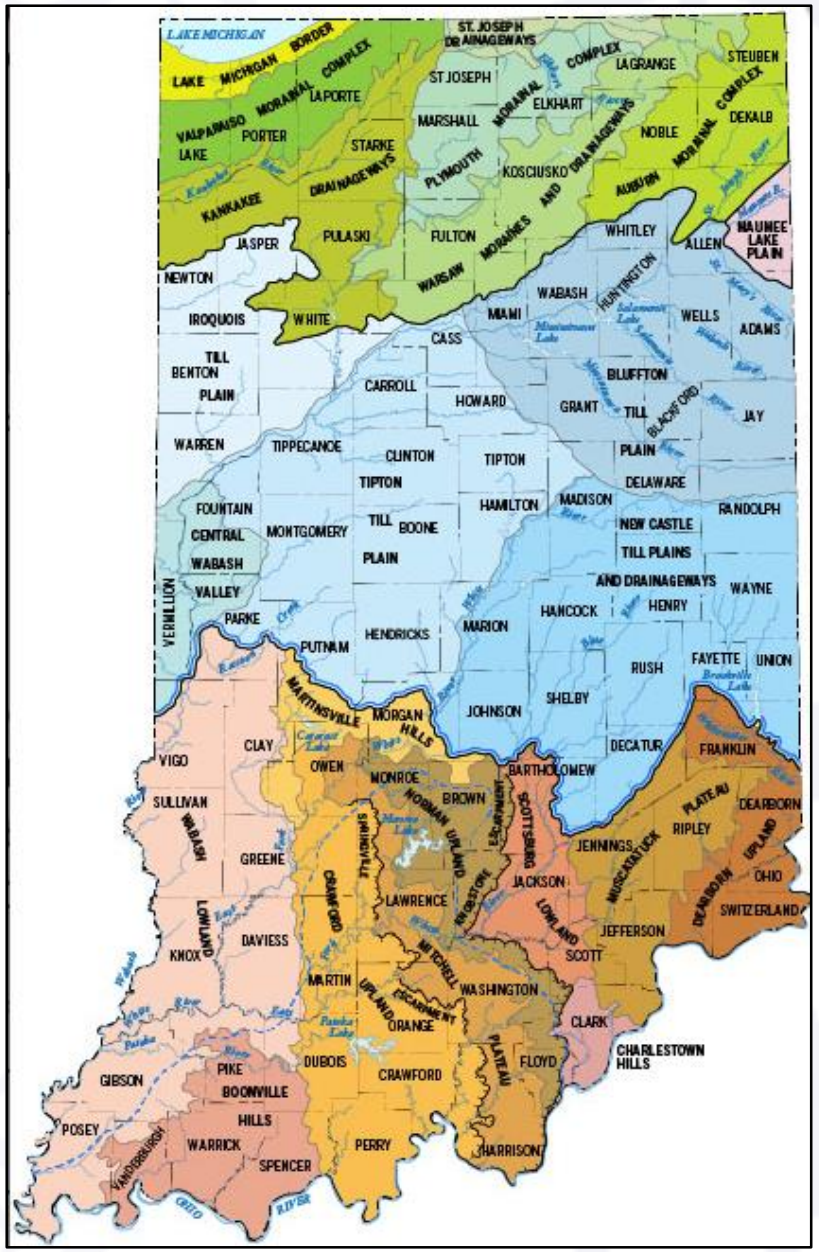
- Landslides are a common occurrence within highway embankments and cut slopes throughout southern Indiana.
- Stabilizing existing landslides is very expensive.
- Persistent maintenance needs can also be very costly.
- Landslides are very dynamic, sometimes changing through the design process. They also have the potential of creating change orders during the construction process.
- Serious landslides have the potential to cause loss of life, injury, and property damage. Such landslides are a cause for emergency repairs.

Airport Road(2018). Orange County, Indiana

Indiana's Topography

- Topography: Shape and features of land surfaces
- Physiographic regions: Areas of similar geologic structure and geomorphic history. Contain similar landforms.

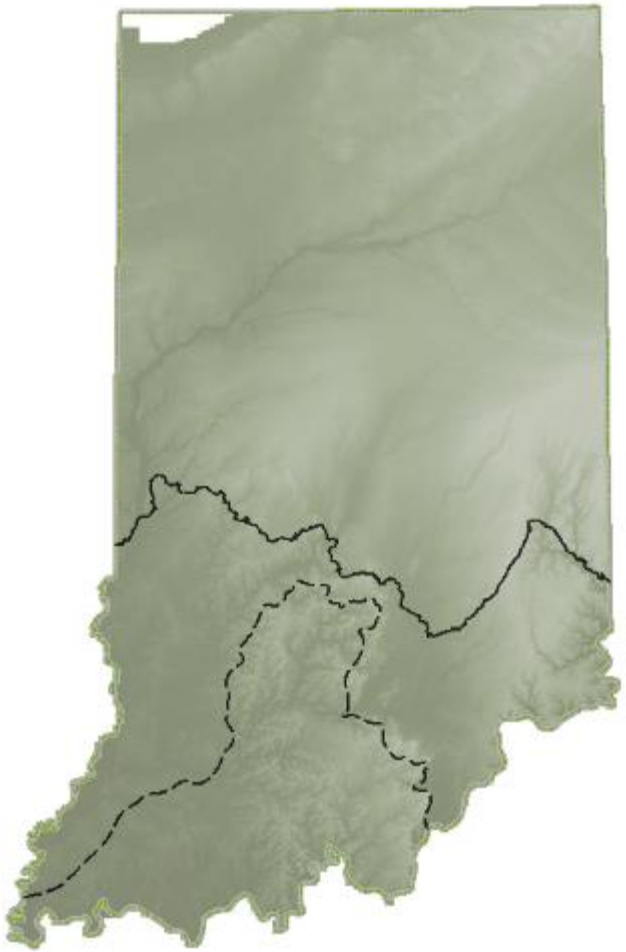
Physiographic Region	Description
Tipton Till Plain	Broad gently rolling plain. 2/3 subject to wetness. Has some steep slopes
Wabash Lowland	Broad valleys flats and low rolling hills. ½ subject to wetness. Some steep slopes
Crawford Upland	Hilly land with cliffs and outcrops of sandstone and limestone 65% is steep slopes
Mitchell Plain	Rolling limestone plateau crossed by deep rocky valleys. Some steep slopes
Norman Upland	Hilly land with rock slopes and outcrop of siltstone. 65% steep slopes
Scottsburg Lowland	Broad valley flats and low rolling hills. Half subject to wetness. Some steep slopes
Muscatatuck Regional Slope	Rolling limestone plateau crossed by deep rocky valleys. ½ subject to wetness. Some steep slopes
Dearborn Upland	Hilly land with rocky slopes and outcrops of limestone and shale. 60% steep slopes



Gray (2000)

Overview of Indiana Geology

- Glacial advances dissect the northern and southern half of Indiana
- Glacial till deposits can be hundreds of feet thick in the northern half of the state
- Residual soil is the dominant unconsolidated deposit beyond the glacial advance, this is limited to the southern half of Indiana
- Depth to bedrock is shallower in the southern half of Indiana, typically less than 50 feet
- Map: Solid gray line is the Wisconsin Glacial Limits(50,000 years ago) and dotted line is Illinoian Glacial Limits(300,000 to 140,000 years ago)



Indiana Map (2019)

NextLevel INDIANA

Indiana Bedrock

Indiana Rock Types:

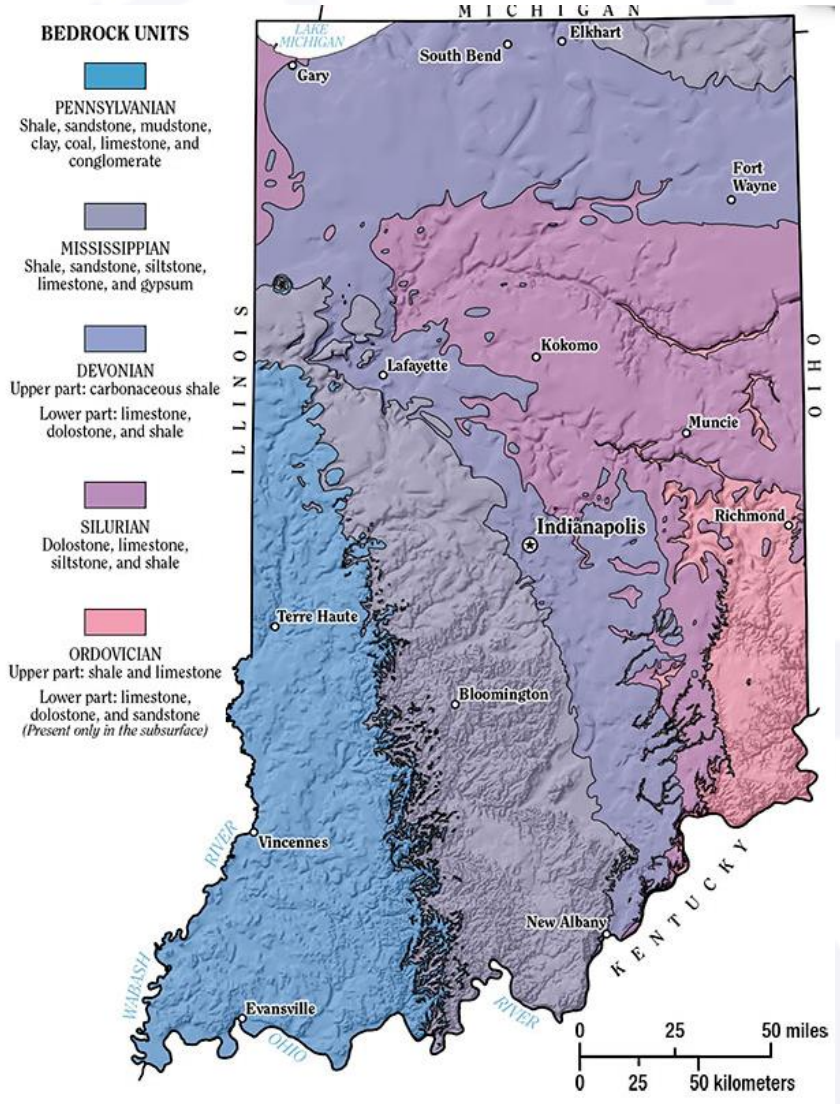
- Shale, Sandstone, Mudstone, Coal, Limestone, Siltstone, and Dolomite

Landslide Prone Rock Types:

- Shale and thinly bedded/ alternating rocks

Landslide Prone Rock Formations:

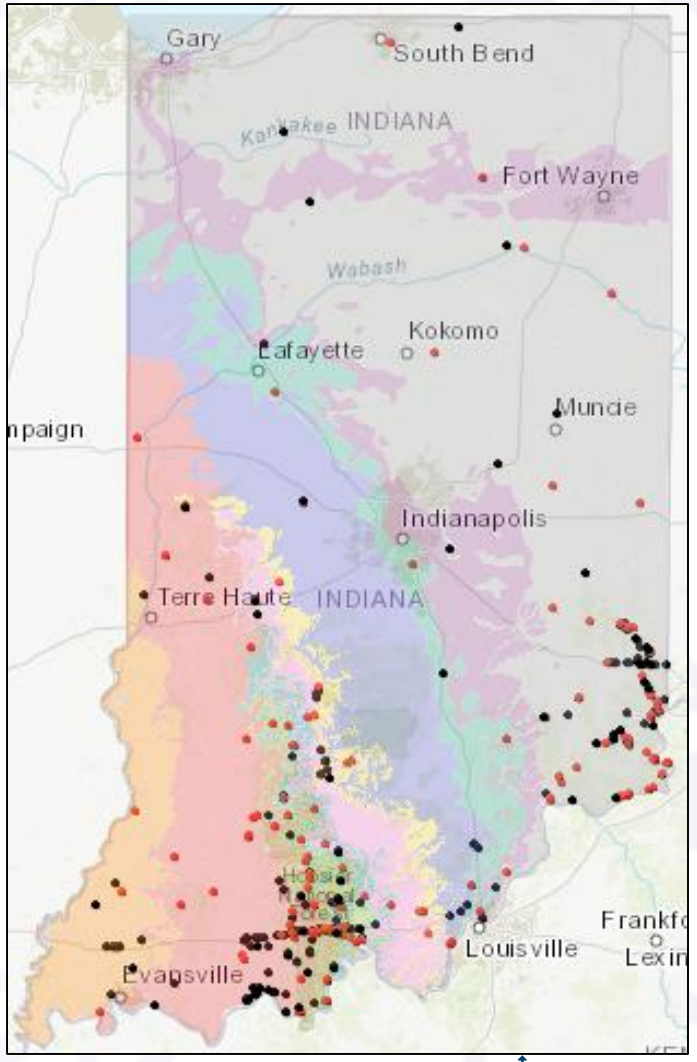
- Kope, Buffalo Wallow, Stephensport, Sanders, West Baden, Dillsboro, Blue River, Patoka, Shelburn, and Raccoon Creek



Indiana Geologic Survey (2019)

Indiana Bedrock Geology & Landslides

- Mapped landslides are relative to Indiana's highway network
- Landslides occur in two primary clusters- South Central and Southeastern
- Limited number in Southwest due to cut slope failures
- Landslides in Indiana are a function of both topography and bedrock geology
- The data mapped is a collection of Seymour & Vincennes GIS data, 1999 JTRP report, and Geotechnical Services data
- Map- Black dots represent historical data and red dots are 2018 active slides



Dots- INDOT GIS data (2018).
Bedrock information- Indiana Map(2018)

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Common Causes of Landslides

- Water or poor drainage
- Slope is too steep (for height)
- Creek at the toe of the slope
- Groundwater at soil-rock interface
- Sloping Bedrock
- Engineering of Fill
- Failed internal/adjacent drainage structures
- Poor soils in natural ground
- Loading from traffic or slopes above the road
- Earthquake or other natural disaster

US 52. Franklin County, Indiana

Potentially Hazardous Slopes

In relation to highway construction:

- Constructed highway embankments
- Cut slopes
- Unvegetated slopes
- Slopes 2:1 or steeper
- Stream banks

SR 445. Greene County, Indiana

Engineered Slopes

Embankments:

- Poor compaction
- Embankment material containing large fragments of broken up shale material
  - Shale can degrade from a hard mass to a fine-grained mass of soil causing settlement in embankments

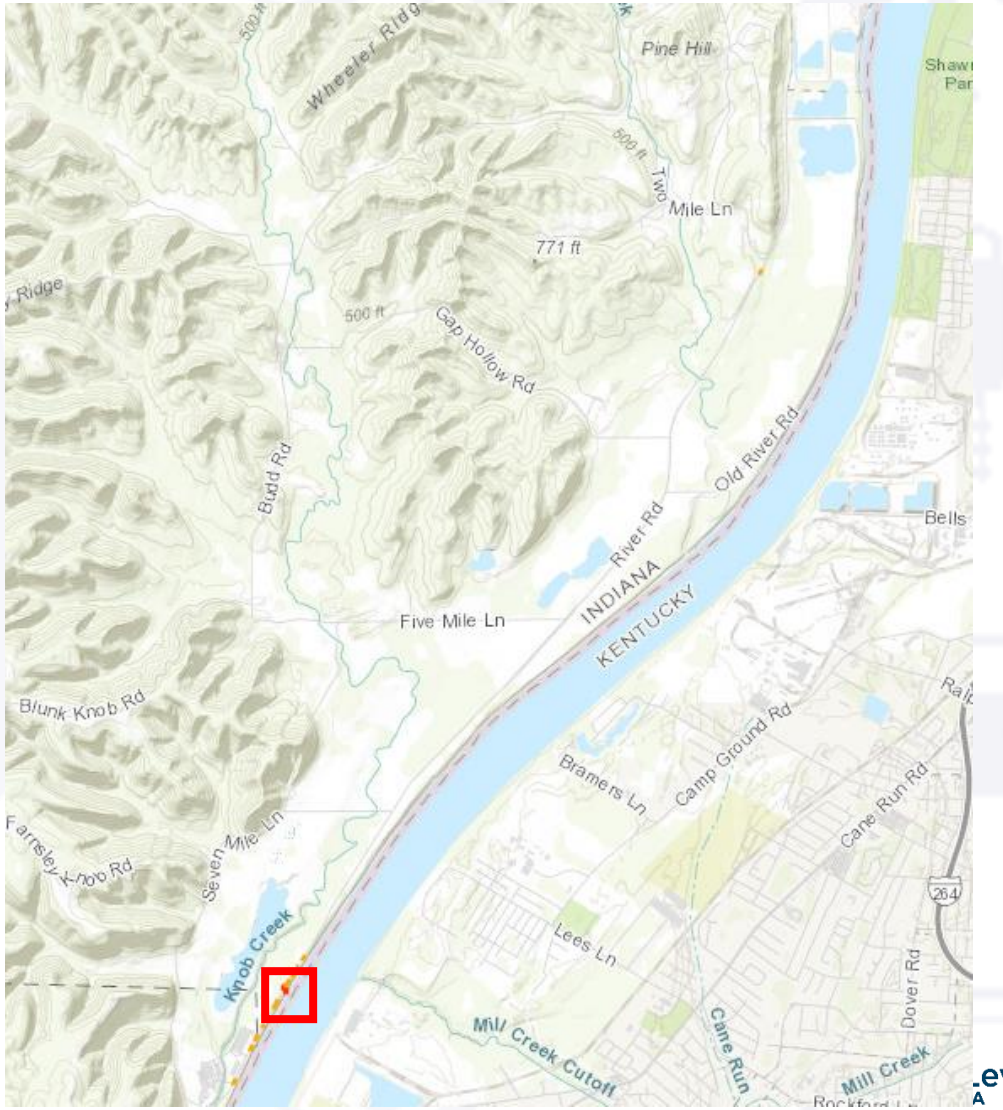
Cut Slopes:

- Thinly layered bedrock(alternating between shale and limestone)
- Sometimes slopes are designed/constructed too steep for soil type – Right of Way/Environmental Constraints

I-69. Monroe County, Indiana(2019)

Stream Bank Erosion

- Failures can be hydraulic, geotechnical, or a combination of both.
- Meandering streams typically have erosion occurring on the outsides of meanders. Undercutting causes slope failures to occur.
- Typically we see failures after flood events when the water levels return to normal conditions - Rapid Drawdown.



INDOT ArcGIS Online Map (2018)

Stream Bank Failure - SR 111 Floyd County

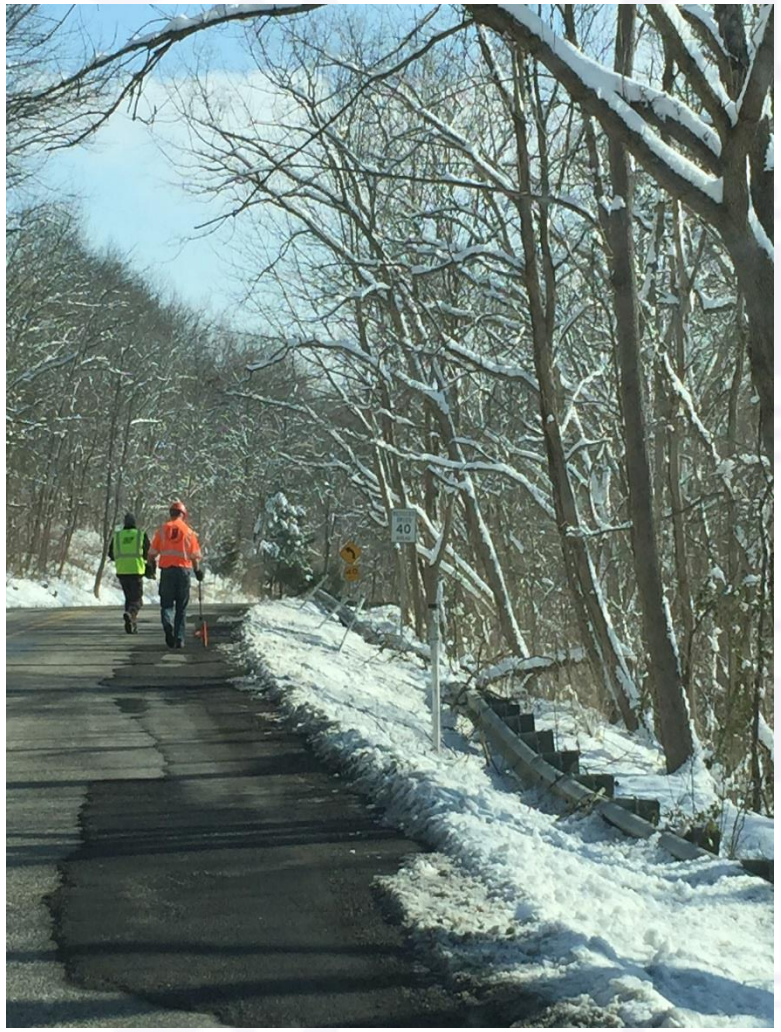
March 28, 2018

May 15, 2018

Common Evidence of Ground Movement

Not limited to, but can include:

- Headscarps
- Toe bulges
- Tension cracks in pavement or slope
- Hummocky appearance of the slope surface
- Misalignment of the guardrail
- Tilting trees, J-shaped trees
- Patching of the roadway surface
- Water seepage on the slope
- Debris blockage or poorly flowing ditches along the toe of the slope
- Some of these conditions can be noted, but will not represent slope instability. Typically, when slope instability is occurring multiple characteristics are present.



US 52. Franklin County, Indiana.

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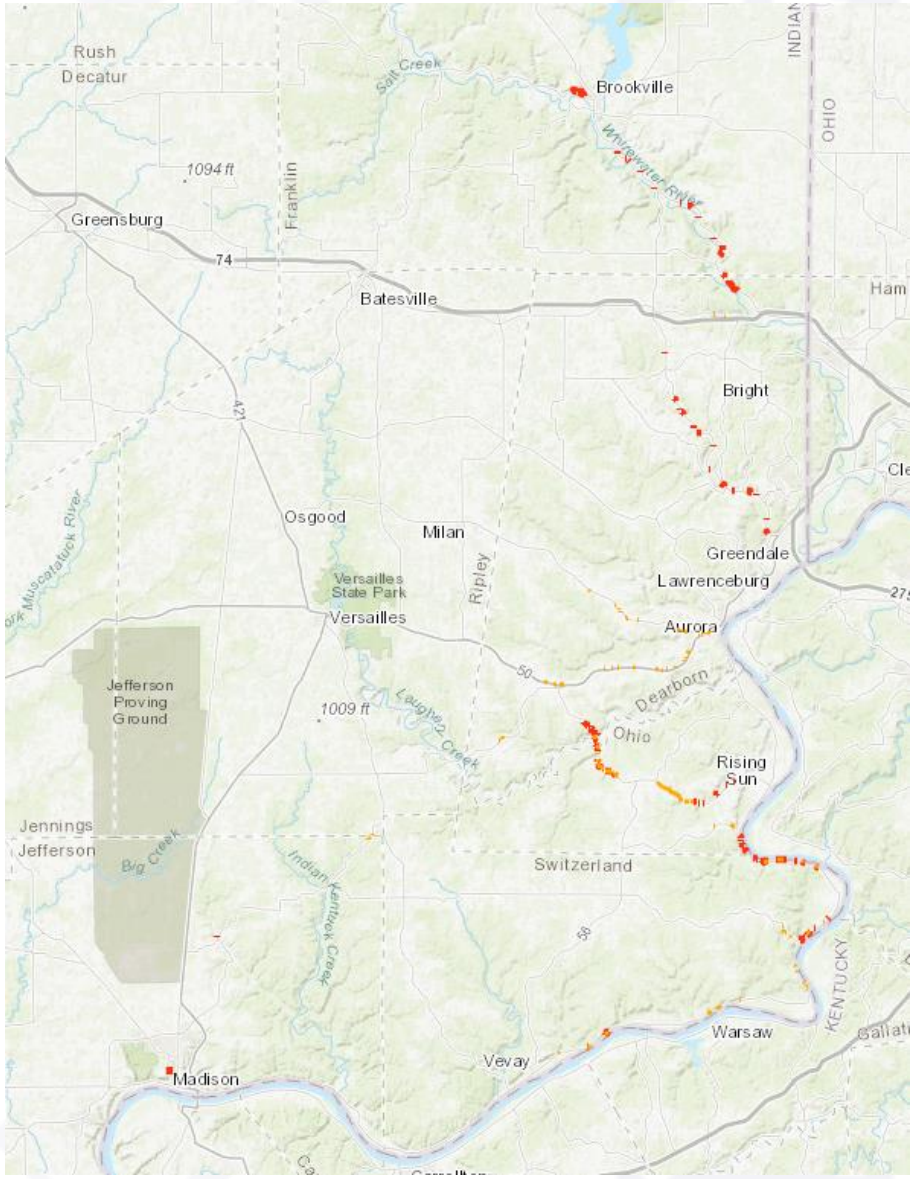
Slide Collector App

- The intent of the collector app:
  - Help identify potential hazardous slopes
  - Assess relative risk
  - Determine a degree of monitoring required
  - Allow for action to be taken to minimize the risk to the public's safety and protect the highway system

- Provides a standardized way to collect data.
- Users can be INDOT district personnel, geotechnical services personnel, and approved geotechnical consultants.
- Map - Red lines are slides mapped by Geotechnical Consultants(2018) and Orange lines are legacy slides mapped by Seymour District



INDOT Collector App Map (2018)

Slide Collector App-SR 1

SR 1. Dearborn County, Indiana(2018). Earth Exploration.

Slide Characteristics Table

Vendor	Drop Down Option- Please select who (Consultant/INDOT) is collecting data.
Status	Identified-District, Verified-Consultant, Verified-INDOT, Programmed, In-Construction, Legacy, Status is Undefined
Slope Type	This field details the nature of the failing slope; is it a cut slope, embankment, or naturally existing slope.
Total Slope Height (ft)	The height of the total slope. Approximations are acceptable in this field. Note this is different from affected slope height.
Slope Steepness	This field is an approximation of the steepness of the failed slope. Typical values will be 2H:1V, 1.5H:1V, 1H:1V, etc.. Approximations are acceptable in this field as they will be later corrected with survey data.
Preliminary Cause	Possible cause of slope failure. List if noticeable.
Possible Solutions	List potential solutions to slope failure. If applicable list a maintenance, moderate, and permanent solution.
Possible Solutions Cost	List potential costs relative to the potential solutions.
Existing Remedial Activities	This field will note any corrective action that has previously been undertaken at a site.
DES	INDOT DES number for slide project, if applicable.
ROUTE_POST_AND_OFFSET	Route post and offset of the roadway the slide is located.

Slide Collector App

DOTRAH.Slide_GeoTech: Earth Exploration

Vendor	Earth Exploration
Status	Verified - Consultant
Slope Type	Natural Slope
Total Slope Height (ft)	35
Slope Steepness	3 : 1
Preliminary Cause	Likely a shale slide. Slope not that steep
Possible Solutions	Pin piles/buried, arching
Possible Solutions Cost	
Existing Remedial Activities	Paving
DES	
ROUTE_POST_AND_OFFSET	6.3 Left

Attachments:
RP 6.3 Left.pdf
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Zoom to Edit
Show Related Records

SR 1. Dearborn County, Indiana(2018). Earth Exploration.

NextLevel INDIANA

Slide Monitor Table

Landslide Length (ft)	This measurement is the apparent length of the landslide at its longest point and parallel to the roadway.
Affected Slope Height (ft)	What is the overall height of the affected slope? In areas where the roadway is mid-slope of an existing natural slope this height should be measured in respect to which slope has failed. Approximations are acceptable in this field.
Roadway Affected Length (ft)	Measurement along the roadway detailing the length of the affected pavement.
Roadway Affected Width (ft)	Measurement at the widest point of the affected roadway. The measure should be made from the edge of pavement to the furthest tension crack.
Pavement Lateral Displacement (in)	This is a measurement in inches of the maximum lateral movement noted at any tension cracks.
Pavement Vertical Displacement (in)	This is a measurement of the maximum vertical movement noted at any tension cracks at the head scarp of the landslide.
Potential for Additional Failure	The potential for the slide to cause additional failure to the roadway based on the current status of the slide and past monitoring reports.
Slide Field Notes	Additional information the inspector wants to note about the slide.

Slide Monitor Table

- Landslides are often very dynamic
- The slide monitor table is separate from the slide details to capture landslide changes in relation to pavement distress
- Multiple slide monitor tables can be added
- Multiple tables allow us to track pavement distress over time
- A hazard rating can be assigned to prioritize landslides based on slide monitor tables

Slide Monitor (Features: 1, Selected: 0)

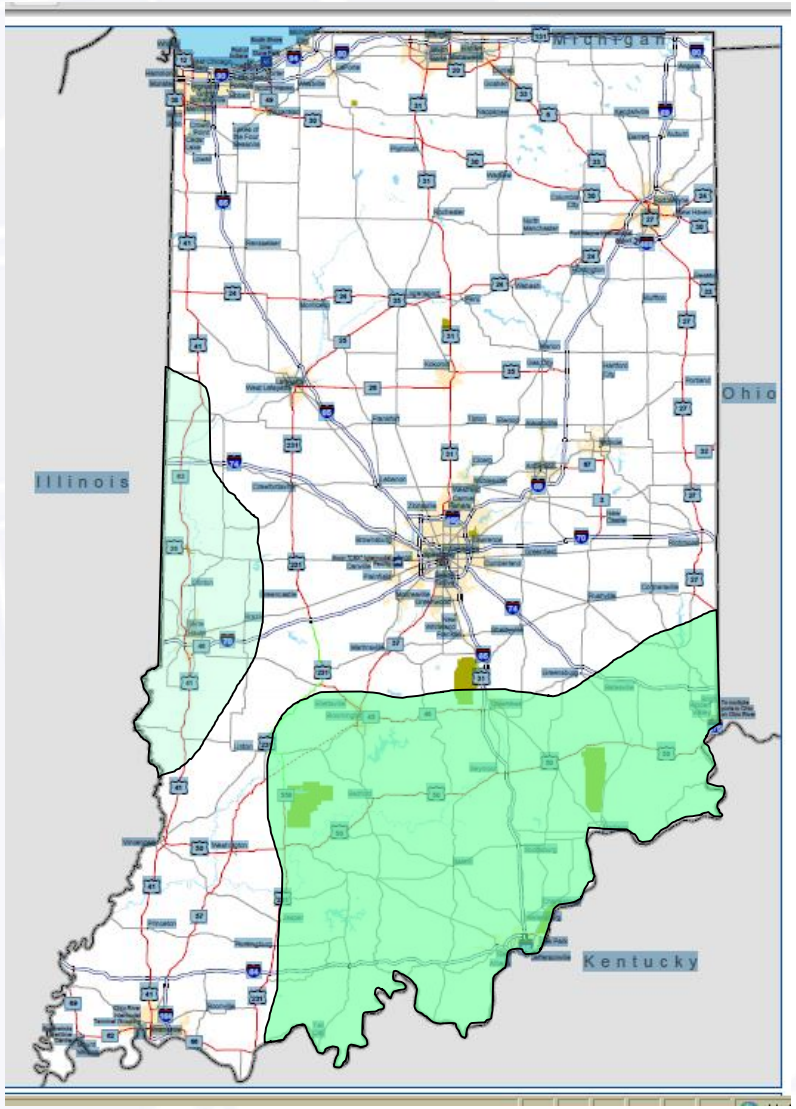
Landslide Length (ft)	Affected Slope Height (ft)	Roadway Affected Length (ft)	Roadway Affected Width (ft)	Pavement Lateral Displacement (in)	Pavement Vertical Displacement (in)	Potential for Additional Failure	Slide Field Notes	*Slide_GeoTech*
450	15	450	20	2	6	Severe		(1) Show

Inventory Tips

- The optimum time for field work for identifying slides is October through April, however, snow may also limit field activities in December through February.
- The more precise the data the better.
- Series of small instabilities closely associated with each other should be combined, however, slope instabilities on opposite sides of the road should be mapped separately.

US 35. Howard County, Indiana

Indiana State Map



Types of Landslides

Circular Failures

Types of Landslides

Circular Failures

Types of Landslides

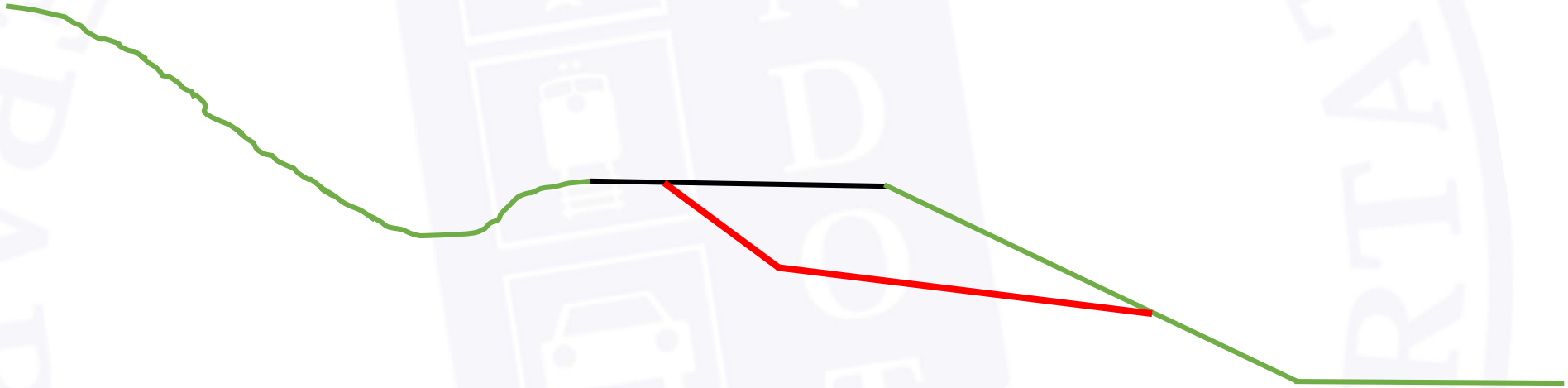
Circular Failures

Types of Landslides

Circular Progressive Failure

Types of Landslides

Sliding Block Failures



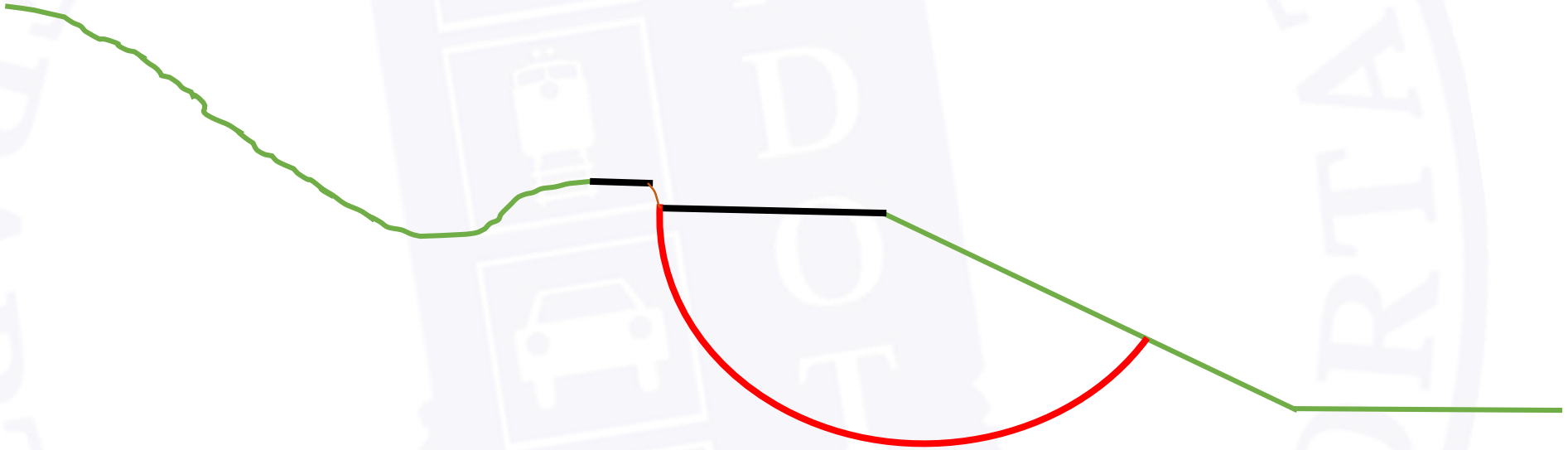
Types of Landslides

Erosion Failures

Could Lead to Larger Problems

Landslide Effects

Cracks in Pavement



Landslide Effects

Cracks in Pavement

US 52. Franklin County, Indiana

Most Popular Landslide Corrections

1. Flatten the Slope
2. Rock Backfill Correction
3. Drilled Piers with Tiebacks
4. Soldier Pile Wall with Tiebacks
5. Reinforced Slope
6. Soil Nail Wall
7. Gabion Wall

Landslide Corrections

Flatten the Slope

Advantages:

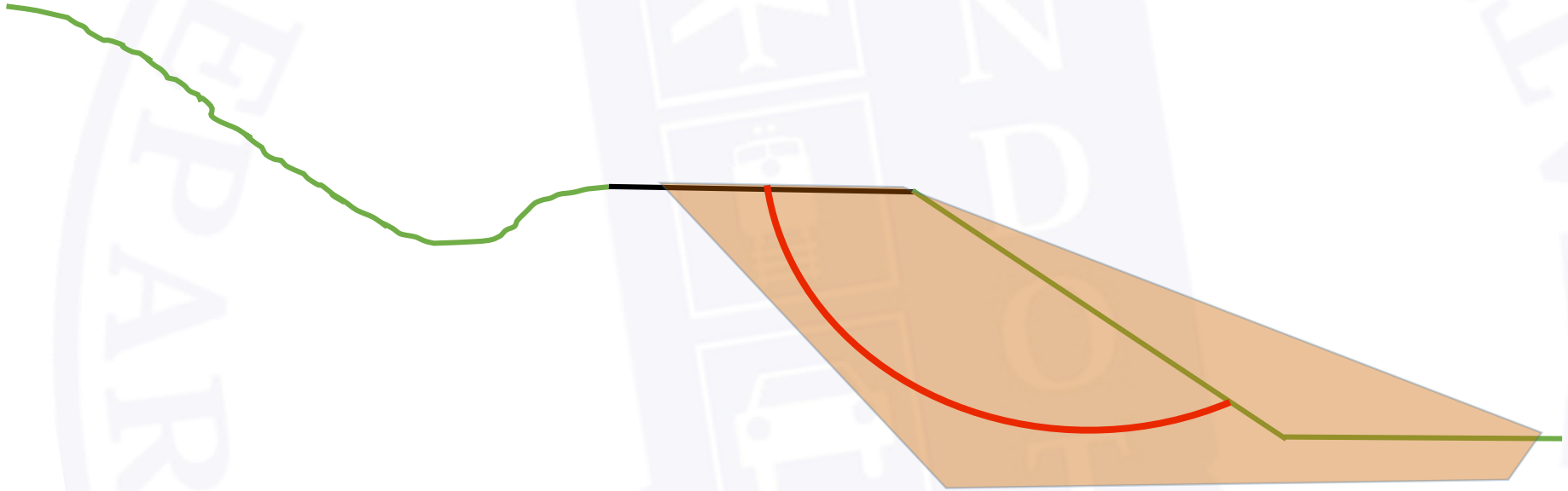
1. Cost effective
2. Failed material can often be reused for fill

Disadvantages:

1. New slope has larger footprint (may require right of way)
2. Road closed or partially closed for construction
3. Depending on height, temporary excavation can be risky

Landslide Corrections

Flatten the Slope



Landslide Corrections

Rock Backfill

Advantages:

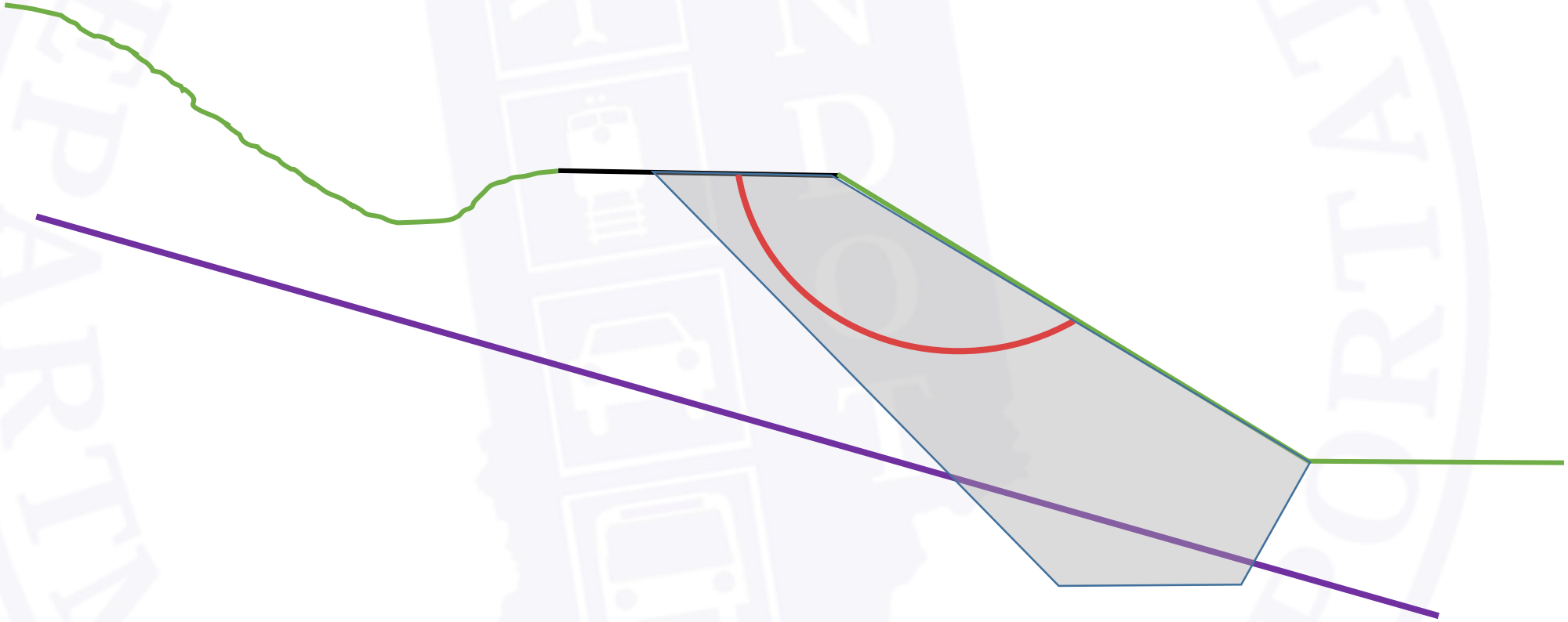
1. Cost effective
2. Depending on analysis, existing slope steepness can generally be maintained
3. Rock backfill keys into bedrock very well

Disadvantages:

1. Requires hauling in rock backfill and hauling away most failed material
2. Road closed or partially closed for construction
3. Depending on height, temporary excavation can be risky

Landslide Corrections

Rock Backfill



Landslide Corrections

Rock Backfill

SR 37. Perry County, Indiana

Landslide Corrections

Drilled Piers or Soldier Piles (usually with Tiebacks)

Advantages:

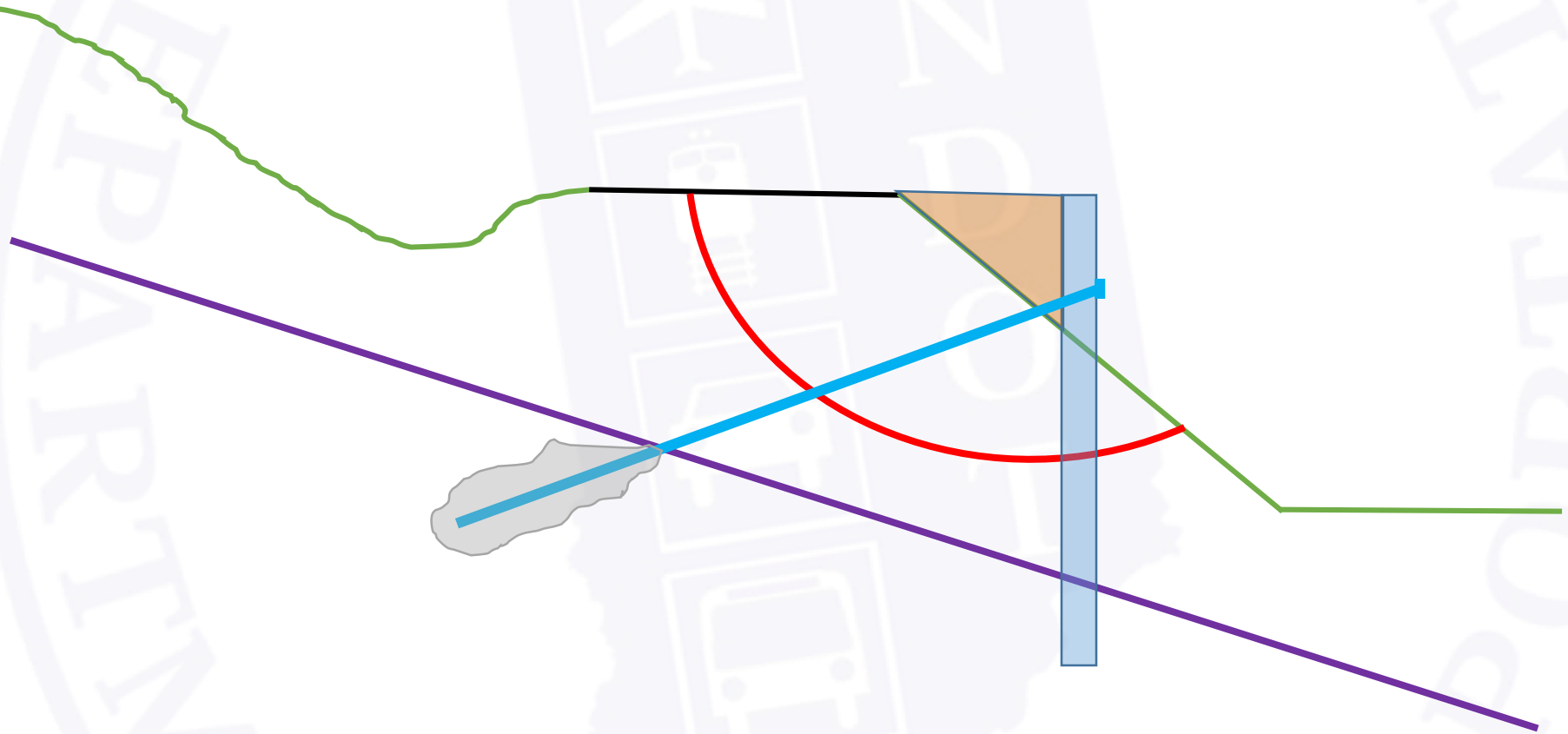
1. Gold standard of landslide repairs
2. Extremely robust system, there has never been a failure of this correction in Indiana
3. Construction time is relatively quick

Disadvantages:

1. Most costly correction in our arsenal, we use it as a last resort when nothing else is feasible
2. Not a redundant system
3. May require monitoring during construction and post construction

Landslide Corrections

Drilled Piers or Soldier Piles (Usually with Tiebacks)



Landslide Corrections

Drilled Pier Wall with Tiebacks

SR 66. Spencer County, Indiana

Landslide Corrections

Soldier Pile Wall without Tiebacks

SR 66. Spencer County, Indiana

Landslide Corrections

Reinforced Slopes

Advantages:

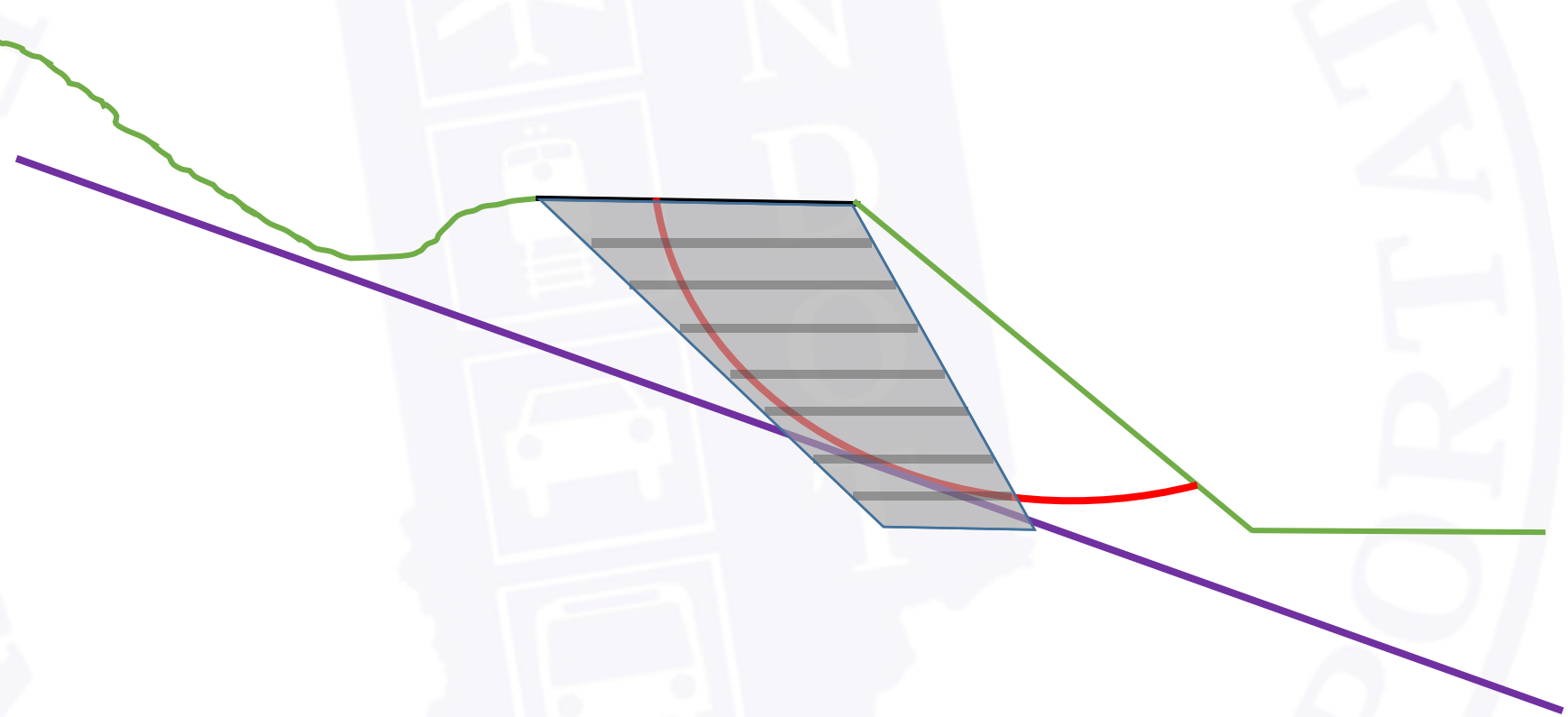
1. Cost effective
2. Robust system with plenty of redundancy
3. Works very well when slide is on a gently sloping bedrock surface

Disadvantages:

1. Very labor intensive
2. Almost always requires closing the road
3. Road closure time often excessive and multiplies with height of reinforcement zone

Landslide Corrections

Reinforced Slopes (Geogrids or Geotextiles or both)



Landslide Corrections

Reinforced Slope

Source:
retainingsolutions.com.au

Landslide Corrections

Reinforced Slope

SR 59. Parke County, Indiana

Landslide Corrections

Soil Nail Walls

Advantages:

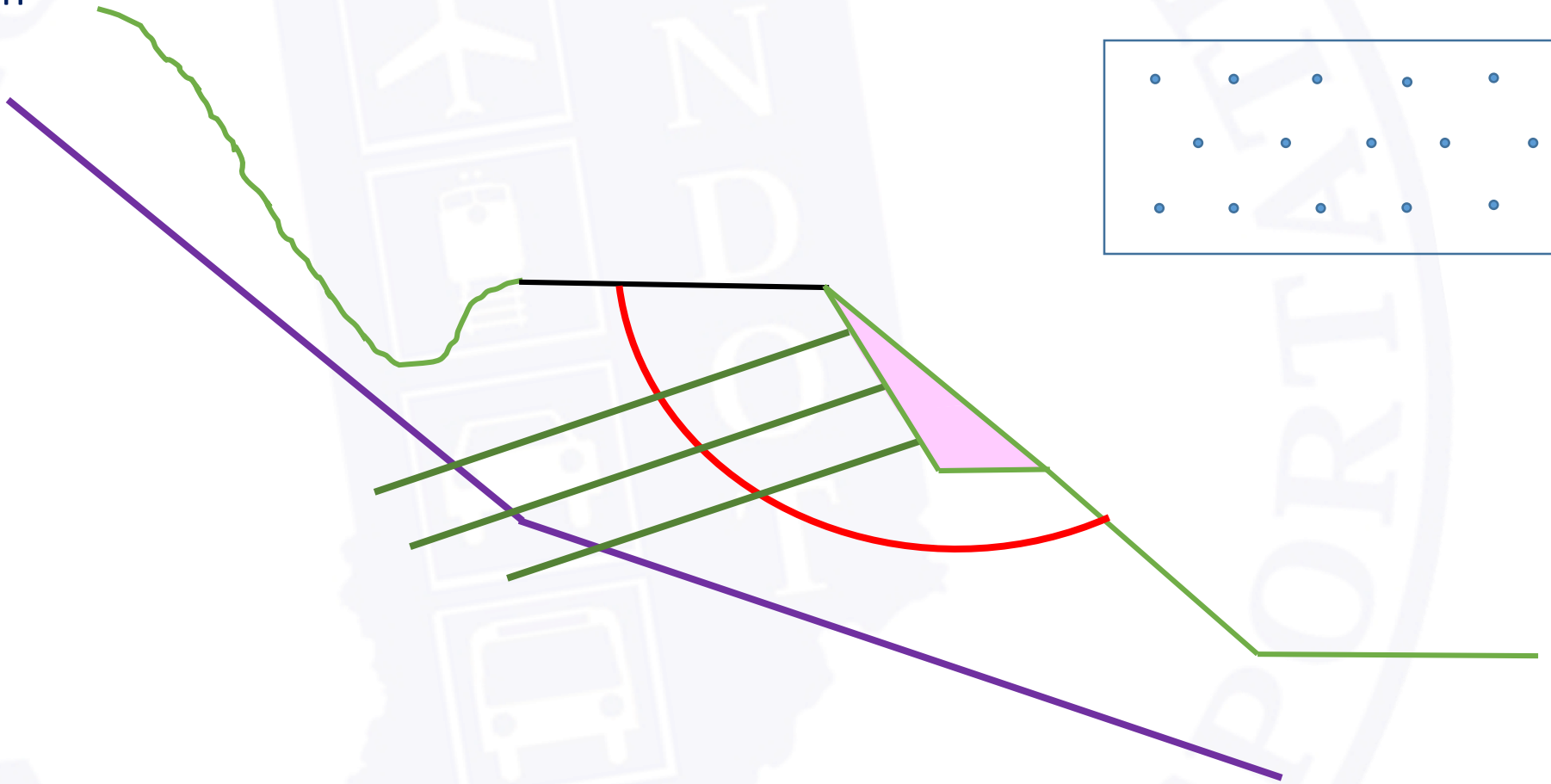
1. Cost effective
2. Plenty of redundancy
3. Works very well when slide is on a steeply sloping bedrock surface
4. Traffic can often be maintained on a limited basis during work, and can be maintained completely during non-working hours

Disadvantages:

1. Require extra work to stabilize below the toe when rivers, creeks, or other issues can cause erosion
2. The elements which provide redundancy can also create nuisance maintenance

Landslide Corrections

Soil Nail Wall



Landslide Corrections

Soil Nail Walls

SR 75. Hendricks County, Indiana

Landslide Corrections

Gabion Walls

Advantages:

1. Cost effective
2. Very quick construction, minimal disturbance to traffic

Disadvantages:

1. Gabion walls have about a 35 year design life as opposed to 75 years
2. Hydraulics is concerned about erosion behind these walls when they are constructed near creeks

Landslide Corrections

Gabion Walls

SR 1. Dearborn County, Indiana (Google Maps)

Resources

- JTRP Report- Deschamps and Lange. (1998). “Landslide Remediation using Unconventional Methods”. Indiana Department of Transportation and Purdue University.
- Ohio Department of Transportation. (2013). “Manual For Landslide Inventory.”
- Indiana Map- https://maps.indiana.edu
- Google Maps

Airport Road(2018). Orange County, Indiana

Questions?

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