Addressing Slope Failures involving Problematic Soils in Kansas

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Overview

- Characteristics and Location of Problematic Soils
- Failure Mechanisms
- Slope Failure Analysis
- Types of Repair Methods
- Examples of Slope Failures in Kansas
  - Location
  - Background & Soil Properties
  - Repair
  - Ongoing Performance/Follow-Up Observations
- Challenges/Lessons Learned
- Going Forward

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Characteristics and Location of Problematic Soils

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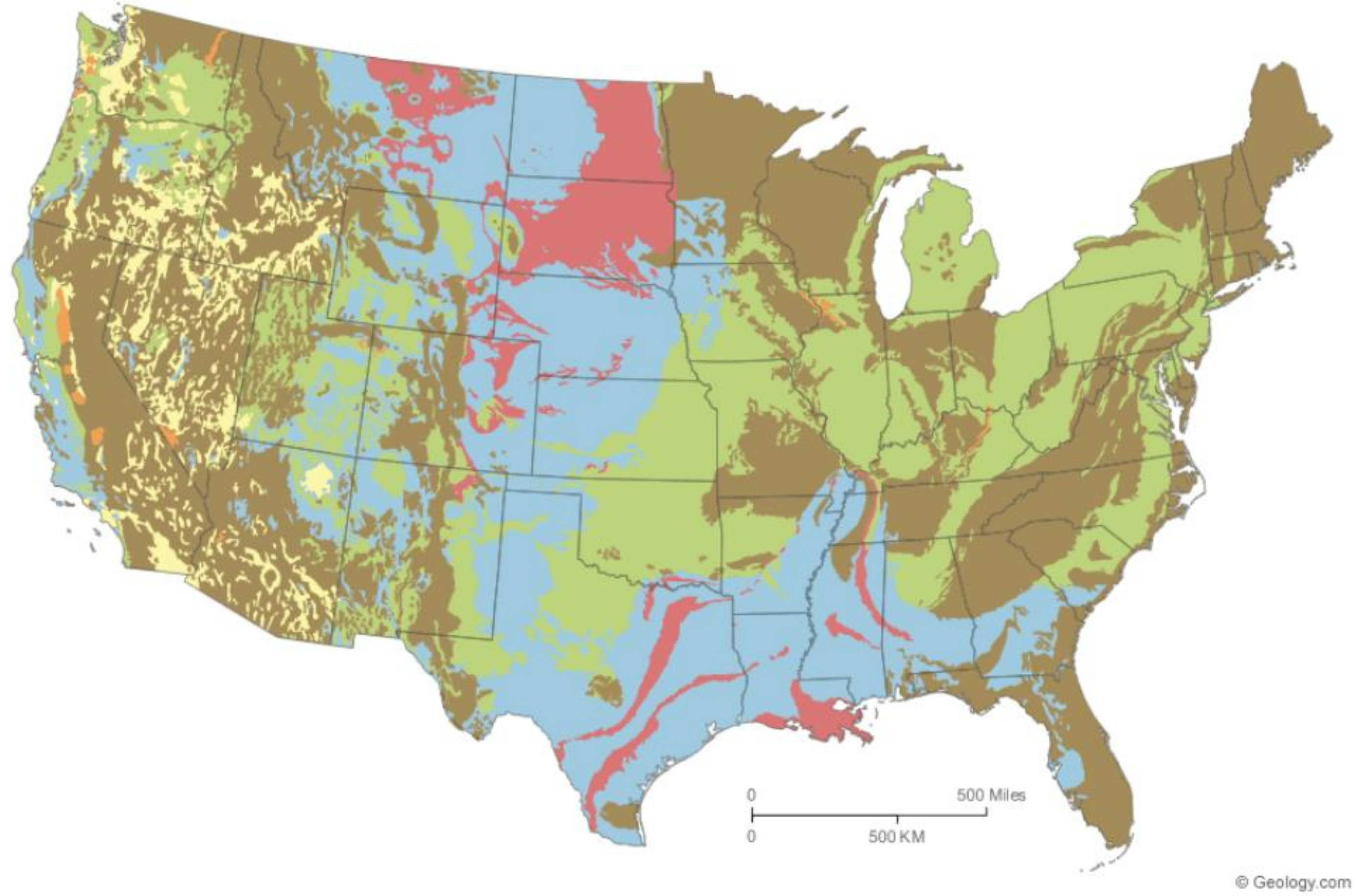
What makes soils so Problematic?

- High Swell Potential
  (expansive soils)
  ↓
- Low strength values
- High Erodibility
- Organics

What makes soils so Problematic?

- Expansive Soils
  - High Liquid Limit and Plasticity Index
  - Mineral content
    - Montmorillonite and Bentonite
    - (smectite, beidellite, vermiculite, attapulgite, nontronite, and chlorite)
  - Cyclic wetting and drying

"Swelling Clays Map of the Conterminous United States" by W. Olive, A. Chleborad, C. Frahme, J. Shlocker, R. Schneider and R. Schuster. 1989



USA Map of Expansive Soils

- Over 50 percent of these areas are underlain by soils with abundant clays of high swelling potential.
- Less than 50 percent of these areas are underlain by soils with clays of high swelling potential.
- Over 50 percent of these areas are underlain by soils with abundant clays of slight to moderate swelling potential.
- Less than 50 percent of these areas are underlain by soils with abundant clays of slight to moderate swelling potential.
- These areas are underlain by soils with little to no clays with swelling potential.
- Data insufficient to indicate the clay content or the swelling potential of soils.

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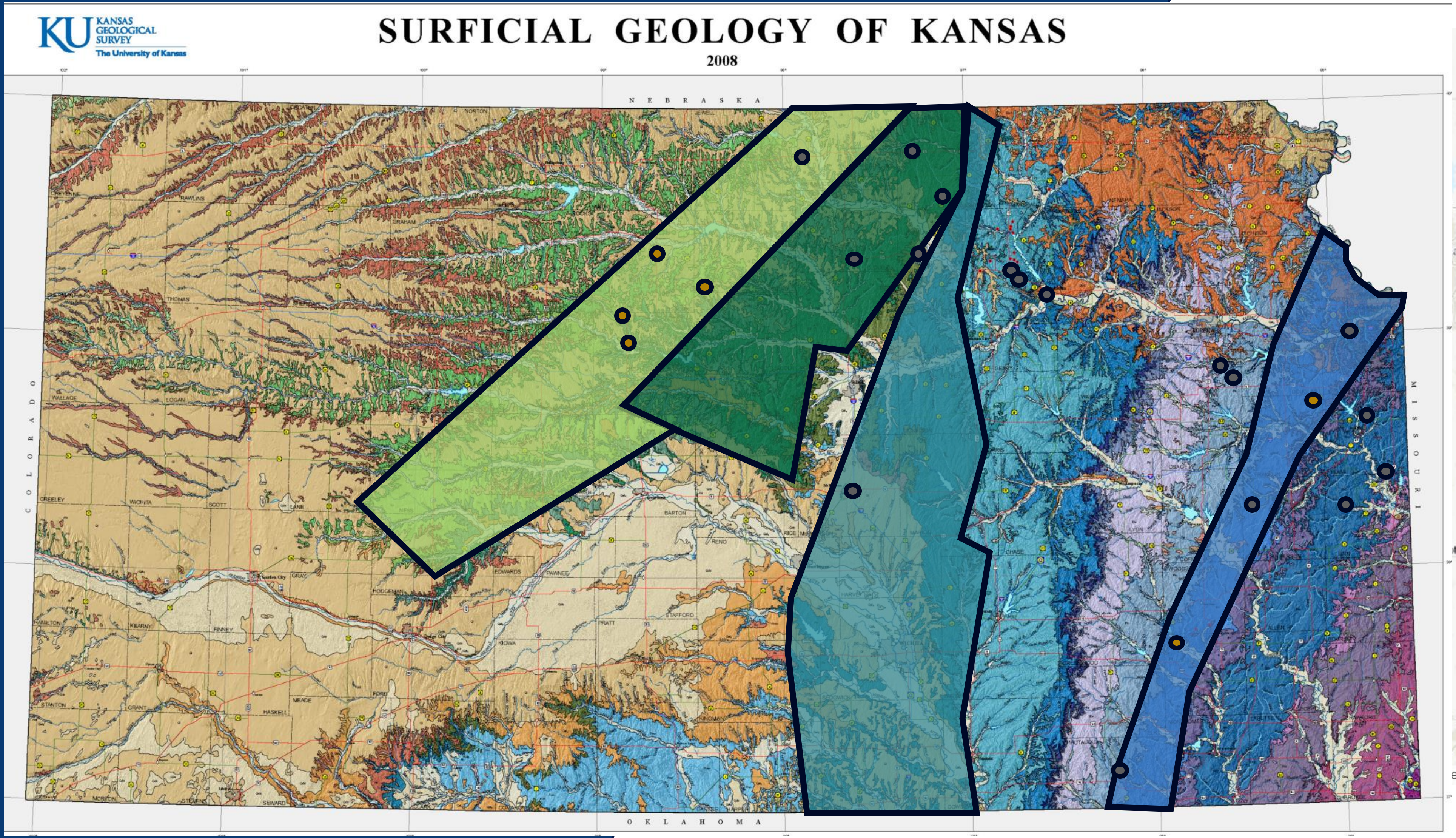
Surficial Geology Map of Kansas



Kansas Geological Survey, 2008, Surficial geology of Kansas: Kansas Geological Survey, Map M-118, scale 1:500,000.

- Single Slope Failure
- Multiple Slope Failures

- Douglas Group
  - Weston Shale
- Sumner Group
  - Wellington Fm
- Dakota Formation
- Granerous Shale/ Charlie Shale

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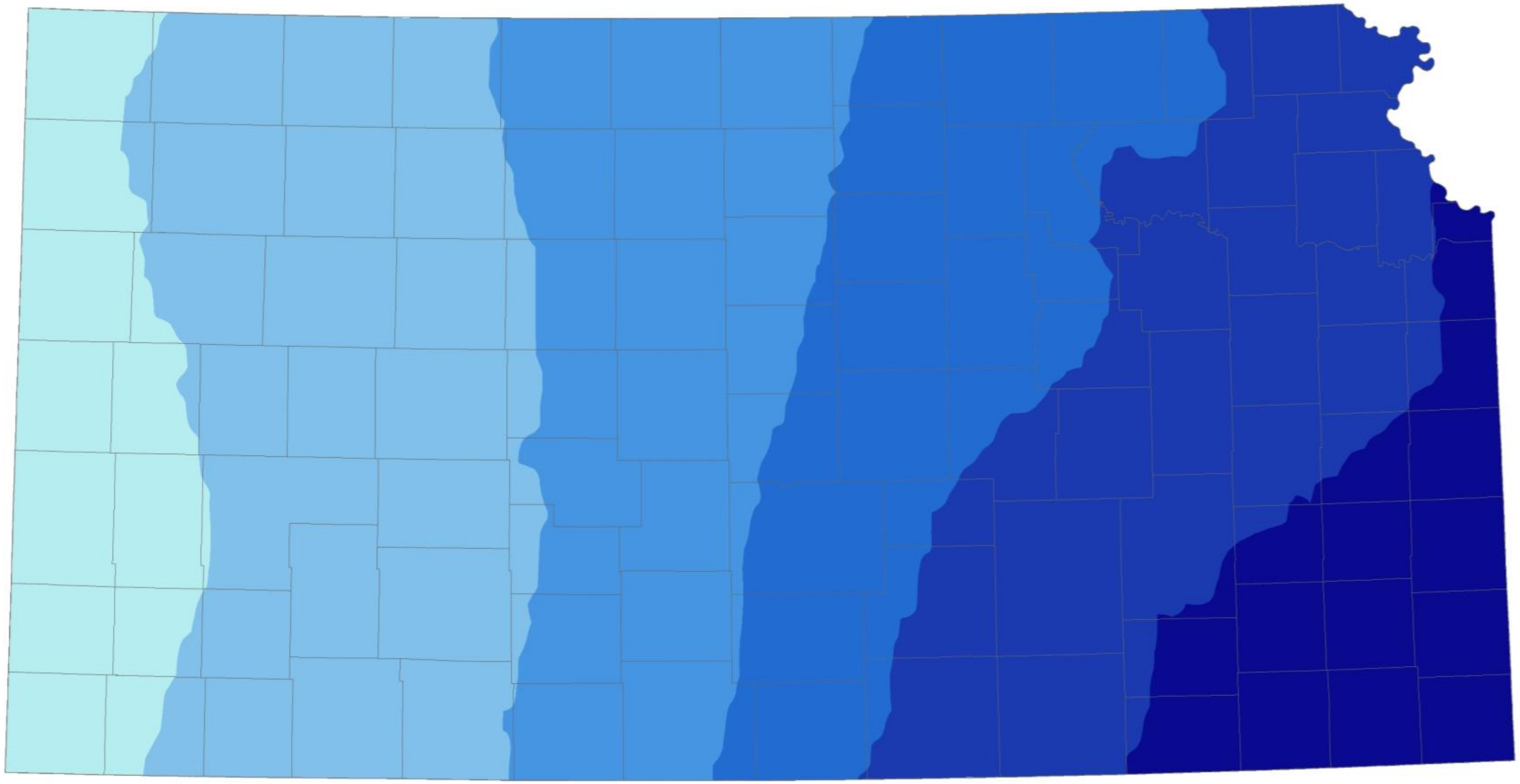
Average Precipitation in Kansas, 1991- 2020



Source: Institute for Policy & Social Research, The University of Kansas; data from National Oceanic and Atmospheric Administration.

Precipitation (inches)

- Less than 20
- 21 - 25
- 26 - 30
- 31 - 35
- 36 - 40
- More than 40

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General Failure Mechanisms

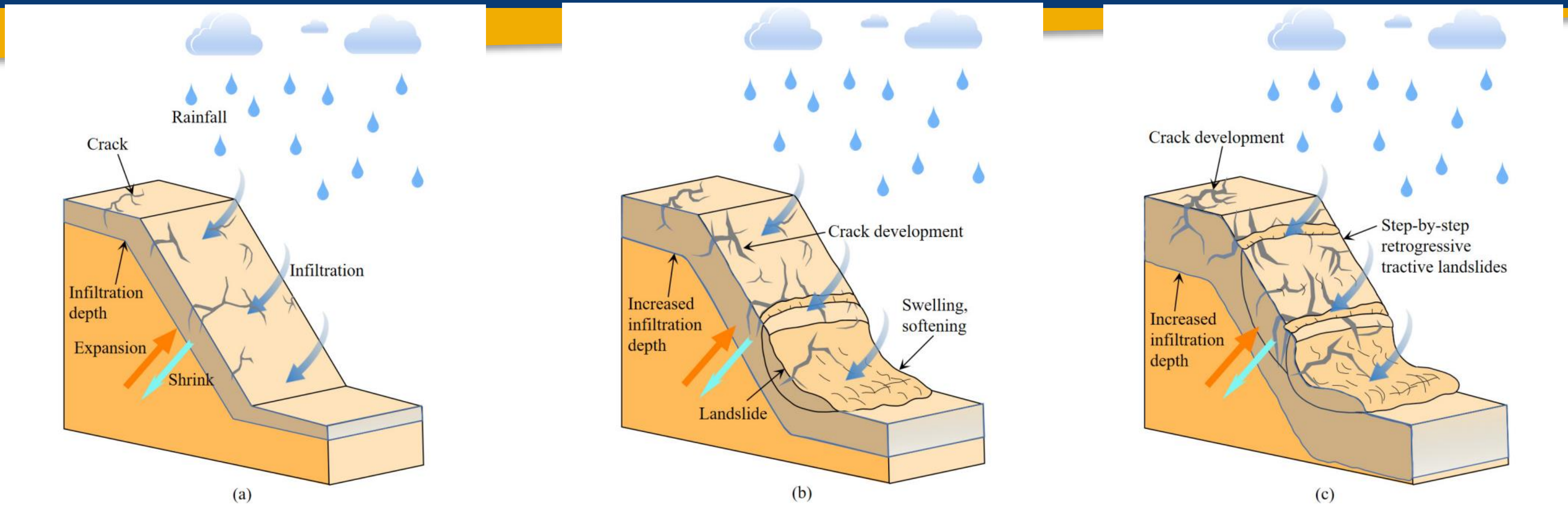

Figure 7. Destabilization and failure of expansive soil slopes: (a) initial state; (b) experience of repeated wet–dry cycles; (c) final failure.

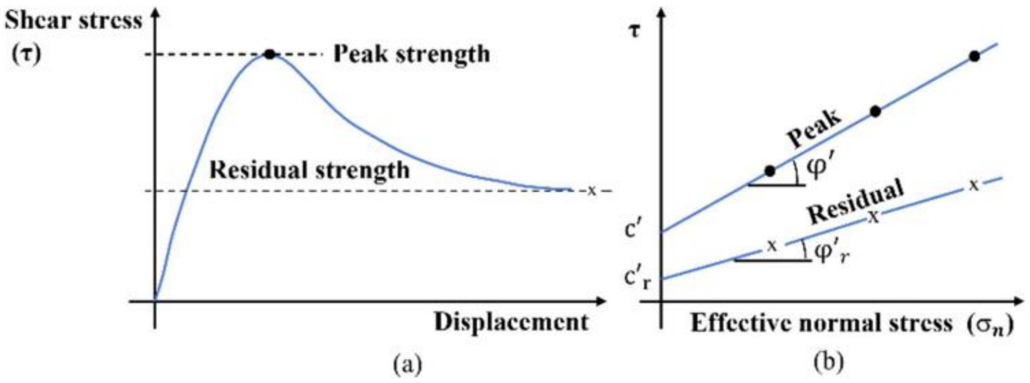

Figure 4. *a) The peak and residual strength and b) the approximated failure envelope for peak and residual conditions (Head & Epps, 2011)*

Additional Driving Factors

- Perched Water
- Load at top of slope
  - Pavement
  - Vehicular Load

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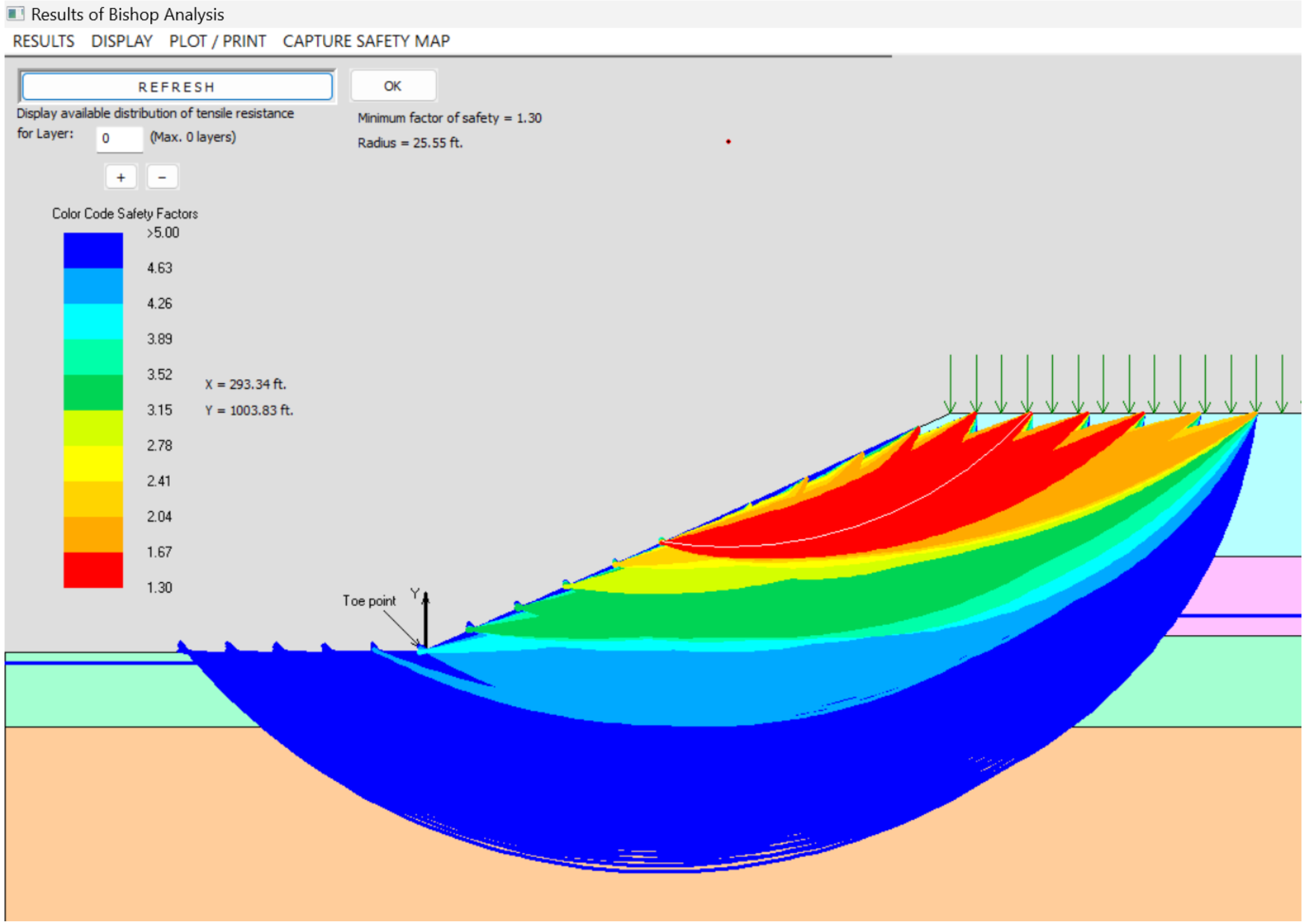
Slope Failure Analysis



ReSSA+

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Most Common Types of Repair Methods

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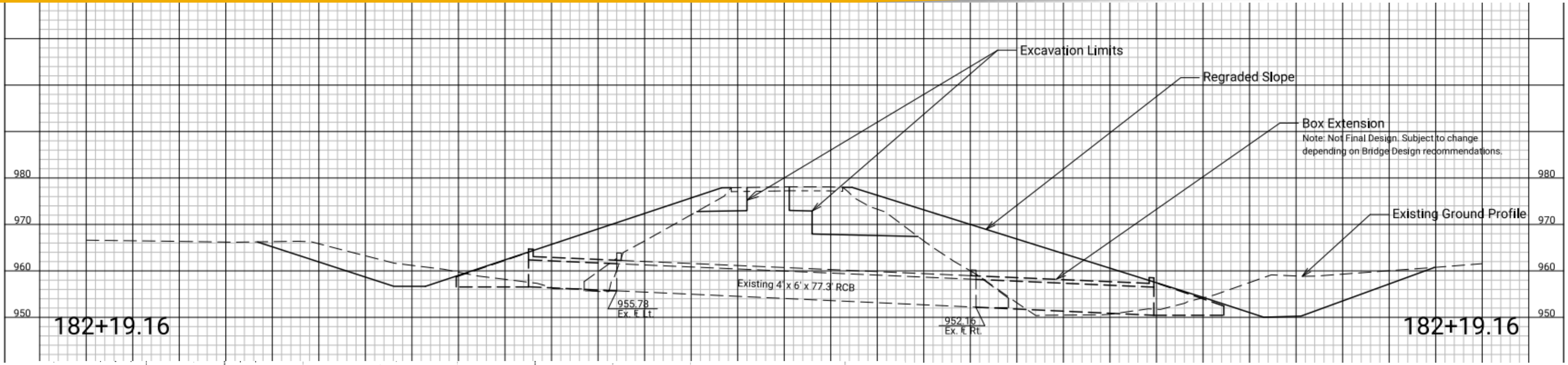
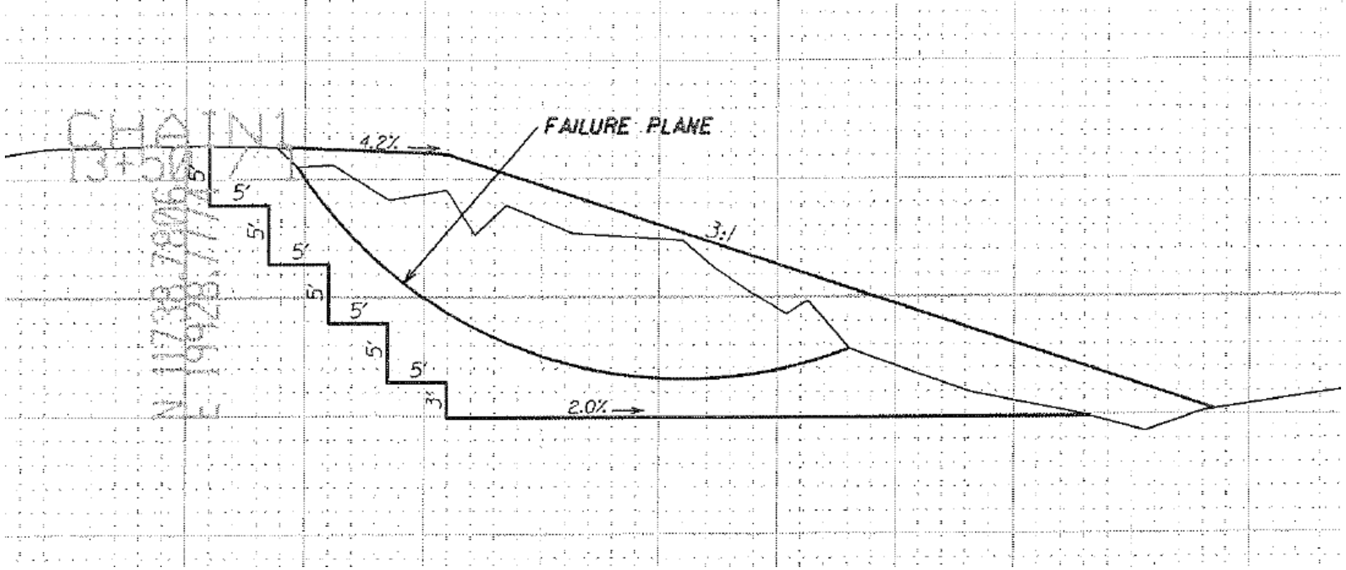
Most Common Types of Repair Methods





Flattening the slope / widening the shoulder

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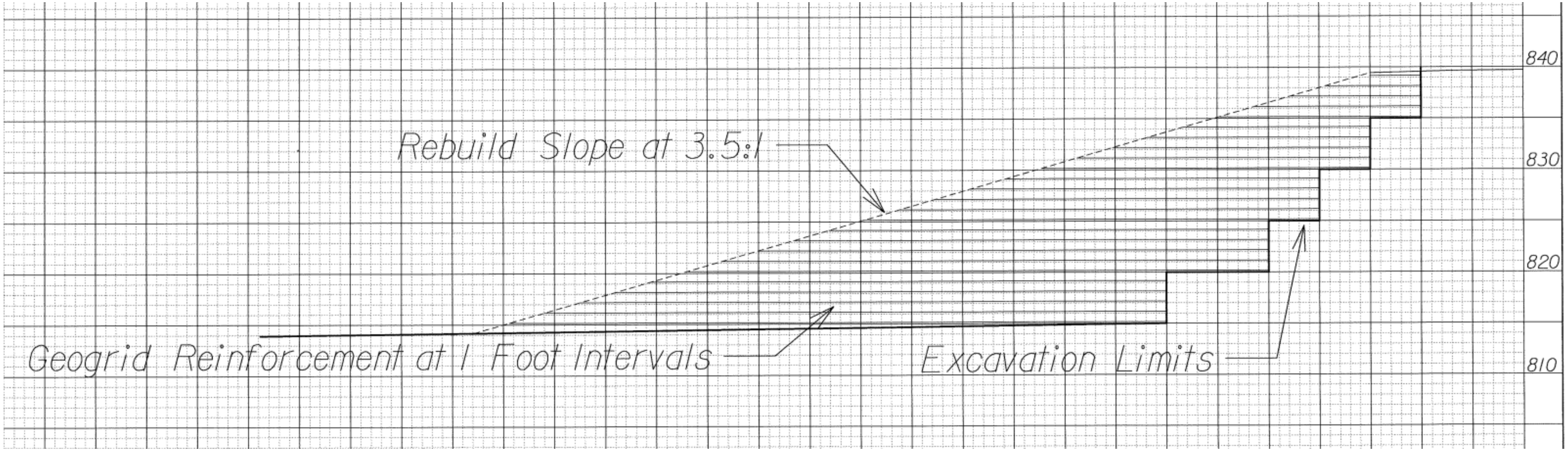
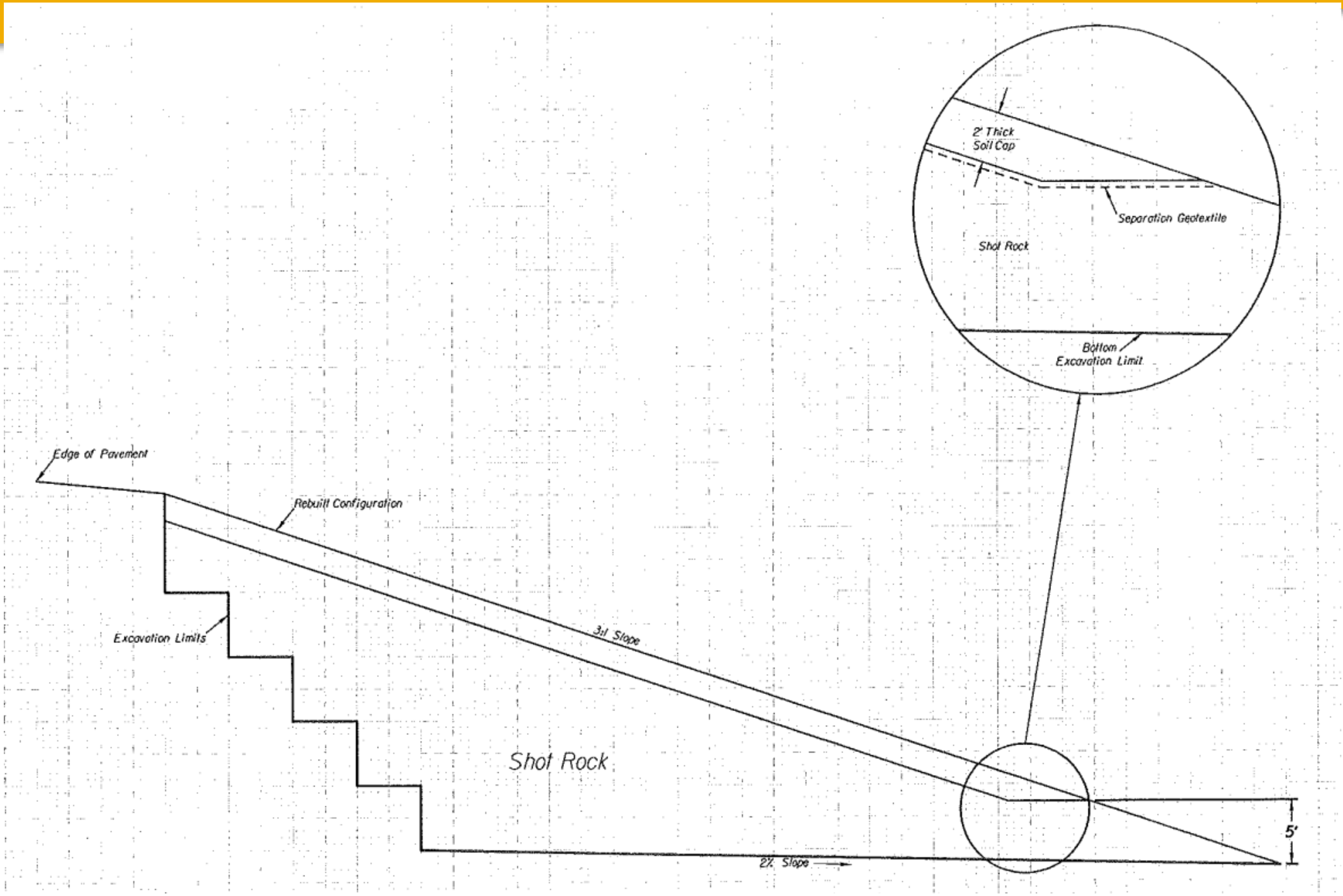
Most Common Types of Repair Methods



Reinforcing Soil Slope with Geogrid

Most Common Types of Repair Methods



Replacing the soil slope with a Rock Embankment

(optional soil cap)

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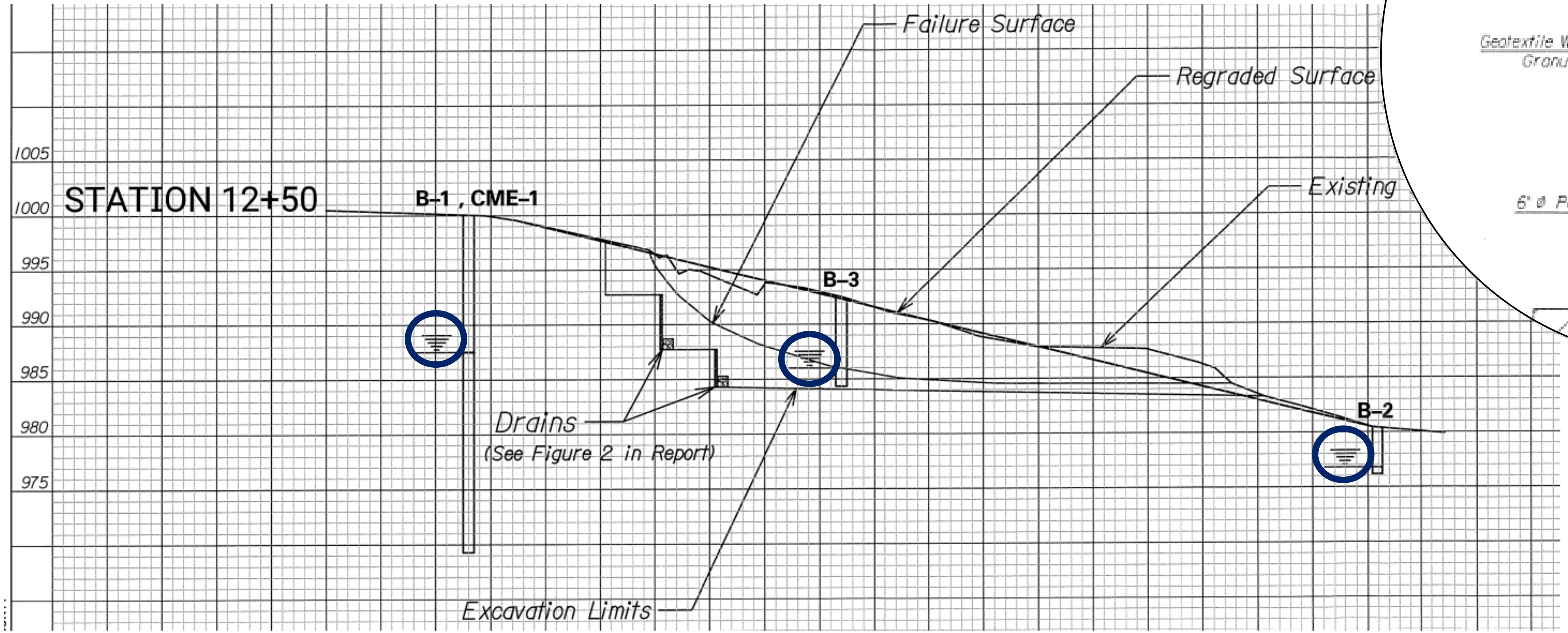
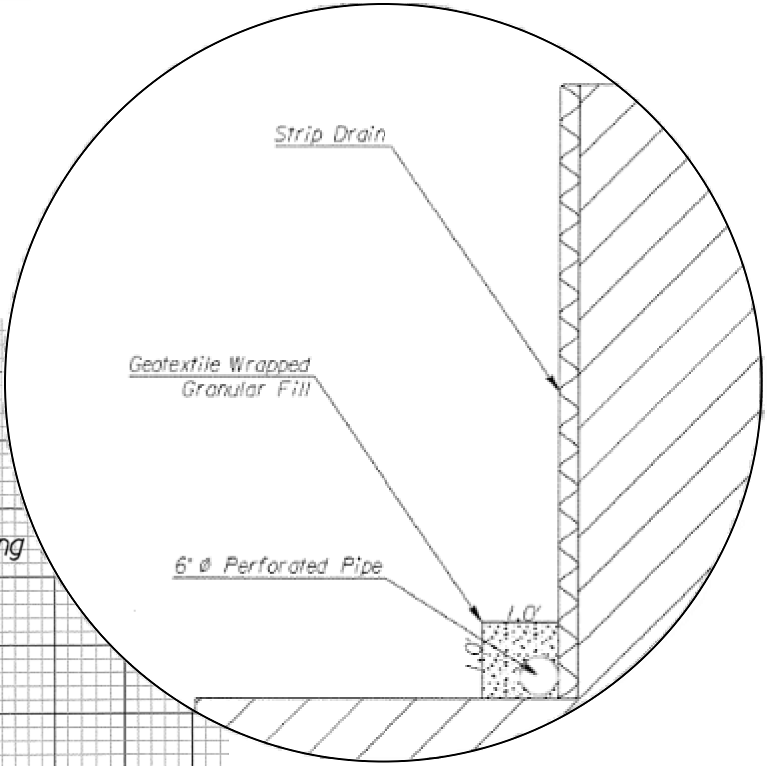
Most Common Types of Repair Methods

Additional Feature to repaired Soil Slopes: Drains along Benches





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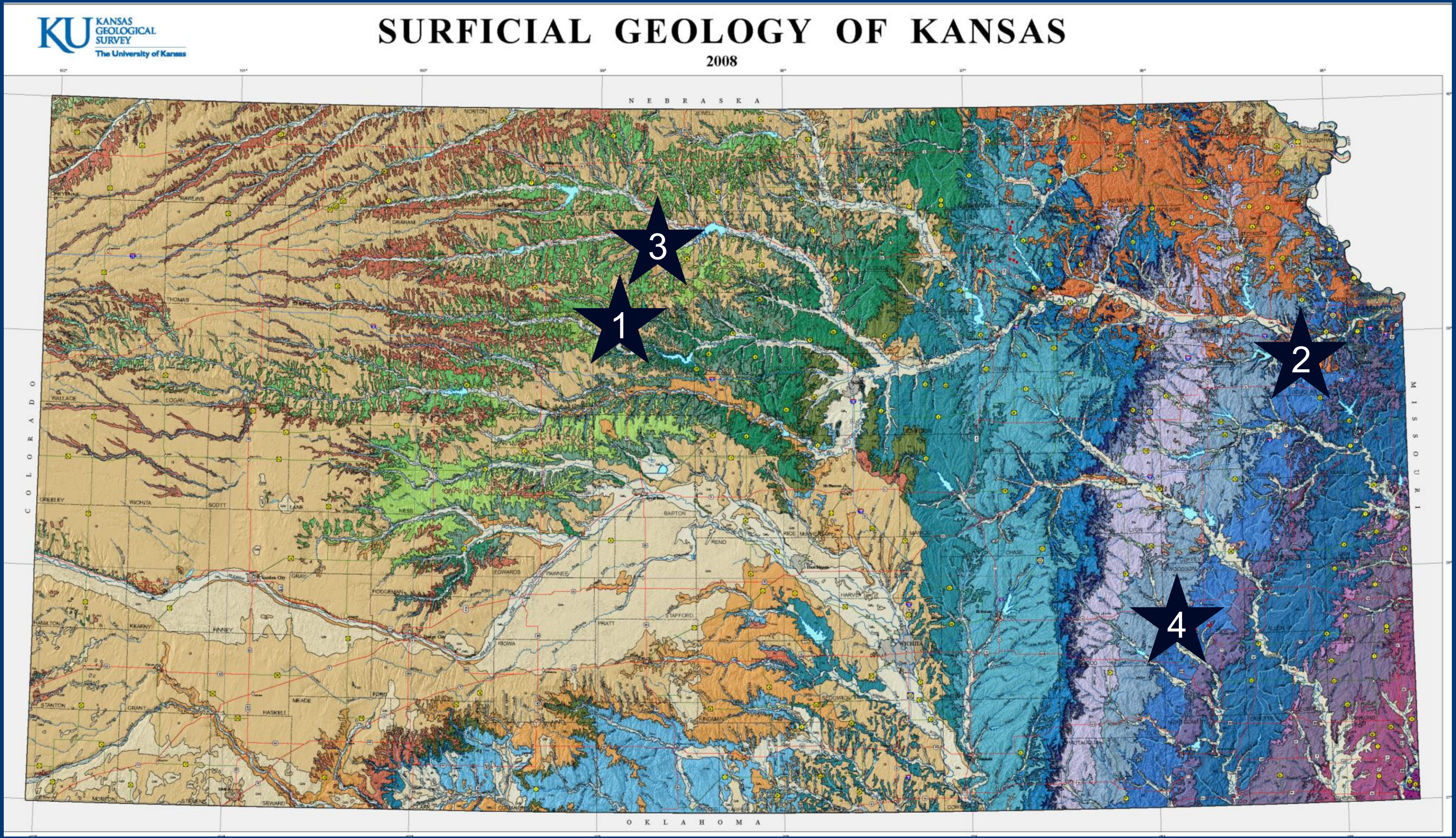

Slope Failure Case Studies

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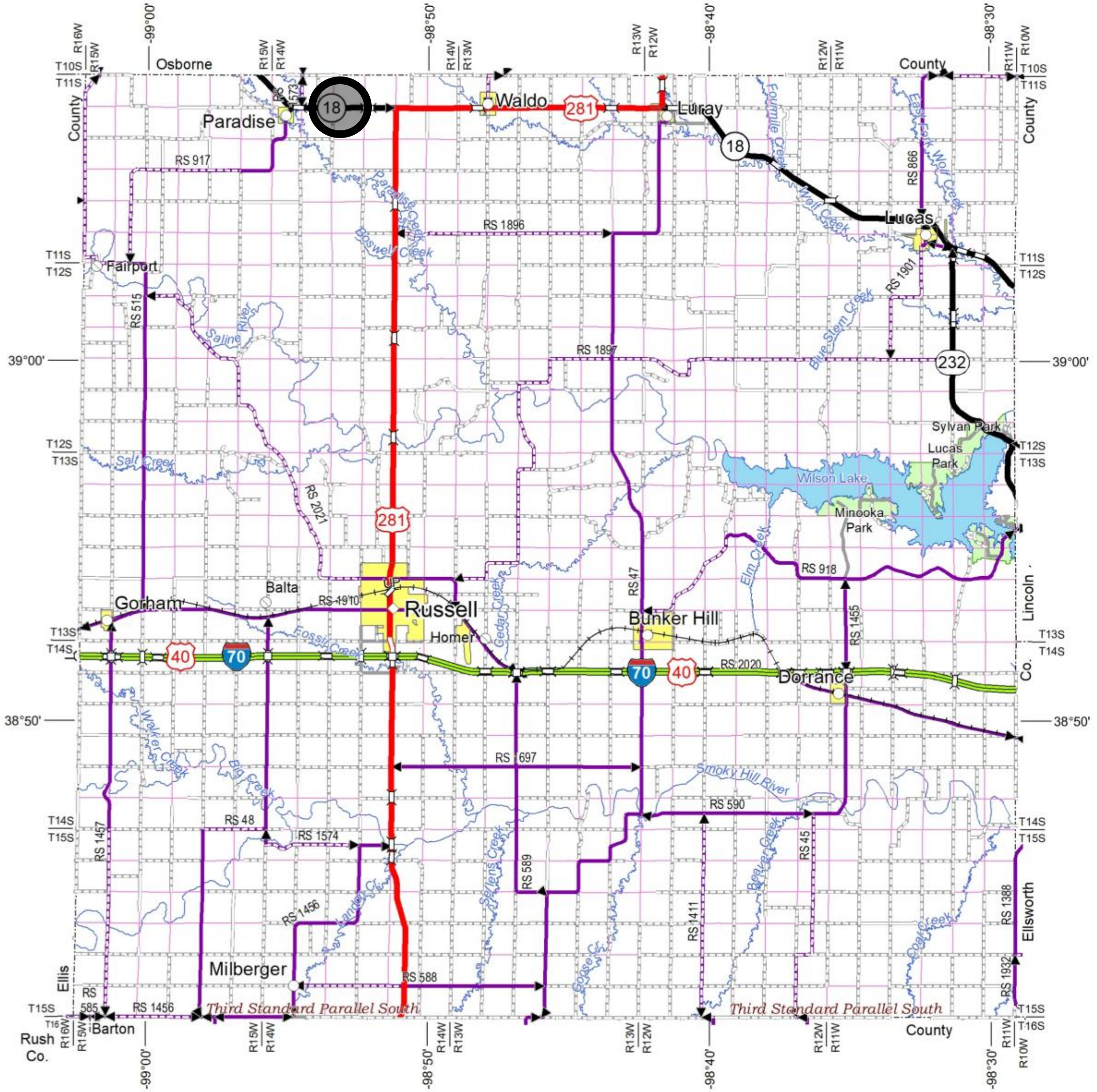
K-18 Failure


Osborne
County
Paradise
Waldo
Luray
Lucas
Fairport
RS 917
RS 1896
RS 515
RS 1897
RS 866
RS 1901
Saline River
Boswell Creek
Blue Stem Creek
Salt Creek
RS 2021
281
18
232
Sylvan Park
Lucas Park
Wilson Lake
Minooka Park
RS 918
Elm Creek
RS 47
Gorham
Balta
RS 4910
Russell
Homer
Cedar Creek
Bunker Hill
RS 1455
Fossil Creek
40
70
RS 2020
Dorrance
Lincoln Co.
RS 1697
Smoky Hill River
Big Creek
RS 48
RS 1574
RS 590
RS 1457
RS 1456
RS 589
RS 1411
RS 45
RS 1388
RS 1932
Ellsworth
Milberger
RS 588
Ellis
Rush Co.
Barton
RS 585
Third Standard Parallel South
39°00'
38°50'
-99°00'
-98°50'
-98°40'
-98°30'

K-18 Failure Background & Soil Properties

Reported Liquid Limits	58 – 87	
Reported Plasticity Indexes	39 – 64	
Reported Effective Friction Angles (ϕ')	8.3°	25.1°
Reported Effective Cohesion (c') (psf)	334	144

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K-18 Failure Background

- 1^{st} signs of Failure: Fall 2017

K-18 Failure Background

- Investigation Requested: mid Oct. 2018

K-18 Failure Background

- 1 week prior to the scheduled investigation: Nov. 2018

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K-18 Failure Background

December 2018

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K-18 Slope Failure Repair

March 2019

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K-18 Slope Failure Repair

- **Slope regraded at pre-failure geometry**
- **Geogrid Reinforcement @ 1-foot vertical spacing**

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K-18 Slope Failure Repair

Ditch regraded to keep water draining from pond from pooling at the toe of the slope.

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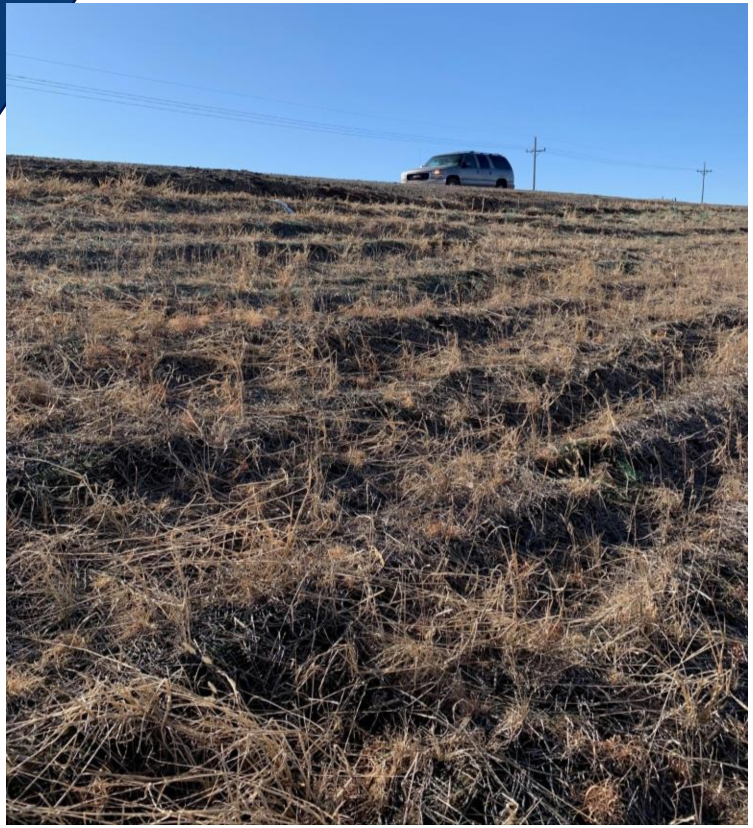
K-18 Slope Failure
Follow-up Visit Observations

January 2020



Rutting Caused by Mowing Operations

Creates Surfaces for Water Infiltration

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K-18 Slope Failure
Ongoing Performance

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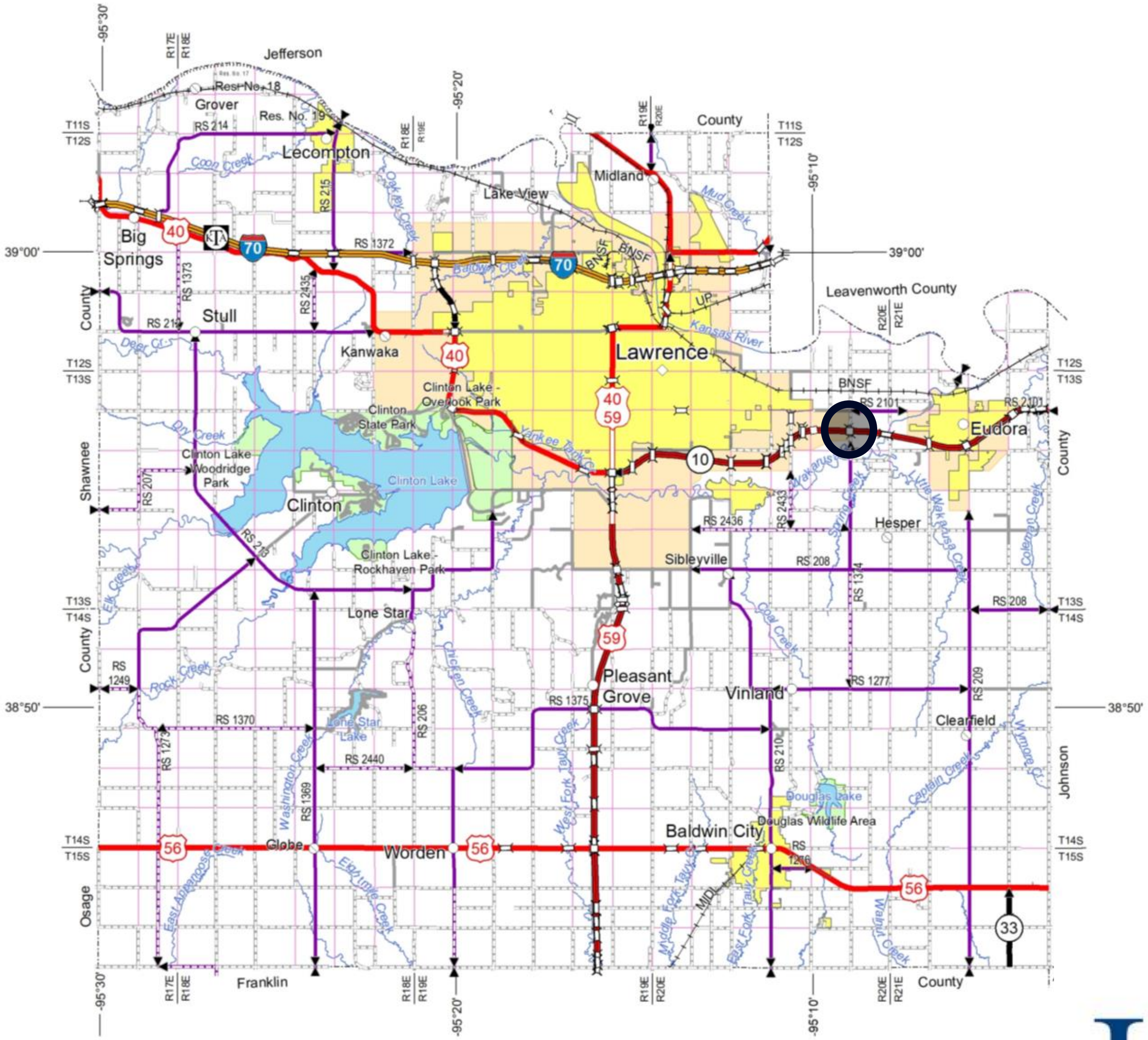
June 2024

1900 Rd Failures



1900 Rd Failure Background & Soil Properties

- 1981 – 2022
- Repair History
  - Geosynthetic Fibers

Reported Liquid Limits	52 – 85
Reported Plasticity Indexes	15 – 53
Reported Effective Friction Angles (ϕ')	18°
Reported Effective Cohesion (c') (psf)	200
Residual Shear Strength	7.4° - 12.1°

Slope Failure Investigation 2022

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Slope Failure Investigation 2022

Slickensides and Cracking along scarps

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1900 Rd Slope Failure Repair

- Removed and Replaced with more suitable soil
- Repair Completed in Spring 2024

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1900 Rd Slope Failure

Follow-up Visit Observations

Tension Cracks

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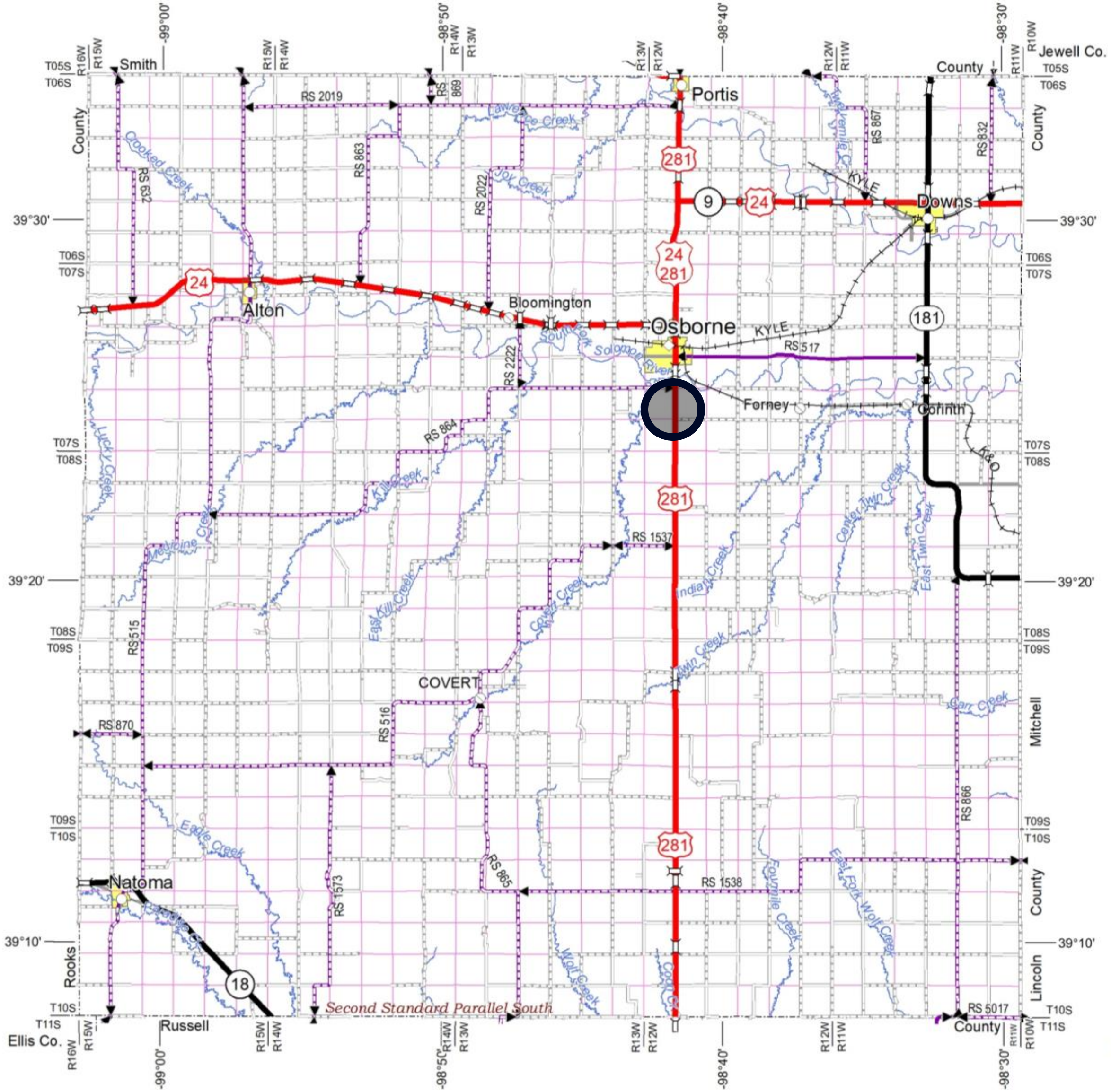
US-281 Failure



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US-281 Failure Background & Soil Properties

Reported Liquid Limits	67
Reported Plasticity Indexes	39

- Time Constraints
  - No lab testing

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US-281 Slope Failure Background

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US-281 Slope Failure Background

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US-281 Slope Failure Repair

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US-281 Slope Failure Repair

September 2016

Drains

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US-281 Slope Failure
Ongoing Performance

Erosion Control Barrier

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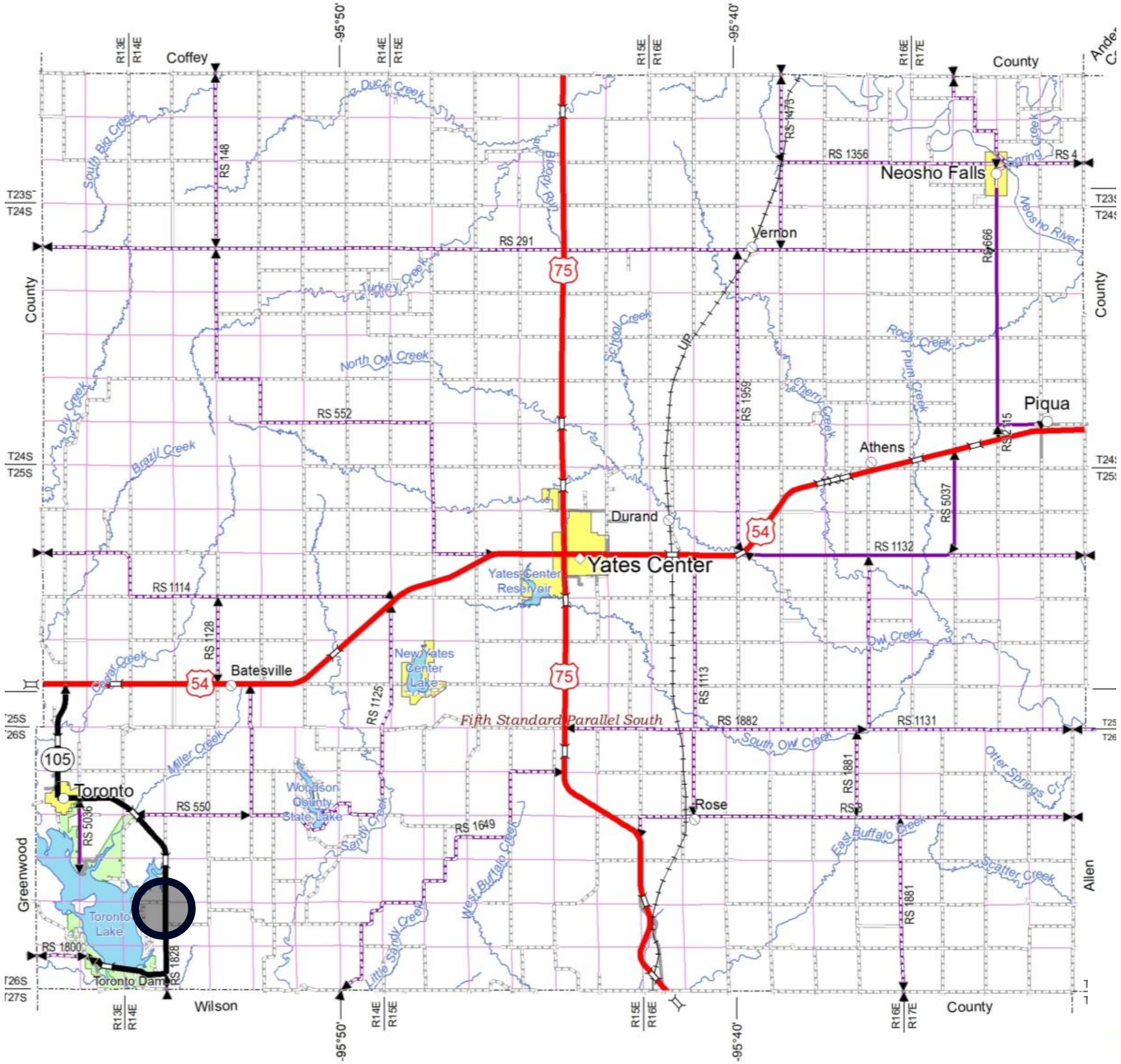
K-105 Failure



K-105 Failure Background & Soil Properties

Reported Liquid Limits	38 – 55	
Reported Plasticity Indexes	17 – 34	
Reported Effective Friction Angles (ϕ')	17.3	30.9
Reported Effective Cohesion (c') (psf)	700	343

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K-105 Slope Failure Background

May 10th, 2019

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K-105 Slope Failure Background

May 22nd, 2019

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K-105 Slope Failure Background

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K-105 Slope Failure Repair

January 2020

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K-105 Slope Failure
Ongoing Performance

April 2025

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General Challenges / Lessons Learned

- **Importance of Follow-up visits**
- Identifying and Addressing Slope Failures before they impact the roadway
- Safely accessing sites to conduct investigations and repairs

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General Challenges / Lessons Learned

- Importance of Follow-up visits
- **Identifying** **and Addressing Slope Failures before they impact the roadway**
- Safely accessing sites to conduct investigations and repairs

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General Challenges / Lessons Learned

Cracking/Settling of Pavement

Inclination of Trees along Slope

- Importance of Follow-up visits
- **<u>Identifying</u> and Addressing Slope Failures before they impact the roadway**
- Safely accessing sites to conduct investigations and repairs

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General Challenges / Lessons Learned

How
- ❑ Material Availability
- ❑ Site Conditions
  - Drainage/Water features
  - Soils Involved

When
- ❑ Budget and Workforce Availability
- ❑ Extent of Failure
- ❑ Public Impact

- Importance of Follow-up visits
- **Identifying and Addressing Slope Failures before they impact the roadway**
- Safely accessing sites to conduct investigations and repairs

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General Challenges / Lessons Learned

- Importance of Follow-up visits
- Identifying and Addressing Slope Failures before they impact the roadway
- **Safely accessing sites to conduct investigations and repairs**

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Going Forward
Moving from a Reactive to a Proactive Approach

Goals

- Identify Failures Early
- Determine when slopes should be repaired vs monitored (Prioritization)
- Improve Record Keeping
- Explore Alternatives

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Going Forward
Moving from a Reactive to a Proactive Approach

Goals

- **Identify Failures Early**
- Determine when slopes should be repaired vs monitored (Prioritization)
- Improve Record Keeping
- Explore Alternatives

Partners

- KU Graduates
- KDOT IT Staff

- Contact Maintenance Personnel about locations of pavement distress
- Develop an inspection schedule

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Going Forward

Moving from a Reactive to a Proactive Approach

Goals

- Identify Failures Early
- **<u>Determine when slopes should be repaired vs monitored (Prioritization)</u>**
- Improve Record Keeping
- Explore Alternatives
- Develop an inspection criteria
- Track Progression of Failures (Instrumentation / Inclinometers)

Partners

- KU Graduates
- KDOT IT Staff

Table 3.2: GAMES MGRS

MGRS	Rating	Definition
3.5 < MGRS ≤ 4.0	Good	No action is needed.
3.0 < MGRS ≤ 3.5	Fair	Minor maintenance to be performed when resources are available. Specific notes should be recorded for special inspection during the next inspection.
2.5 < MGRS ≤ 3.0	Poor	Maintenance should be performed before the end of next season. List an increased inspection schedule until maintenance is performed.
MGRS ≤ 2.5	Severe	Maintenance should be performed as soon as possible in the current season.

Table 3.3: KDOT GAMES Checklist

KDOT GAMES Inspection Form

Survey Date:		Height: ft	Loess present	Yes	No
Route:		Length: ft			
County #:		Slope Angle:	Internal drainage present	Yes	No
Mile marker:		AADT:			
Distance from centerline to toe:		GPS coordinates:			
Year constructed:		Soil Type:			
District: (circle one)	1 2 3 4 5 6	Circle: Cut / Fill / Other (specify):			

Rating	% of slope condition 4 Good	3 Fair	2 Poor	1 Severe	Weight (%)	Score	Notes
Circle: Slope Movement/Bulge/Creep					24.4%		
Cracking					21.3%		
Internal Drainage					12.4%		
External Drainage					10.2%		
Maintenance Actions (< 10 yrs)					8.0%		
Face Surface Erosion/Scour					7.8%		
Embankment Surcharges					5.9%		
Standing Water against Slope					5.3%		
Vegetation/Riprap Cover					4.6%		
Special Concerns							
Recommendations							

If any inspection category is rated "Severe," apply a one-time 0.5 reduction to final rating score.	Yes	No	**Rating Score:**	
Modifiers	M_H: / M_S:	M_A: / M_T:	**Risk Adjusted Rating Score:**	

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Going Forward
Moving from a Reactive to a Proactive Approach

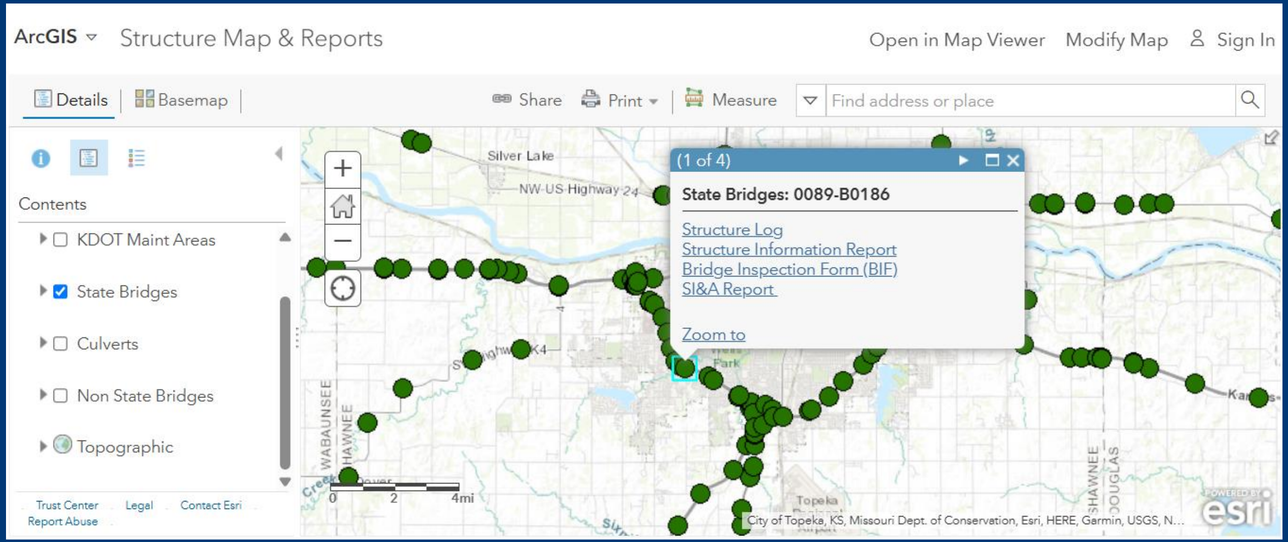
Goals

- Identify Failures Early
- Determine when slopes should be repaired vs monitored (Prioritization)
- **Improve Record Keeping**
- Explore Alternatives

Partners

- KU Graduates
- KDOT IT Staff

- Develop an interactive GIS Database



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Going Forward
Moving from a Reactive to a Proactive Approach

Goals

- Identify Failures Early
- Determine when slopes should be repaired vs monitored (Prioritization)
- Improve Record Keeping
- **Explore Alternatives**
  - **Repair Methods**
  - **Budgeting**

References/Acknowledgements

Slide 6. “Expansive Soils Map for the United States.” *Geology.com*, geology.com/articles/soil/.

Slide 7. “Surficial Geology of Kansas.” Kansas Geological Survey, 2008, Surficial geology of Kansas: Kansas Geological Survey, Map M-118, scale 1:500,000.

Slide 8. “Average Precipitation in Kansas, 1991-2020”. Institute for Policy & Social Research, The University of Kansas; data from National Oceanic and Atmospheric Administration, ksdata.ku.edu/ksdata/ksah/climate/precip30yr_9120.jpg.

Slide 9. “Figure 7. Destabilization and failure of expansive soil slopes: (a) initial state; (b) experience of repeated wet–dry cycles; (c) final failure.”
Luo, Peng, and Min Ma. “Failure Mechanisms and Protection Measures for Expansive Soil Slopes: A Review.” *Sustainability*, vol. 16, no. 12, 16 June 2024, pp. 5127–5127, www.mdpi.com/2071- 1050/16/12/5127, https://doi.org/10.3390/su16125127. Accessed 16 Jan. 2025.

Slide 9. “Figure 4. a) The peak and residual strength and b) the approximated failure envelope for peak and residual conditions (Head & Epps, 2011)”
Bek, Anja, et al. “Influence of Shear Rate on the Soil’s Shear Strength.” *Environmental Engineering*, vol. 8, no. 1-2, 1 Dec. 2021, pp. 39–47, https://doi.org/10.37023/ee.8.1-2.6.

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THANK YOU

ANY QUESTIONS?

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