Mechanisms and Mitigation of Highway Landslide Collapse in Indiana

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Geologic Conditions in Indiana

BEDROCK UNITS

PENNSYLVANIAN
Shale, sandstone, mudstone, clay, coal, limestone, and conglomerate

MISSISSIPPIAN
Shale, sandstone, siltstone, limestone, and gypsum

DEVONIAN
Upper part: carbonaceous shale; Lower part: limestone, dolostone, and shale

SILURIAN
Dolostone, limestone, siltstone, and shale

ORDOVICIAN
Upper part: shale and limestone; Lower part: limestone, dolostone, and sandstone (Present only in the Silurian)

Youngest Bedrock

Oldest Bedrock
Geologic Conditions in Indiana
There are four general landslide-type possibilities in Indiana:

- High bluff peeloff
- Groundwater blowout
- Deep-seated
- Shallow colluvial

There are various combinations of these generalized landslide types, as one type of mechanism may lead to another during the sliding, or the slide may be complex, exhibiting different modes of failure in different portions of the slide.
High Bluff Peeloff - Landslide Types in Indiana
High Bluff Peeloff - Landslide Types in Indiana

US 50 Ripley County Gabion Wall Failure
High Bluff Peeloff - Landslide Types in Indiana

US 50 & US 241 Gabion Wall Failure
14 HP 89 sections - 410 ft long - spaced 6 ft center-to-center
Extend 10 ft into sound bedrock
High Bluff Peeloff - Landslide Types in Indiana

SR 66
Spencer County

Re-Grading
High Bluff Peeloff - Landslide Types in Indiana

SR 66
Spencer County
High Bluff Peeloff - Landslide Types in Indiana

SR 66 at 66.3RP

Re-Grading
Groundwater Blowout - Landslide Types in Indiana

Diagram showing the relationship between groundwater blowout and landslide movement.

- **Perched Water**
  - *Ground Surface Before Slide*
  - *Ground Surface After Slide*
  - *Sand*
  - *Clay or Low Permeability Layer*
  - *Slide Runout*
  - *Seepage*
  - *Slide Movement*
Groundwater Blowout - Landslide Types in Indiana

SR 237
1.05RP
Tell City

El 544
El 436
Groundwater Blowout - Landslide Types in Indiana

SR 237
1.05RP
Tell City
We lost 3/4 of the road in this rain event.
Groundwater Blowout - Landslide Types in Indiana

SR 1
Old Road
in Cedar Grove
Groundwater Blowout - Landslide Types in Indiana

SR 1 Old Road in Cedar Grove

Needs toe protection
Deep-Seated - Landslide Types in Indiana

- Scarp
- Potential Ponded Water (sag pond)
- Ground Surface Before Slide
- Ground Surface After Slide
- Clay or Low Permeability Layer
- Rotational or Wedge-shaped Slide Plane
- Typically More than 6 to 10 Ft.
- Groundwater/Surface Water
- Slide Movement
Deep-Seated - Landslide Types in Indiana

I-74 Landslide
Geofoam
Deep-Seated - Landslide Types in Indiana

I-74 Landslide Geofoam

20 ft high
Deep-Seated - Landslide Types in Indiana

I-74 Landslide Geofoam
Deep-Seated - Landslide Types in Indiana

I-74 Landslide Geofoam
Deep-Seated - Landslide Types in Indiana

I-74 Landslide Geofoam
Deep-Seated - Landslide Types in Indiana

SR 37
RP 11.4
Perry County
Deep-Seated - Landslide Types in Indiana

SR 37
RP 11.4
Perry County
Deep-Seated - Landslide Types in Indiana

SR 37
RP 11.4
Perry County

550 piers, 30 inches in diameter – 28 to 30 ft deep
Rip-rap key was placed two feet within the competent sandstone bedrock.
Deep-Seated - Landslide Types in Indiana

SR 37
RP 11.4
Perry County
Deep-Seated - Landslide Types in Indiana

SR 37
RP 11.4
Perry County
Deep-Seated - Landslide Types in Indiana

US 50 Slide at SR 62

Replacing the fill
Deep-Seated - Landslide Types in Indiana

SR 37
RP 11.4
Perry County
In 1952 bin-wall was constructed
Deep-Seated - Landslide Types in Indiana

SR 46
RP 150
Dearborn County
Drilled Shaft Wall

Drilled shaft with tiedback 4 ft in diameter - 7 ft center to center – 40 ft deep
Deep-Seated - Landslide Types in Indiana

SR 46
RP 150
Dearborn County
Drilled Shaft Wall
Deep-Seated - Landslide Types in Indiana

SR 56 Switzerland County Vevay Drilled Shaft Wall
Deep-Seated - Landslide Types in Indiana

SR 56 Switzerland County Vevay Drilled Shaft Wall

2000 ft long wall
300 drilled shafts with tied-back
3 ft in diameter
8 ft center to center
5 ft into the bedrock
Deep-Seated - Landslide Types in Indiana
Deep-Seated - Landslide Types in Indiana

US 150
Shallow Colluvial - Landslide Types in Indiana
Shallow Colluvial - Landslide Types in Indiana

US 50
Shallow Colluvial - Landslide Types in Indiana
Shallow Colluvial - Landslide Types in Indiana

Slide Correction on I-74, 7/10th mile east of SR1 and I-74

Mixture being spread over geotextile
Case History
S.R. 237 in Perry County, IN
General Site Plan

PROJECT LOCATION
FROM STA. 49+00 TO STA. 52+40 LINE "A"
Aerial View of the Site

Landslide area
S.R. 237 was originally built in 2003. This particular slope is approximately one-half mile long and was designed to be 2:1 and up to 112 feet high.
Geotechnical Challenges

- High embankment fills
- Slopes designed as steep as 2:1, placed on sloping natural ground
- Variations in rock surface elevations
- Fills consist of soils, shale and sandstone
- Environmental constraints
Slope after original construction.
First Slope Failure

- In May 2010 during heavy rain, the slope moved.
- The road edge and guardrail experienced vertical displacement.
- Northbound driving lane closed.
First Slope Failure
First Slope Failure
First Slide

- Possible causes for the first slide:
  - Actual slope measured steeper than 2:1 with the height of 112 feet, combined with the type of fill used (co-mingled soil and shale) was unstable.
  - Possible inadequate benching.
  - Water pouring from slope (excessive groundwater).
  - Heavy rainfall in spring.
Boring location plan for the first slide.
A soil nail wall with a design-build contract requiring a seven year warranty.

Extend outlet drainage pipe to the toe of the east slope.

The contractor proposed a new H-pile encased in concrete wall with tiebacks and a shotcrete facing after the bid which was accepted by INDOT.
After First Correction
Second Slope Failure

- In April 2012 during heavy rain, the slope in front of the wall moved. It gradually dropped vertically approximately 12 feet due to new failure.
Second Slope Failure

Roadway

Tie Back Wall

Existing Slope
Second Slope Failure
Second Slope Failure
Second Slope Failure
Second Slide

- Possible causes for the second slide:
  - Surface slide triggered by heavy rainfall.
  - Failure of outlet pipe of spring box which was buried underneath the roadway.
  - Insufficient investigation after the first slide (Borings were only 40 feet deep.)
Boring location plan for the second slide.
Design for Second Slide

- **Phase-1 Design**
  - Drainage correction: includes spring box repair & horizontal drains

- **Phase-2 Design**
  - Rock backfill (chosen)
  - Three tier soil nail walls
Correction Using Rock Backfill

Note: This option may not be used in any area where 50 feet of additional slope toe width can't be acquired.

Roadway

Tie Back Wall

Existing Slope

Rock Backfill

Must be a minimum of 40 feet and must remove all failed material

Excavate at 1:1 slope with benches Filter Fabric Required

Drainage Pipe

#6 Crushed Stone

Minimum of 50 feet beyond toe of existing slope

Des No: 1005625
County: Perry
SR 237 Slope Failure
Correction Using Three Tier Wall
Problems With Rock Backfill

- Slide aggravated further after letting in March 2013 due to heavy rains.
- Massive amount of water seeped out of the slope.
- The rock backfill was not viable option anymore because it would require the 1:1 temporary slope.
- Potential destabilization of existing soldier pile wall.
Another Surprise:

- During exploratory excavation for the spring box repair, coal mine shafts were uncovered.
Mine Shaft Discovery
Mine Shaft Discovery
More Investigation

- Resistivity study done to search for mines.
More Investigation

- Resistivity study done to search for mines.
- More borings to verify the locations of suspected mines under the roadway as per geophysical study (resistivity testing).
- Borings reveal several collapsed mine shafts under roadway.
Revised Solution

- **Phase-1 Design**
  - Drainage correction
    - Mine shaft interceptor drain
    - Grout the mine shafts

- **Phase-2 Design**
  - Drilled pier (3 ft. dia.) with tieback socket into rock
Interceptor Drains
Drainage Correction
Grouting to Fill Mine Shafts
The new drilled pier wall was originally proposed to be 15 feet from the existing wall.

The construction of new drilled pier wall affecting the integrity of existing soldier pile wall.
Additional Changes to the Design

- Move the proposed drilled pier wall 40 ft away from existing soldier pile wall (25 ft further) to provide safe excavation for inside lagging and backfill.

- Change temporary casing to a permanent casing for drilled piers due to possible co-mingled fill material.

- Provide casing for tieback un-bonded length to avoid major loss of grout due to unclassified fill material.
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Questions?

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