2022 SME Minnesota Conference

The Impact of Stress History on Undrained Shear Strength of Clays in Northern Minnesota

Kurt J. Schimpke, PE

Barr Engineering Co.

Minneapolis, MN

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Agenda

- Geologic characteristics
- Stress history
- Drained vs. undrained behavior
- Link between stress history and shear strength
- Assessment methodology
- Results
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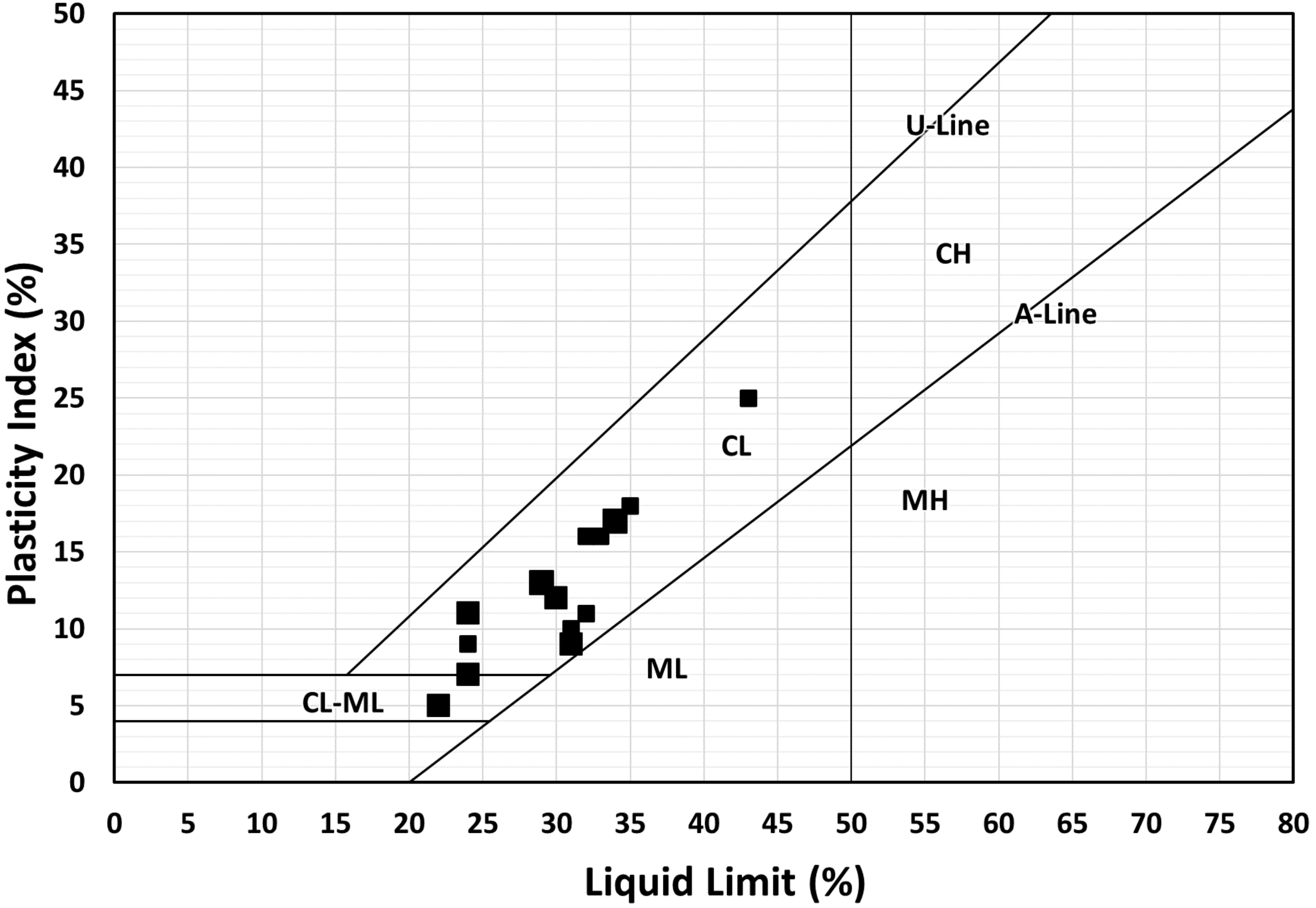
Geologic Characteristics

- Widespread glacial deposits – clay and sands
- Glacial till - fine-grained soils with gravel, cobbles, and boulders
- Clays are generally over-consolidated and stiff to hard due to glaciation

Geologic Characteristics (cont.)



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Stress History

$$Over\ Consolidation\ Ratio = OCR = \frac{\sigma'_p}{\sigma'_{v0}}$$

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Stress History (cont.)

Max past pressure

$$Over\ Consolidation\ Ratio = OCR = \frac{\sigma'_p}{\sigma'_{v0}}$$

Current pressure

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Stress History (cont.)

Max past pressure

$$Over\ Consolidation\ Ratio = OCR = \frac{\sigma'_p}{\sigma'_{v0}}$$

Current pressure

OCR	Condition	General Behavior
1	Normally Consolidated	Weak, compressible
1-3	Slightly Over-Consolidated	Stronger, less compressible
>3	Heavily Over-Consolidated	Strong, stiff

Stress History (cont.)

Clay

Stress History (cont.)

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Clay

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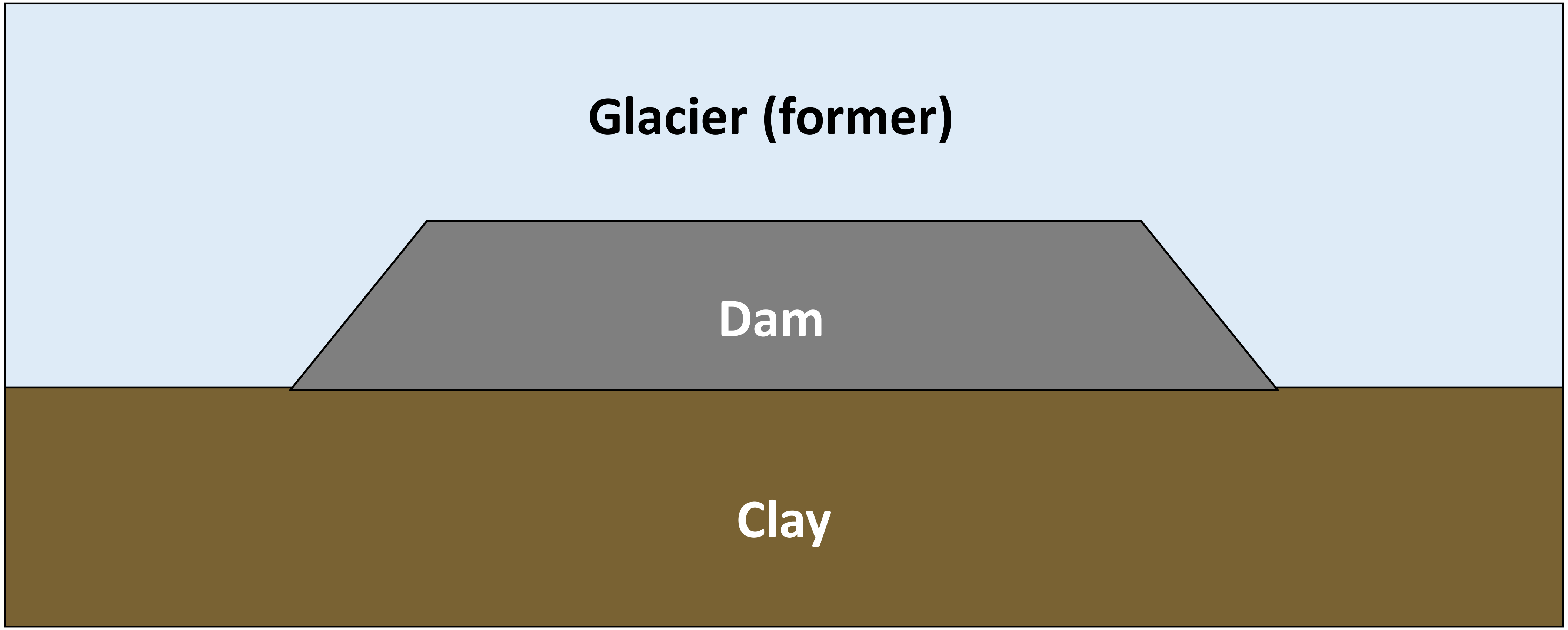
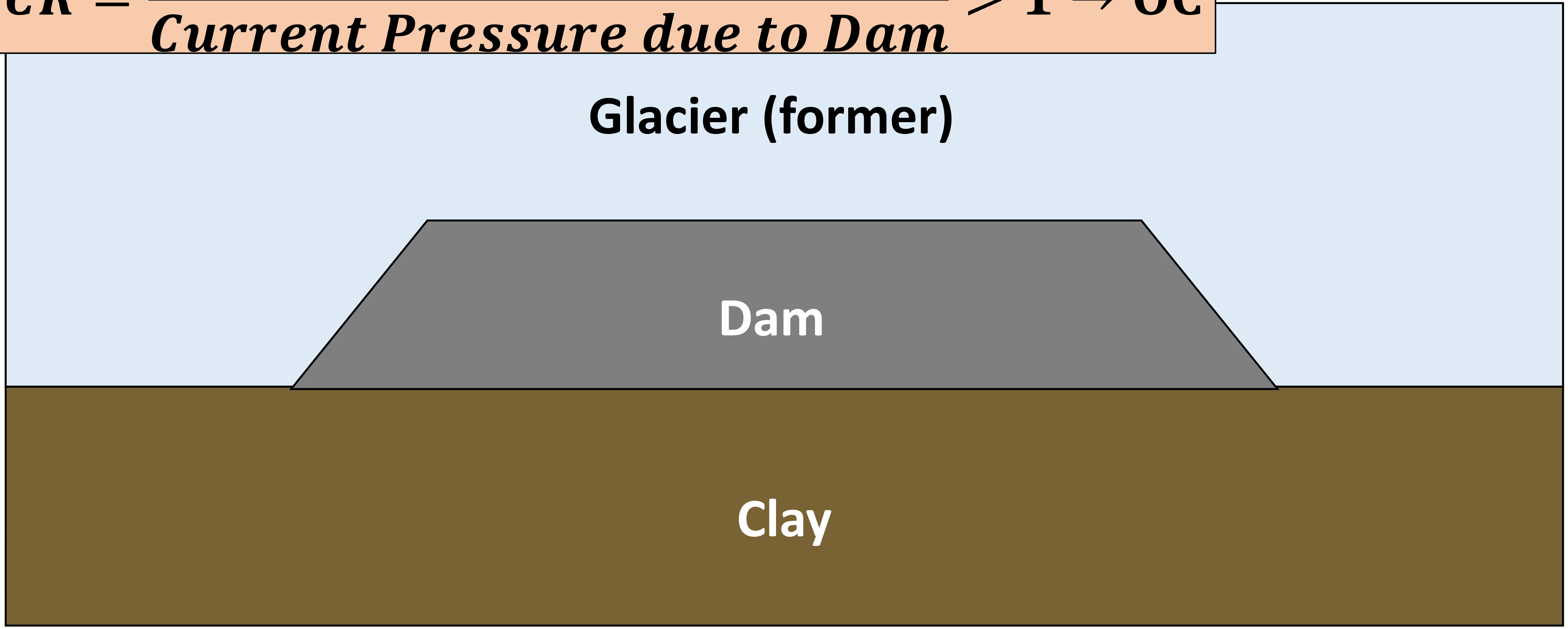


Stress History (cont.)

$$OCR = \frac{Past\ Pressure\ due\ to\ Glacier}{Current\ Pressure\ due\ to\ Dam} > 1 \rightarrow \mathbf{OC}$$



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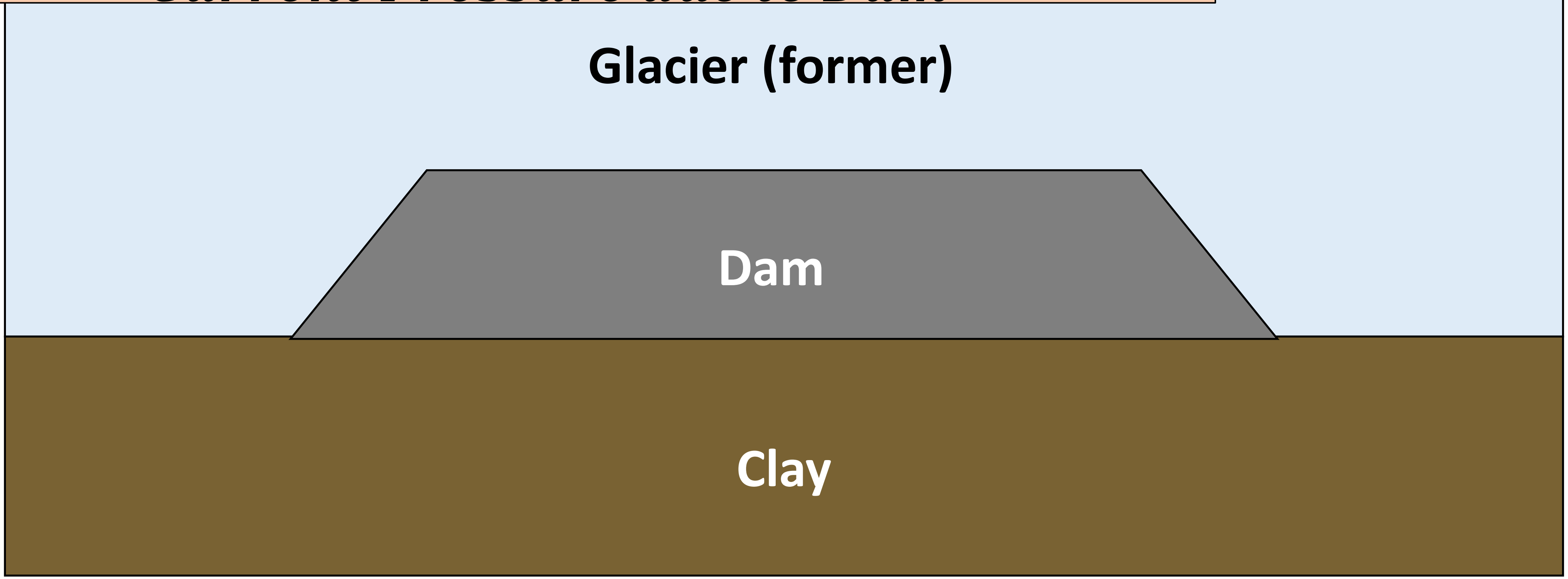

Stress History (cont.)

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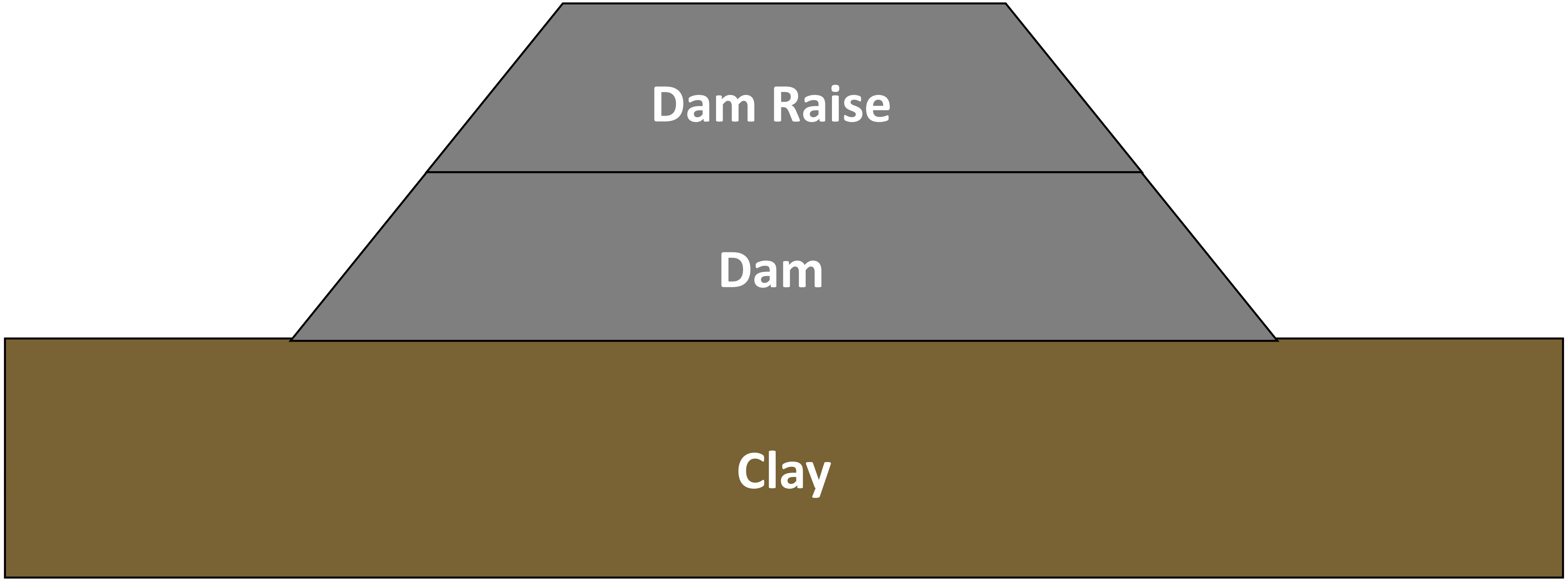

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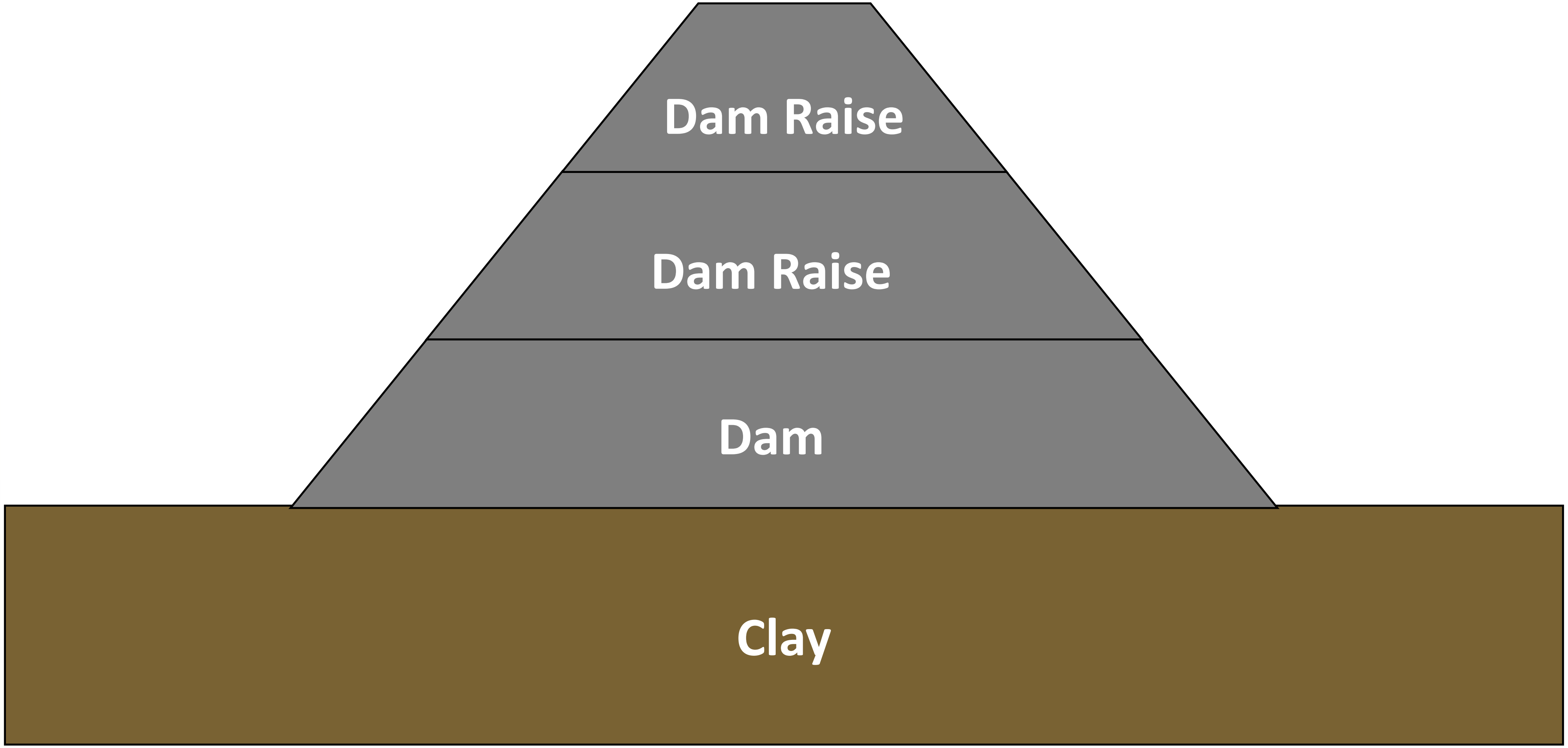

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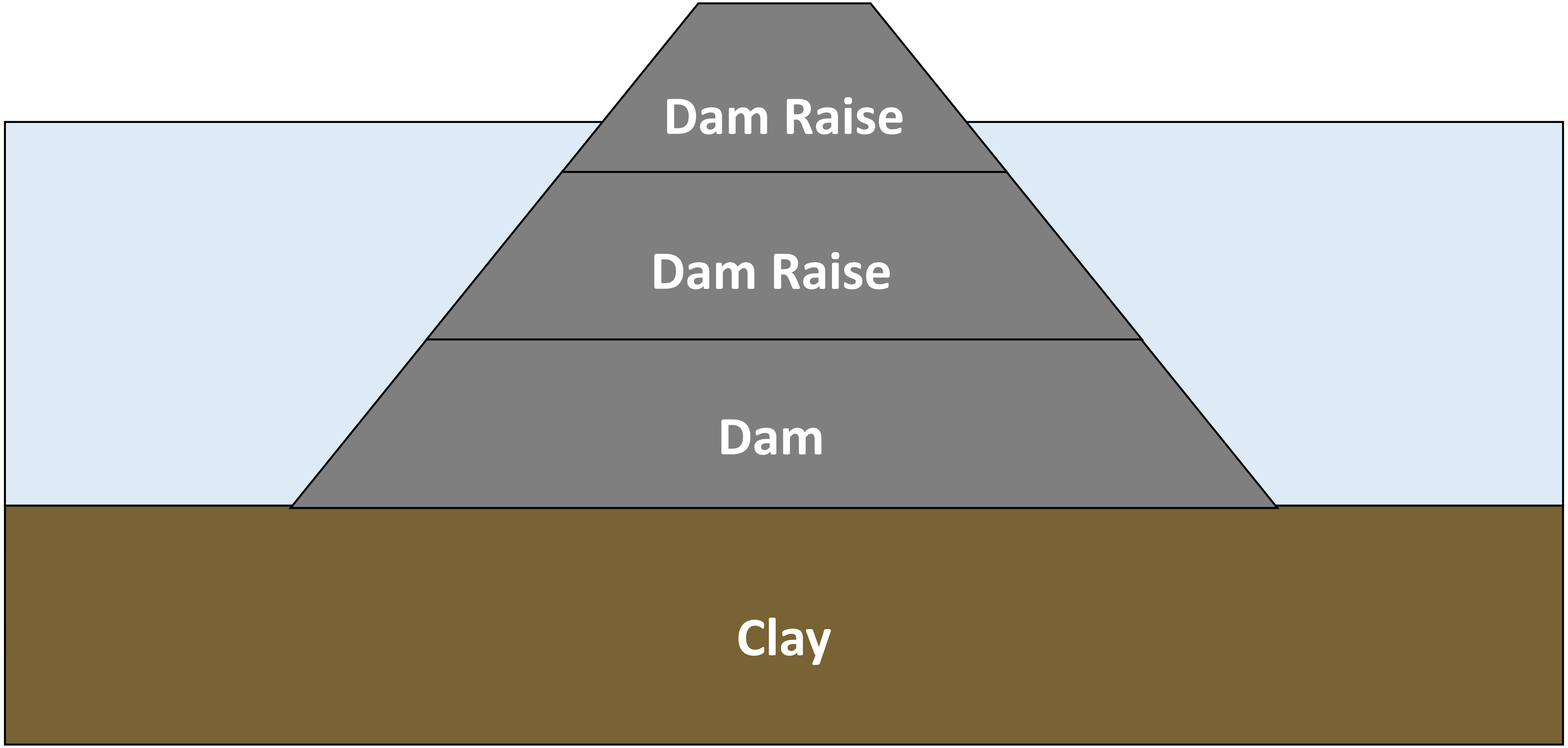

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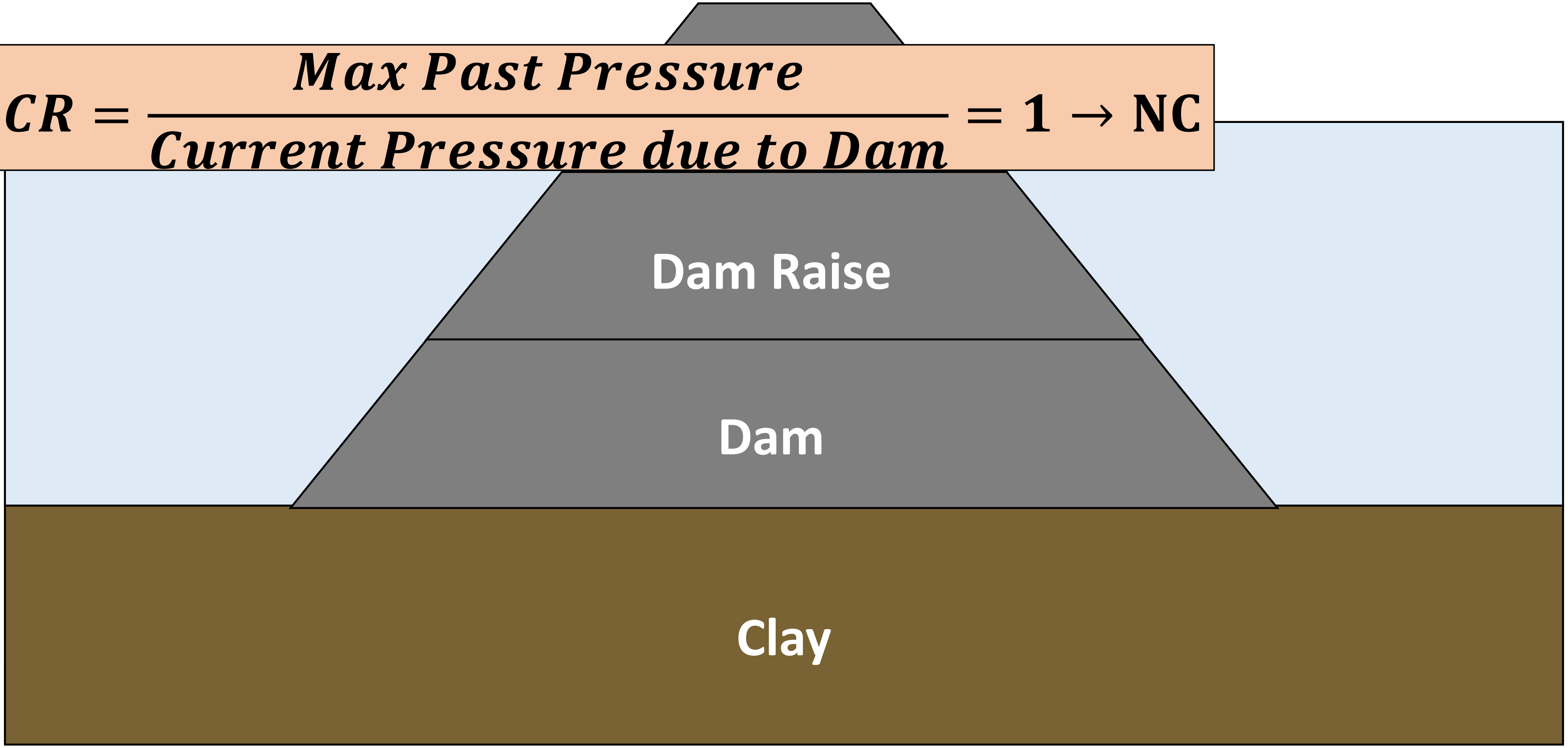

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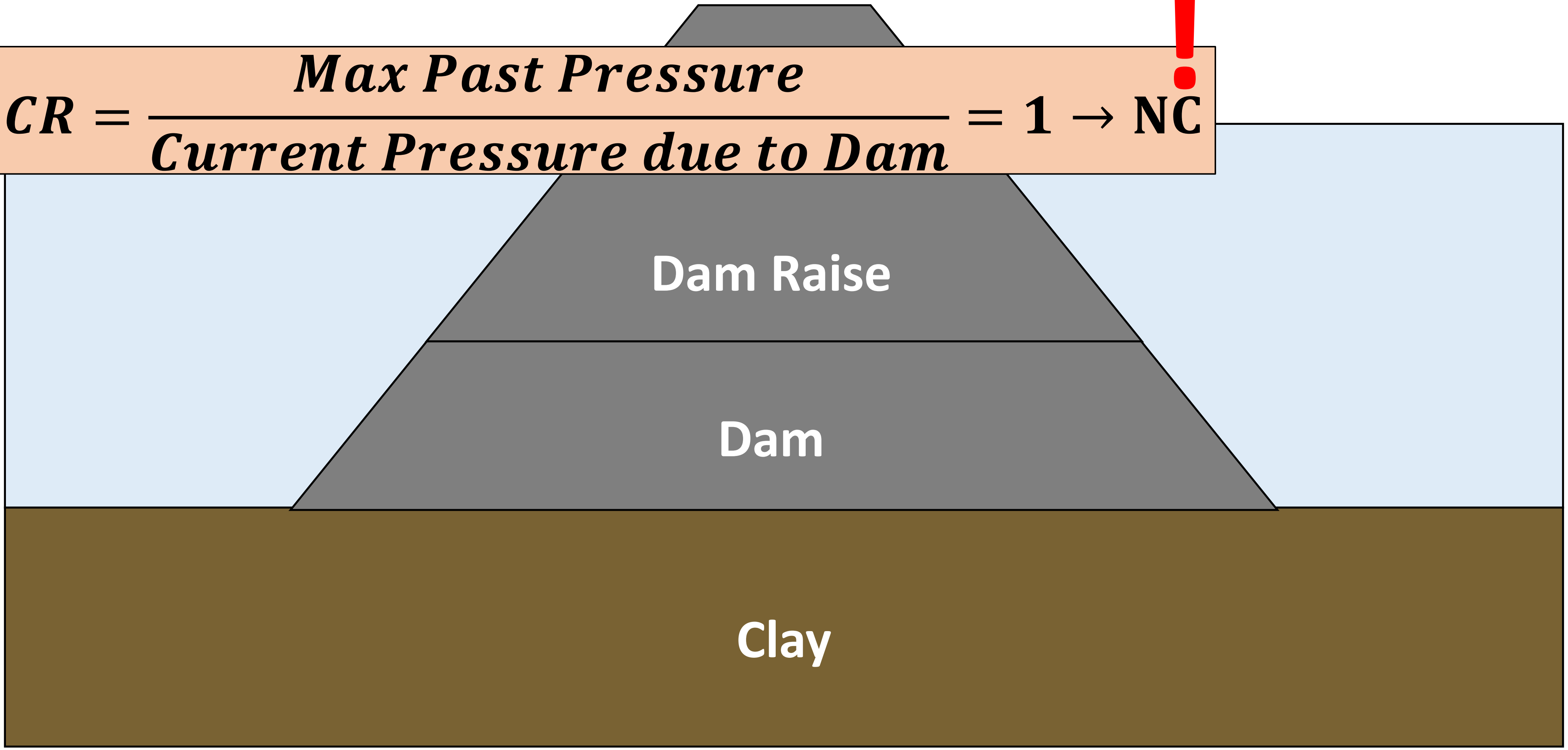

Common Mistake…

assuming a stiff, over-consolidated clay will remain that way

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Drained vs. Undrained Behavior

- Pertains to rate of shear/loading and material permeability

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- If excess pore-water pressures develop → undrained

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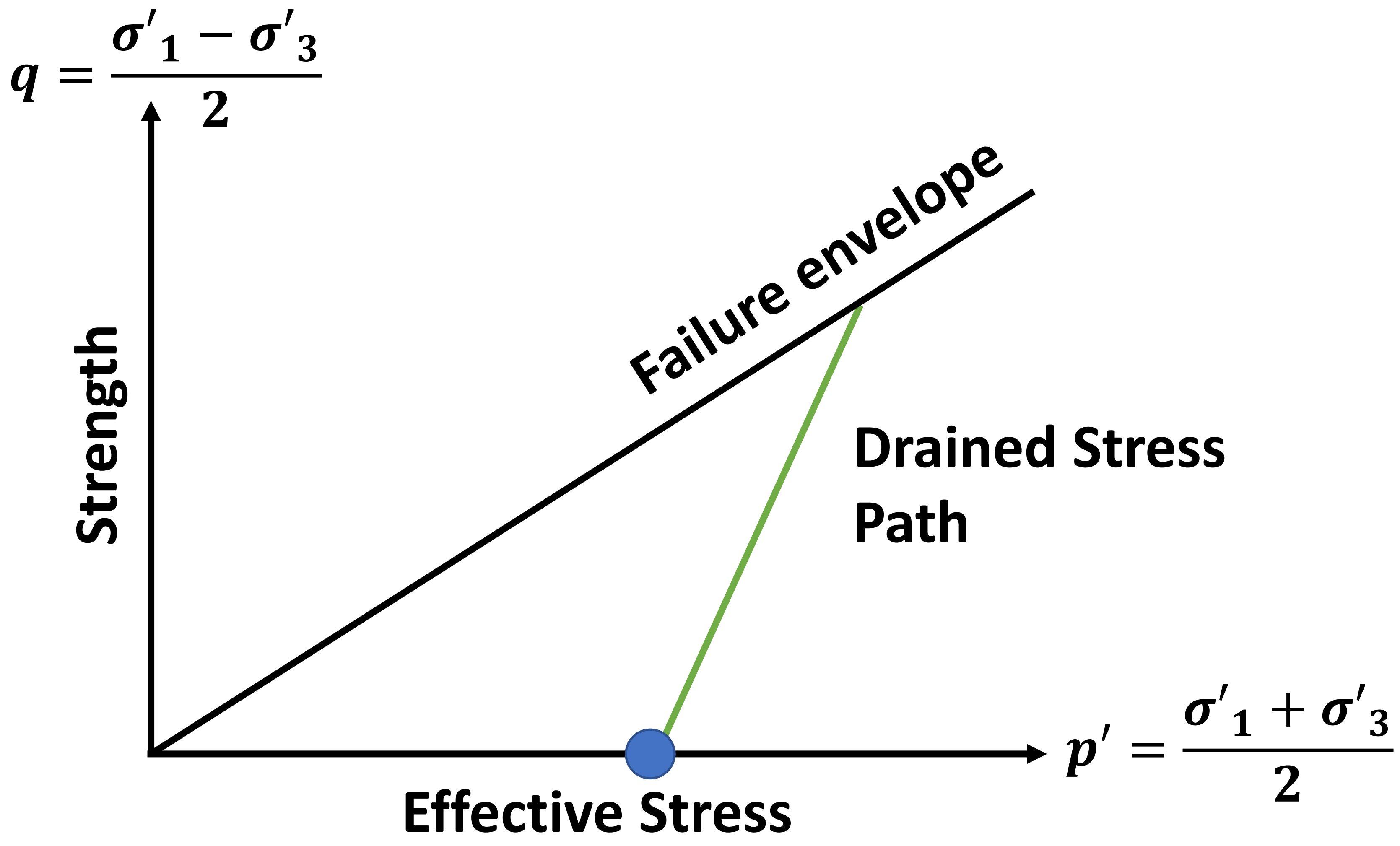
- Pertains to rate of shear/loading and material permeability
- If excess pore-water pressures develop → undrained
- If no excess pore-water pressures develop → drained

Drained vs. Undrained Behavior (cont.)



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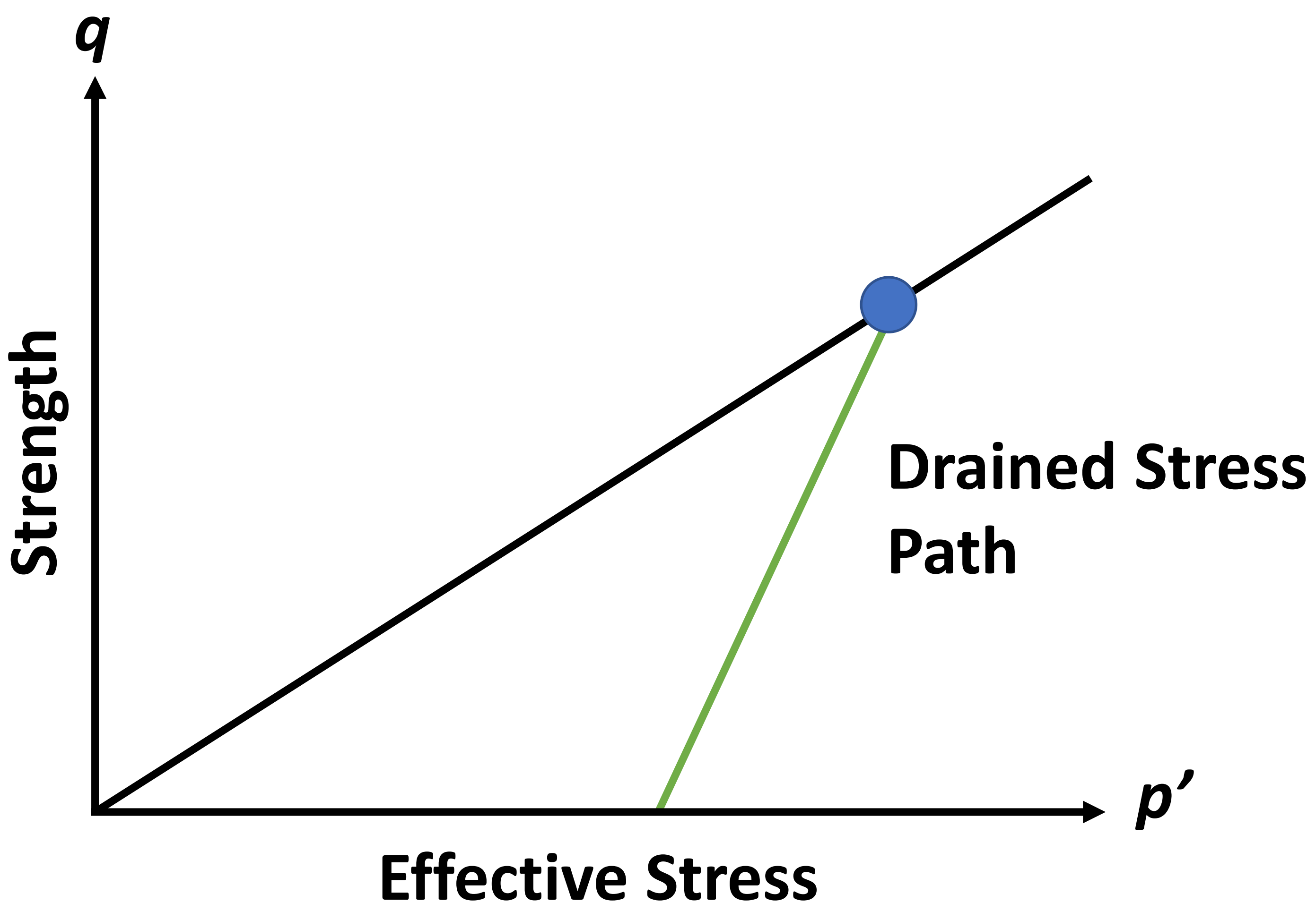

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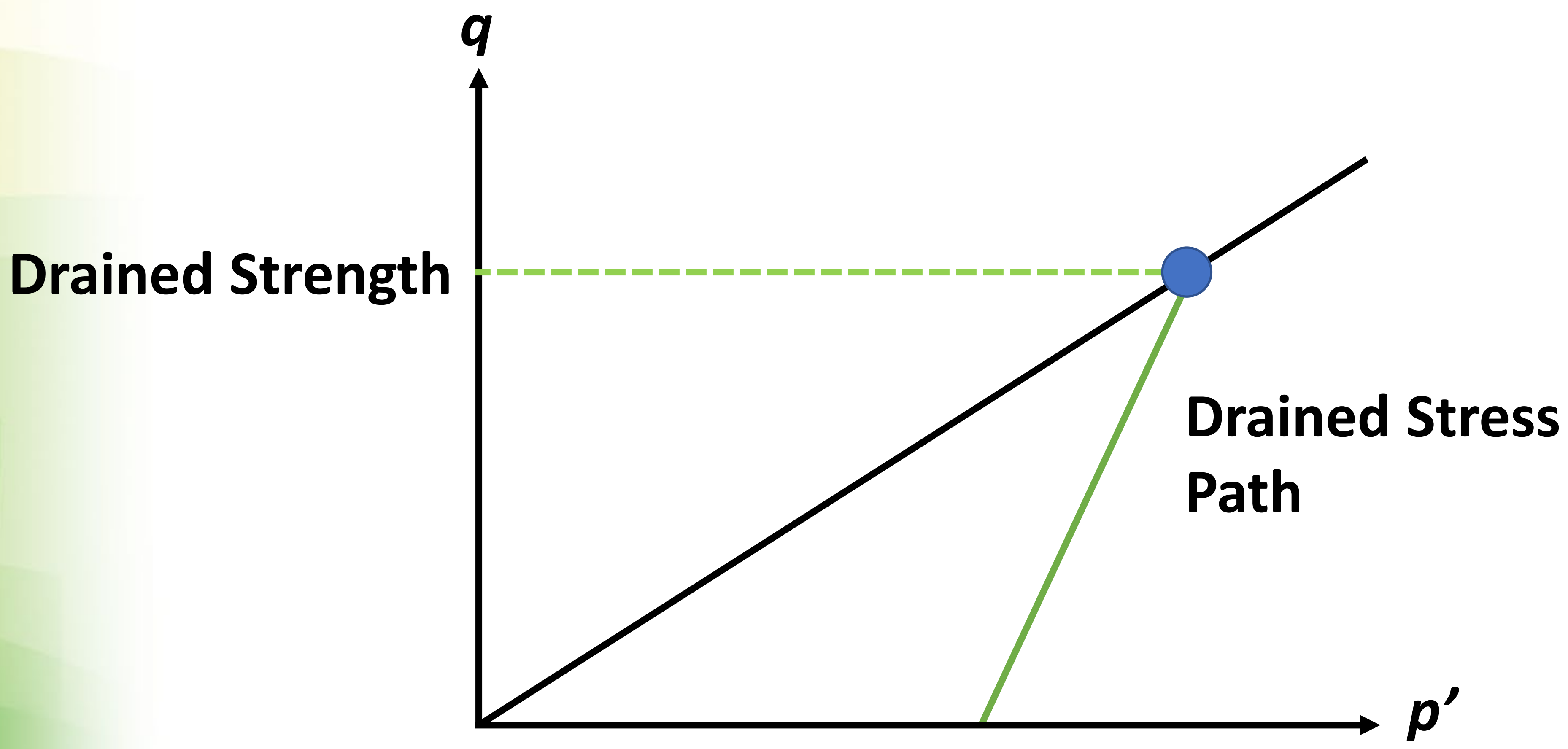

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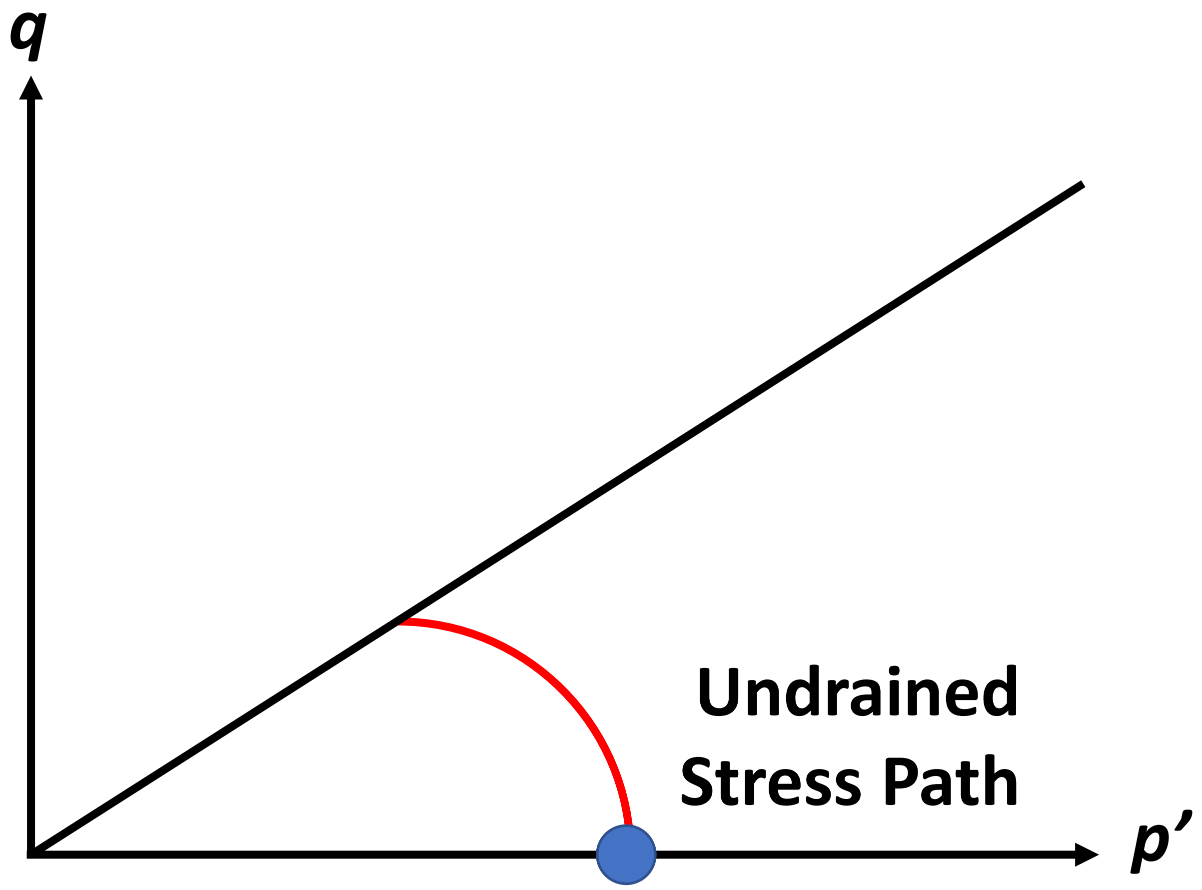

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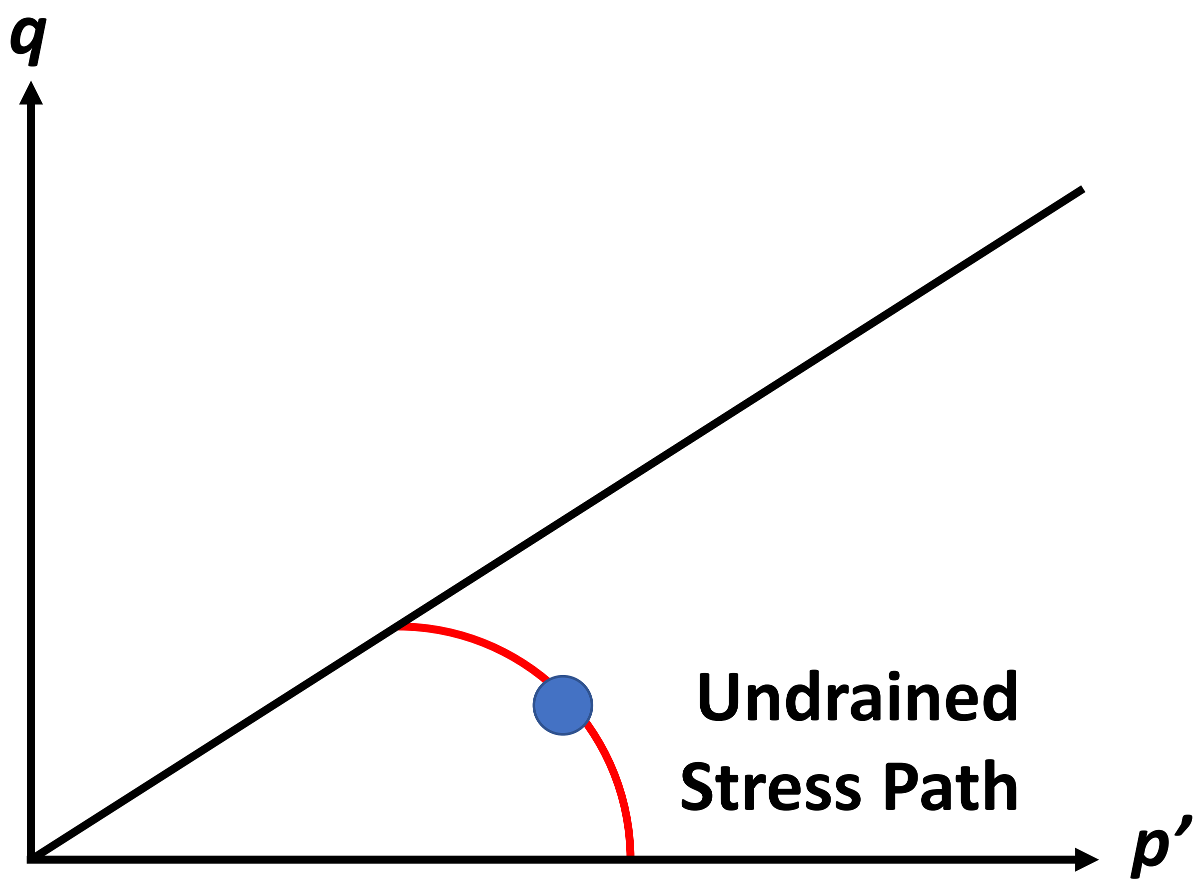

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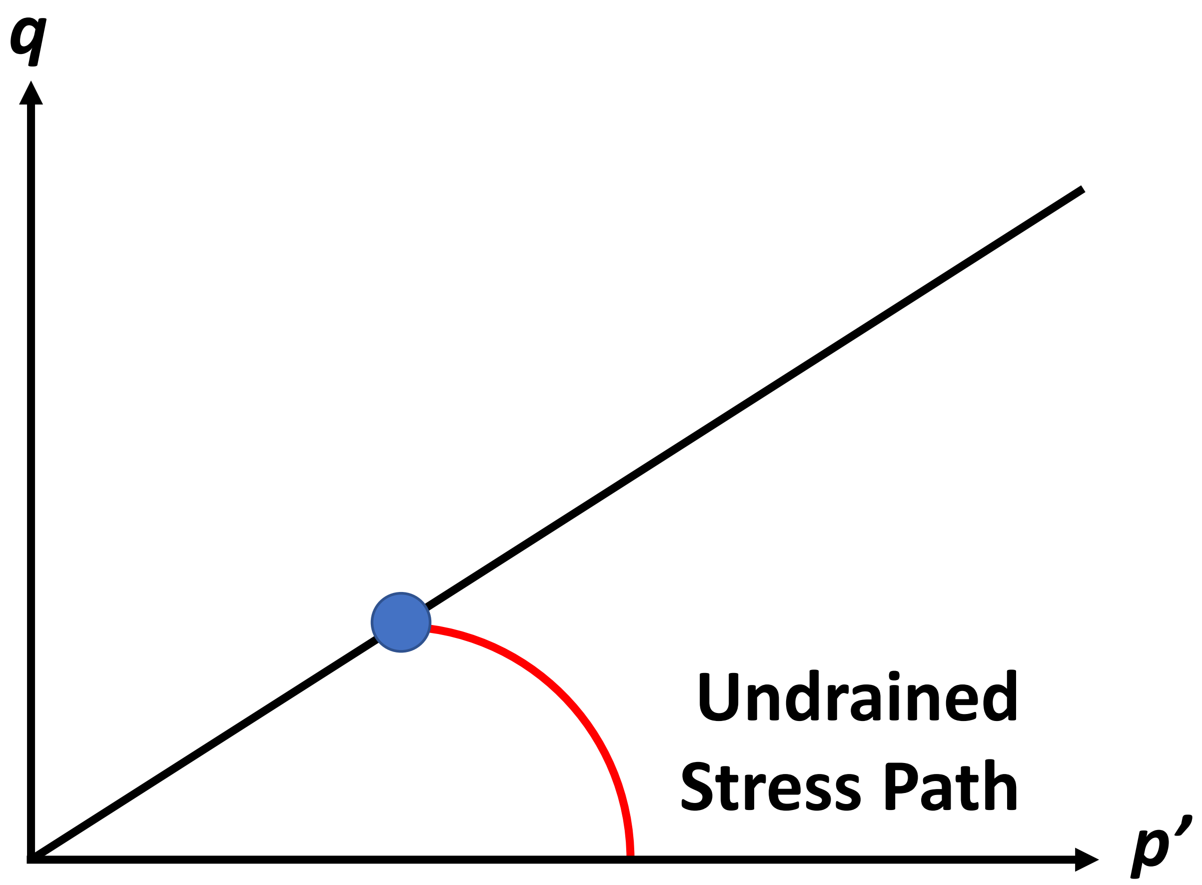

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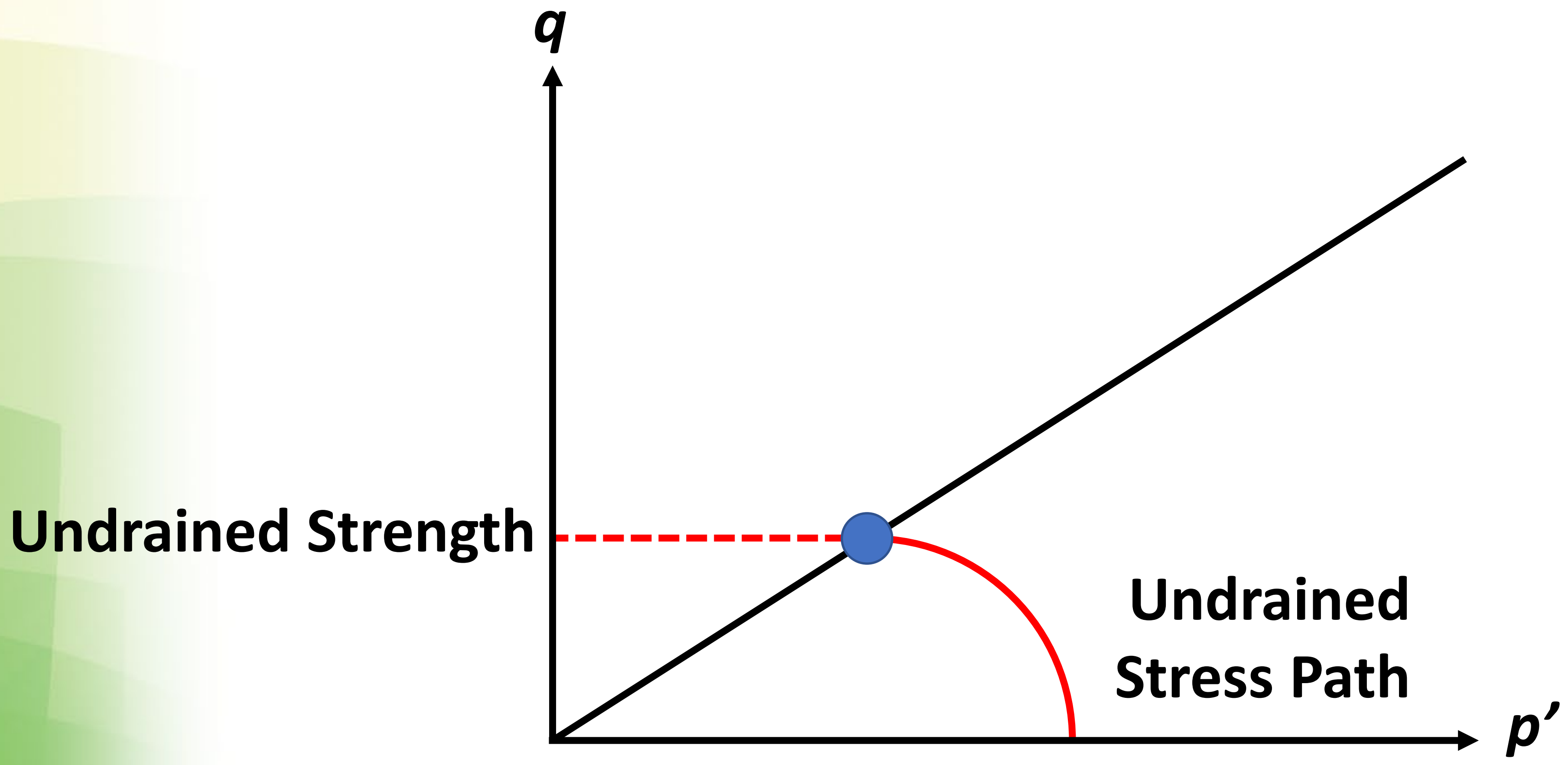

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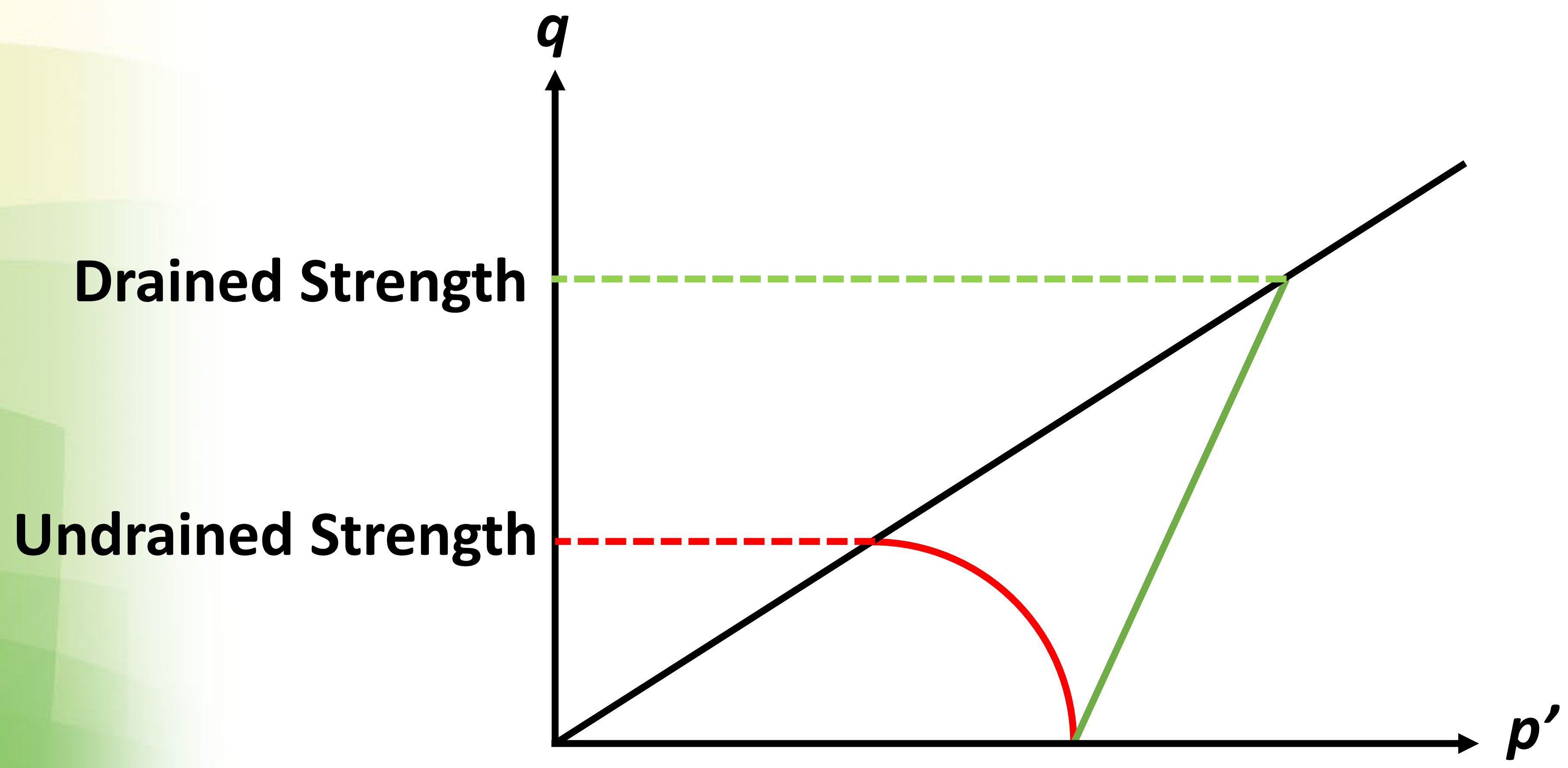

Drained vs. Undrained Behavior (cont.)

Characteristic	OC	NC
Shear Behavior	Dilative	Contractive
Excess Pore-Water Pressure	Negative, then 0	Positive
Typical Failure Condition	Drained	Undrained
Relative Strength	Higher	Lower

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Drained vs. Undrained Behavior (cont.)

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Shear Behavior	Dilative	Contractive
Excess Pore-Water Pressure	Negative, then 0	Positive
Typical Failure Condition	Drained	Undrained
Relative Strength	Higher	Lower

If an OC clay becomes NC and we don't account for the change in behavior, we may be unconservative

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Stress History And Normalized Soil Engineering Properties (SHANSEP)

10664 JULY 1974 GT7

JOURNAL OF THE GEOTECHNICAL ENGINEERING DIVISION

NEW DESIGN PROCEDURE FOR STABILITY OF SOFT CLAYS

By Charles C. Ladd,[1] M. ASCE and Roger Foott,[2] A. M. ASCE

SHANSEP (cont.)

- Inter-relates stress history and strength

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- Accounts for disturbance through over-consolidation during laboratory testing

SHANSEP (cont.)

- Inter-relates stress history and strength
- Allows for determination of strength at varying OCRs
- Accounts for change in behavior when material goes from OC to NC
- Accounts for disturbance through over-consolidation during laboratory testing
- Is implemented using laboratory consolidation and strength tests

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SHANSEP (cont.)

$$\frac{s_u}{\sigma'_{vc}} = \left(\frac{s_u}{\sigma'_{vc}}\right)_{NC} (OCR)^m$$

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Assessment Methodology

- Collect Samples
- Perform Laboratory Consolidation Testing
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Collect Samples

Increasing Sample Quality

3-in Thin Wall Tubes

5-in Thin Wall Tubes

5-in Thin Wall Tubes with Piston Sampler

Block Sample

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Collect Samples

Increasing Sample Quality

3-in Thin Wall Tubes

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Block Sample

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Assessment Methodology

1. Collect Samples
2. **Perform Laboratory Consolidation Testing**
3. Calculate OCR
4. Perform Laboratory Strength Testing
5. Develop Stress History-Strength Relationship

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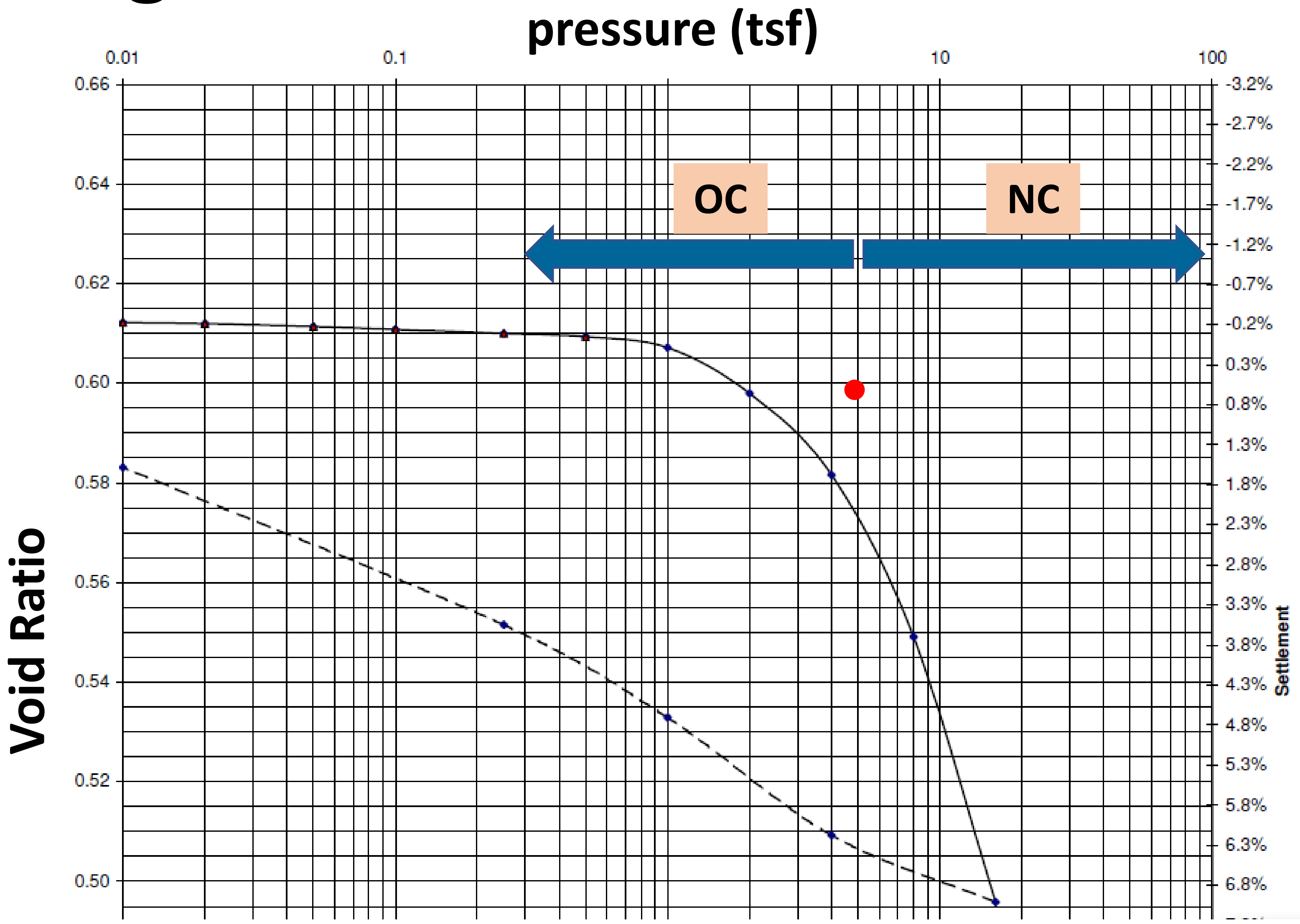
Perform Laboratory Consolidation Testing



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Assessment Methodology

- Collect Samples
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Perform Laboratory Consolidation Testing

Max past pressure (from lab)

$$\textit{Over Consolidation Ratio} = OCR = \frac{\sigma'_p}{\sigma'_{v0}}$$

Current pressure (in field)

Assessment Methodology

- Collect Samples
- Perform Laboratory Consolidation Testing
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- **Perform Laboratory Strength Testing**
- Develop Stress History-Strength Relationship

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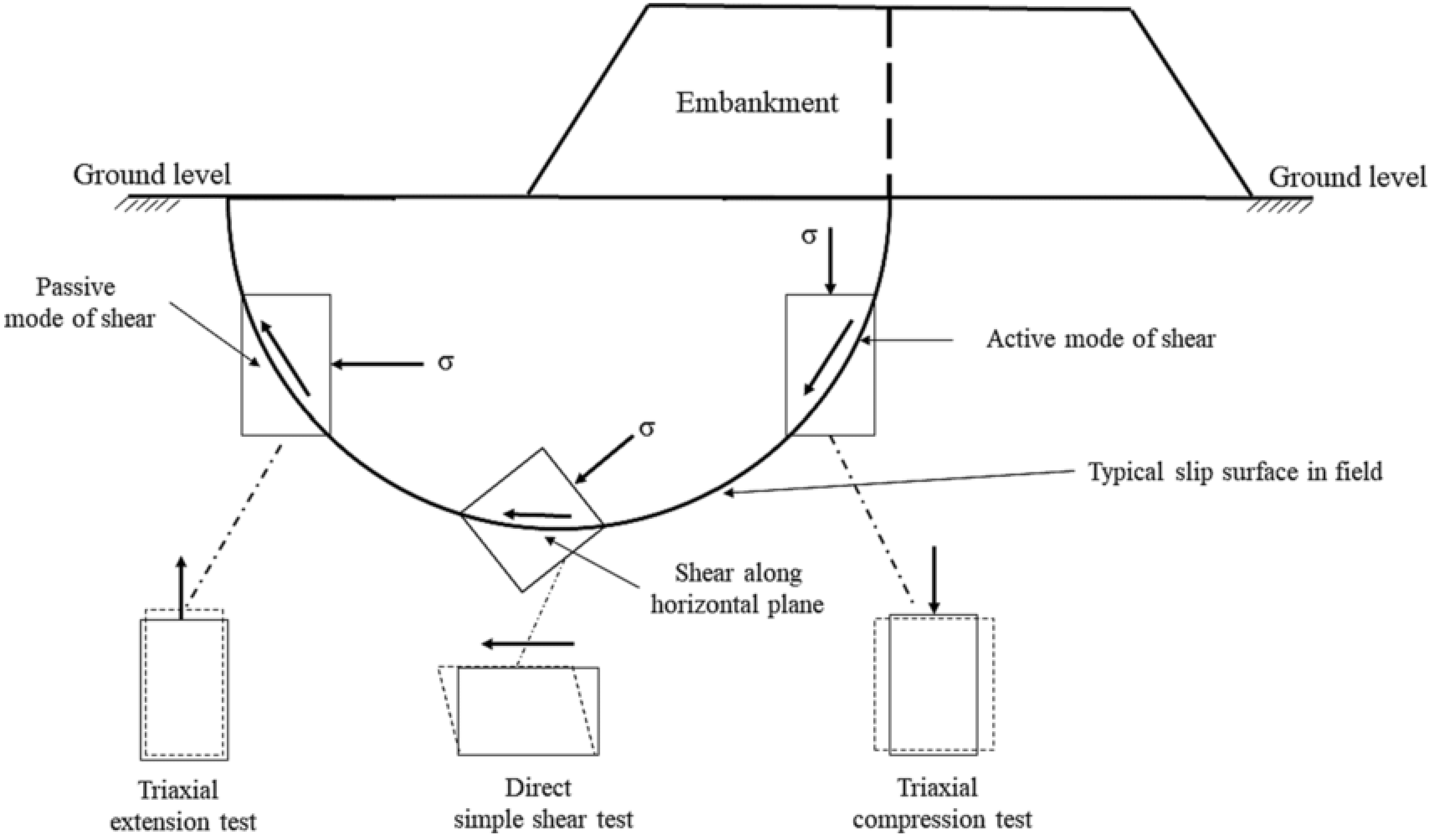
Perform Laboratory Strength Testing



Mistry et al (2021)

Assessment Methodology

Collect Samples

Perform Laboratory Consolidation Testing

Calculate OCR

Perform Laboratory Strength Testing

Develop Stress History-Strength Relationship

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$$\frac{s_u}{\sigma'_{vc}} = \left(\frac{s_u}{\sigma'_{vc}}\right)_{NC} (OCR)^m$$

Ladd and Foot (1974)

Develop Stress History-Strength Relationship (cont.)

$$\frac{s_u}{\sigma'_{vc}} = \left(\frac{s_u}{\sigma'_{vc}}\right)_{NC} (OCR)^m$$

Undrained shear strength ratio at OCR = 1

Develop Stress History-Strength Relationship (cont.)

$$\frac{s_u}{\sigma'_{vc}} = \left(\frac{s_u}{\sigma'_{vc}}\right)_{NC} (OCR)^m$$

Curve fit from lab testing

Undrained shear strength ratio at OCR = 1

Develop Stress History-Strength Relationship (cont.)

Undrained shear strength ratio at given OCR

$$\frac{s_u}{\sigma'_{vc}} = \left(\frac{s_u}{\sigma'_{vc}}\right)_{NC} (OCR)^m$$

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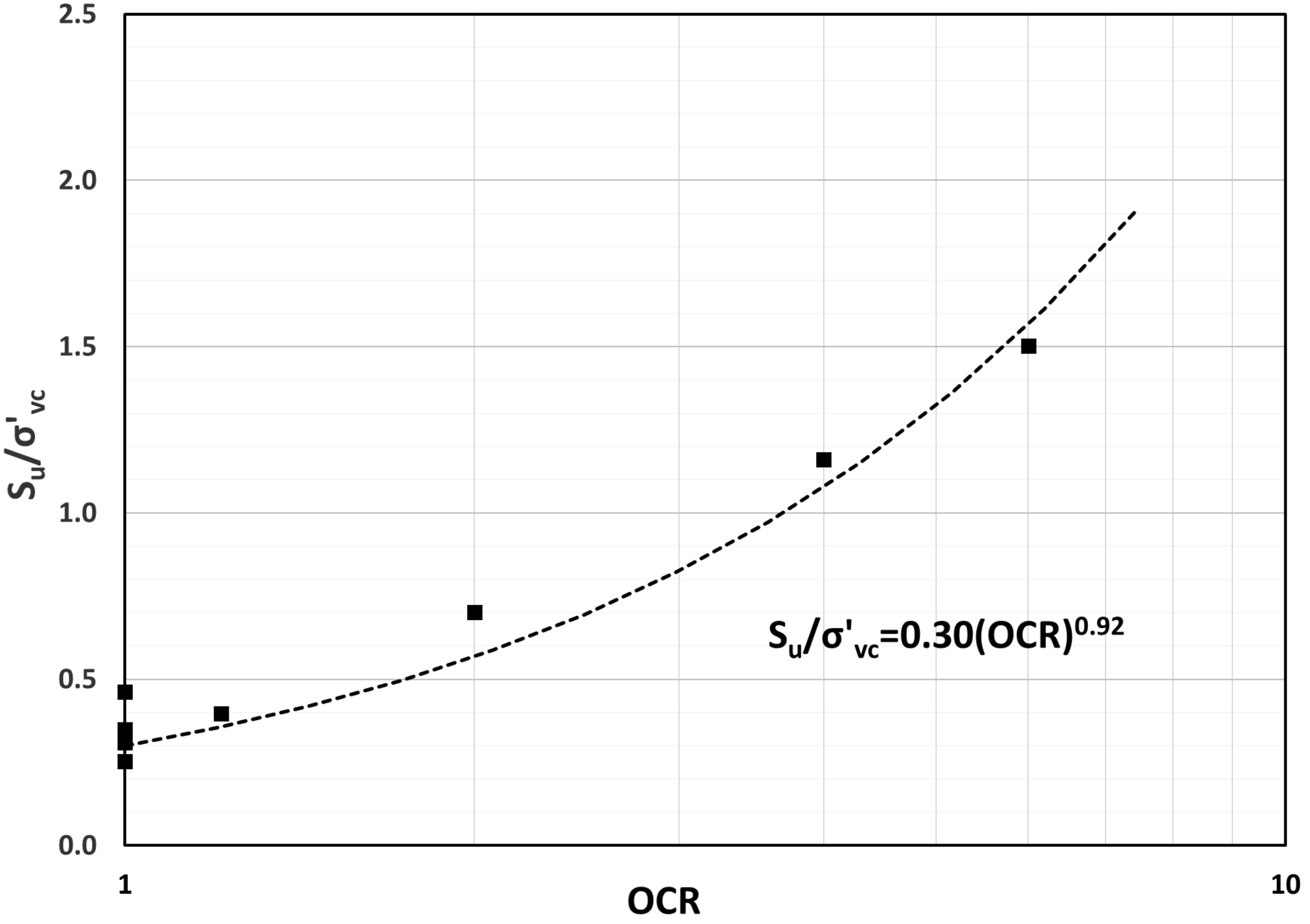

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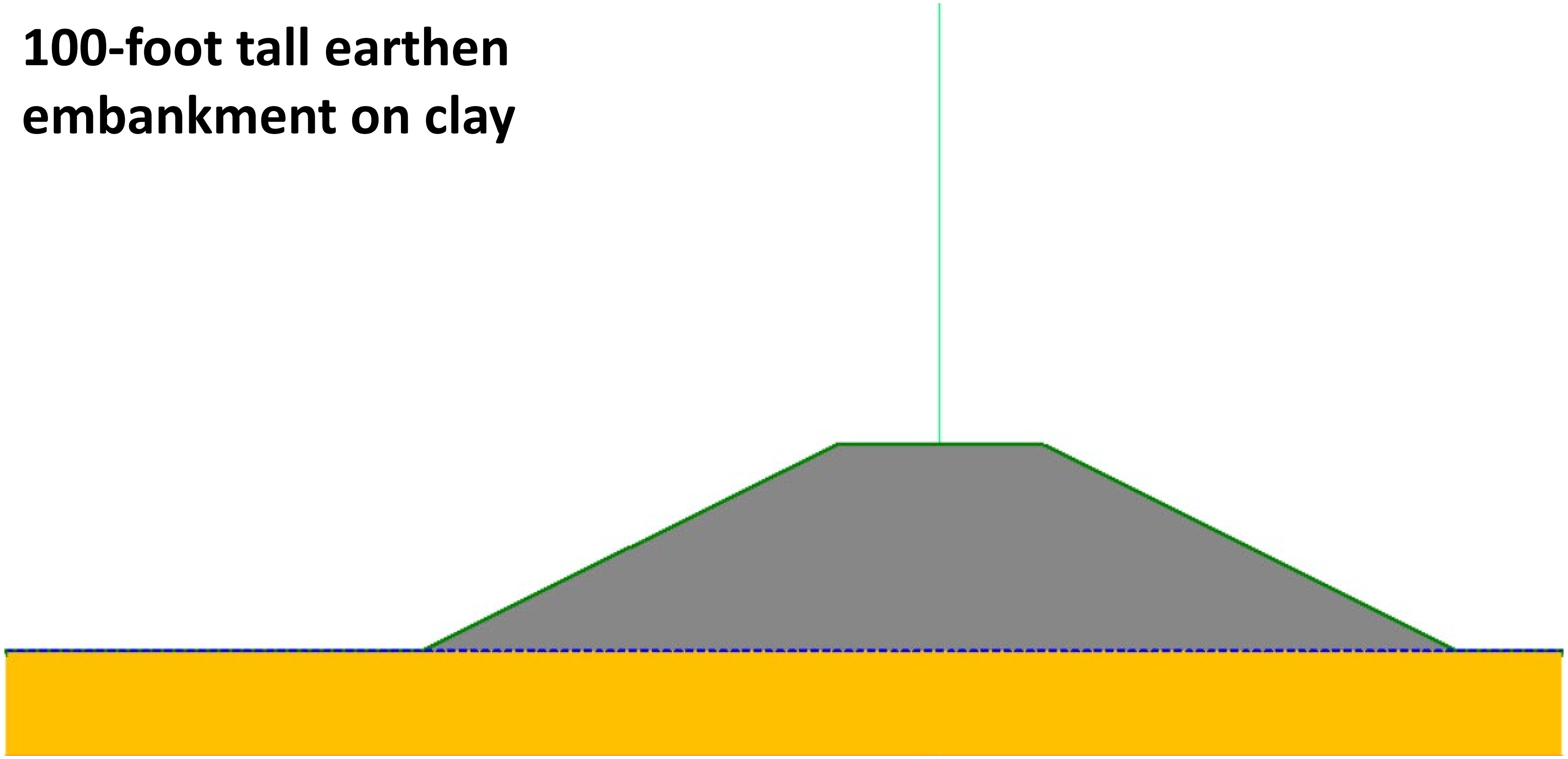
Hypothetical Example

100-foot tall earthen embankment on clay



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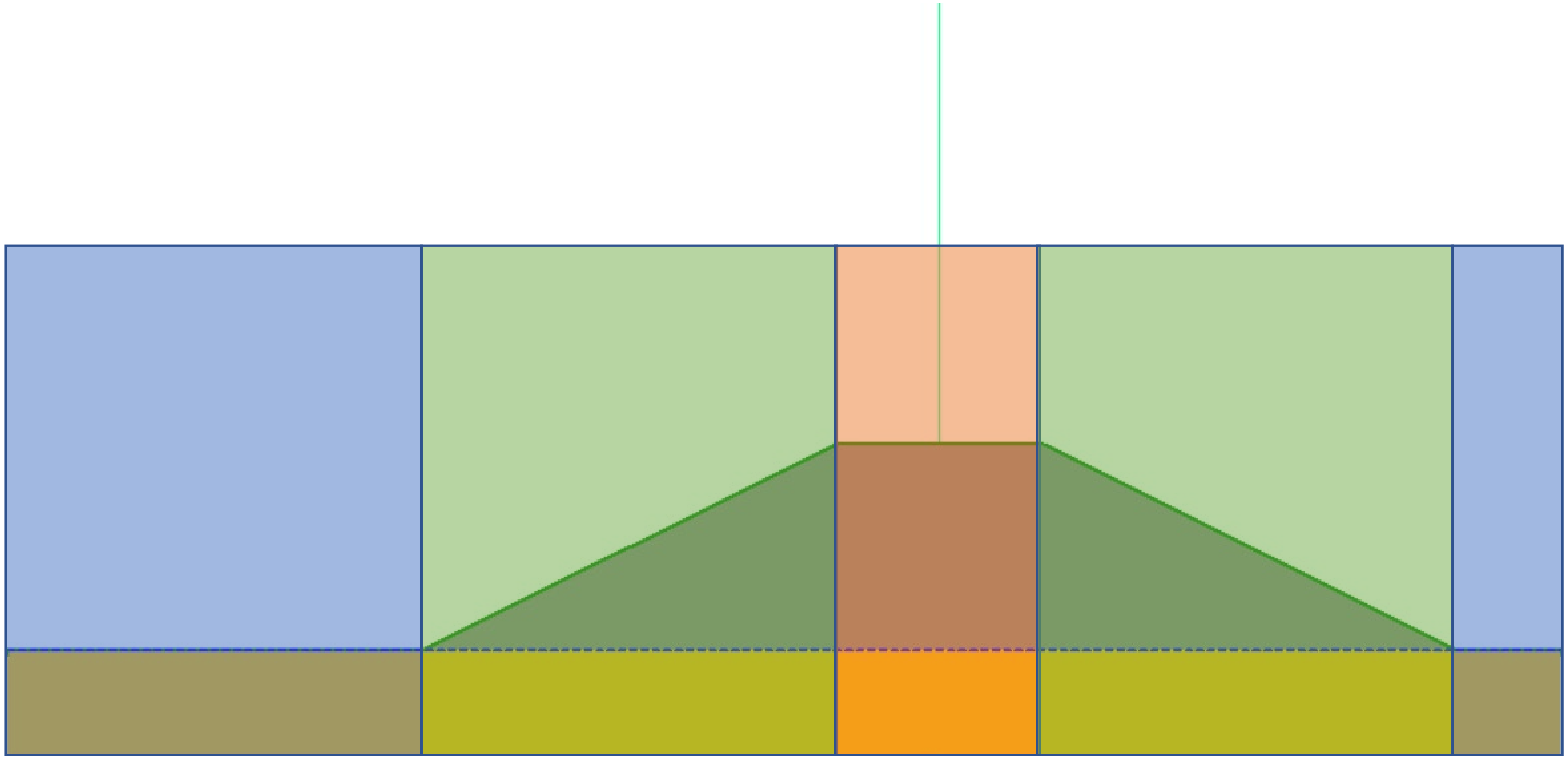

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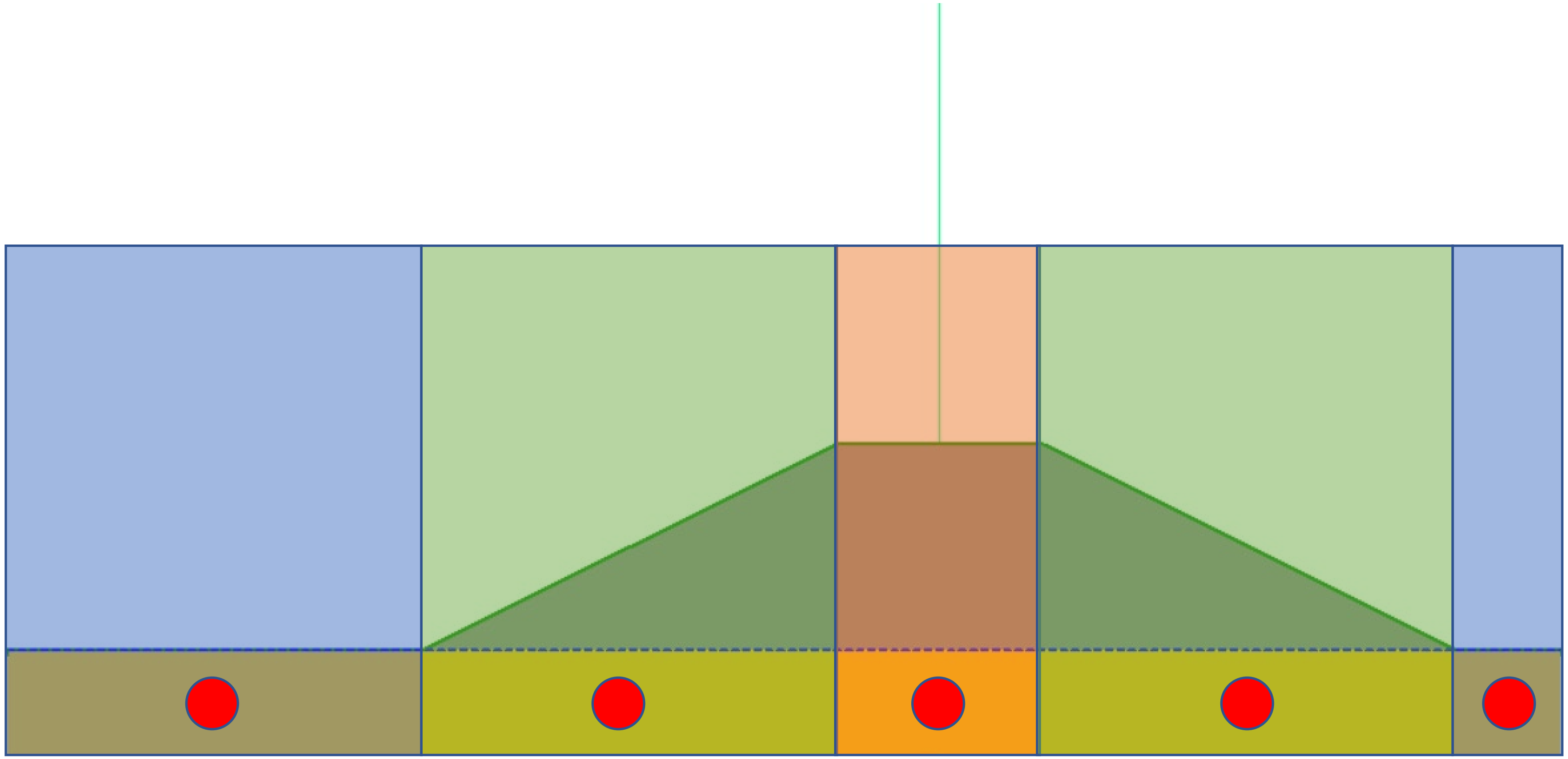
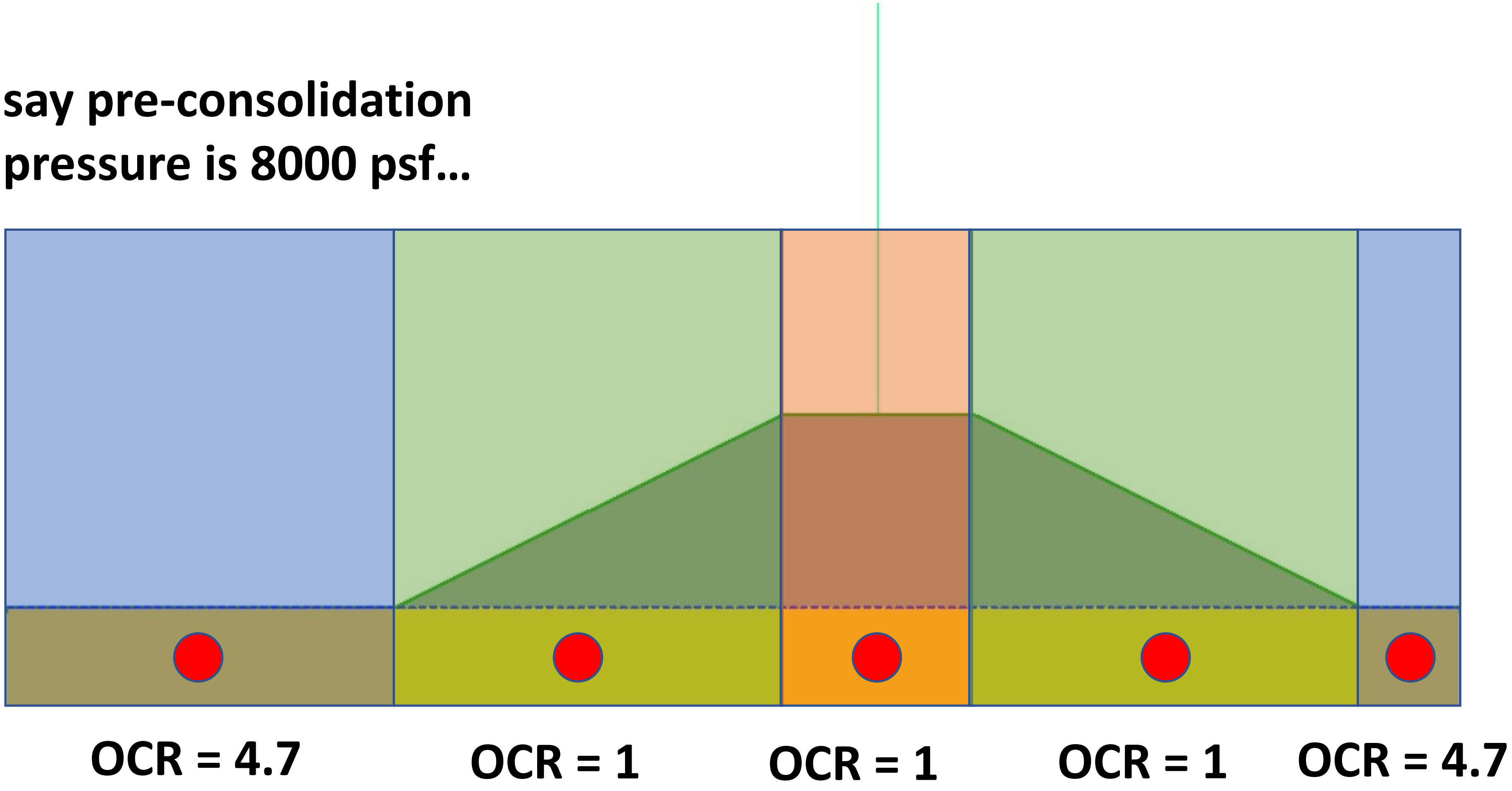


Hypothetical Example (cont.)

100-foot tall earthen embankment on clay

say pre-consolidation pressure is 8000 psf…



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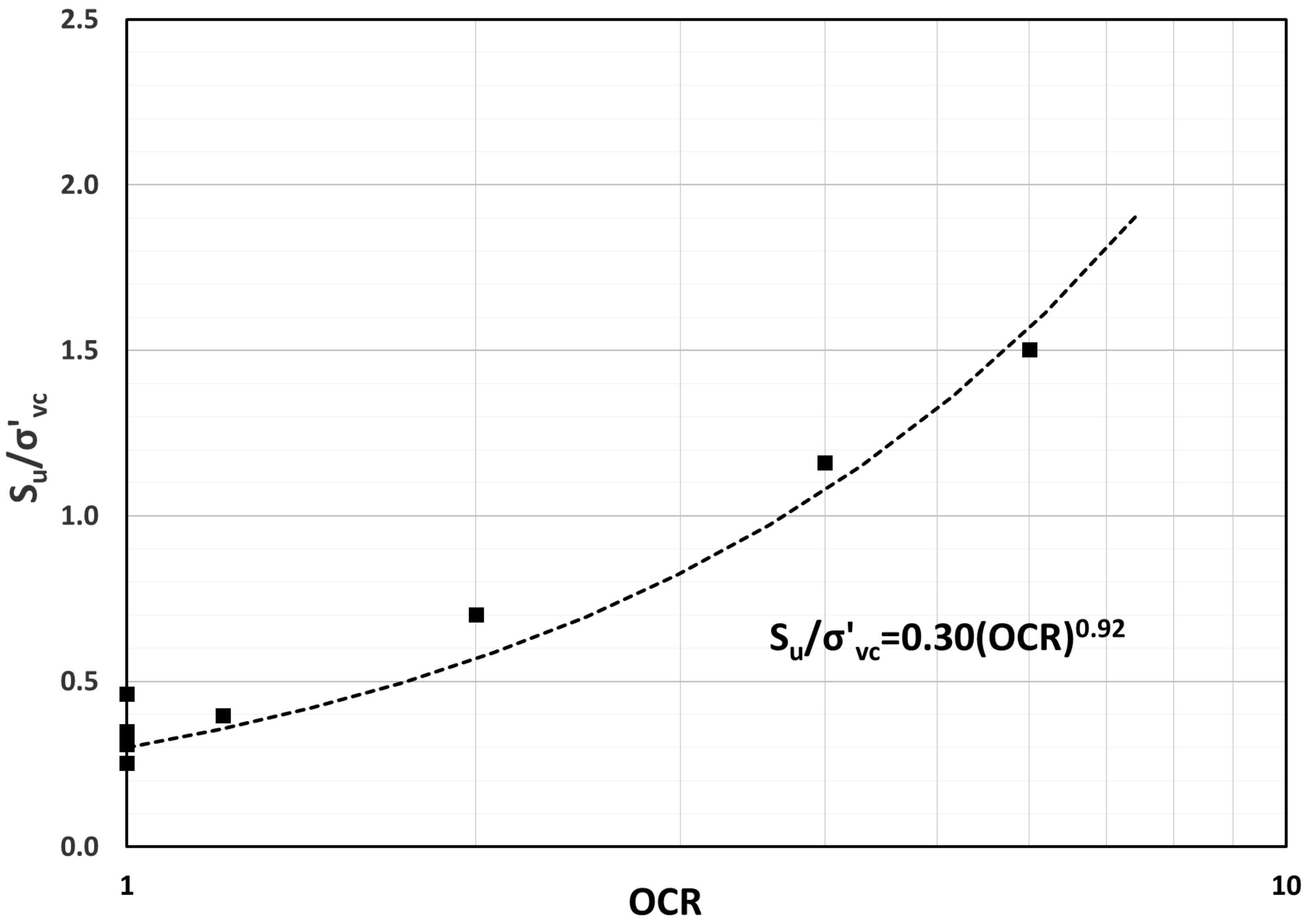

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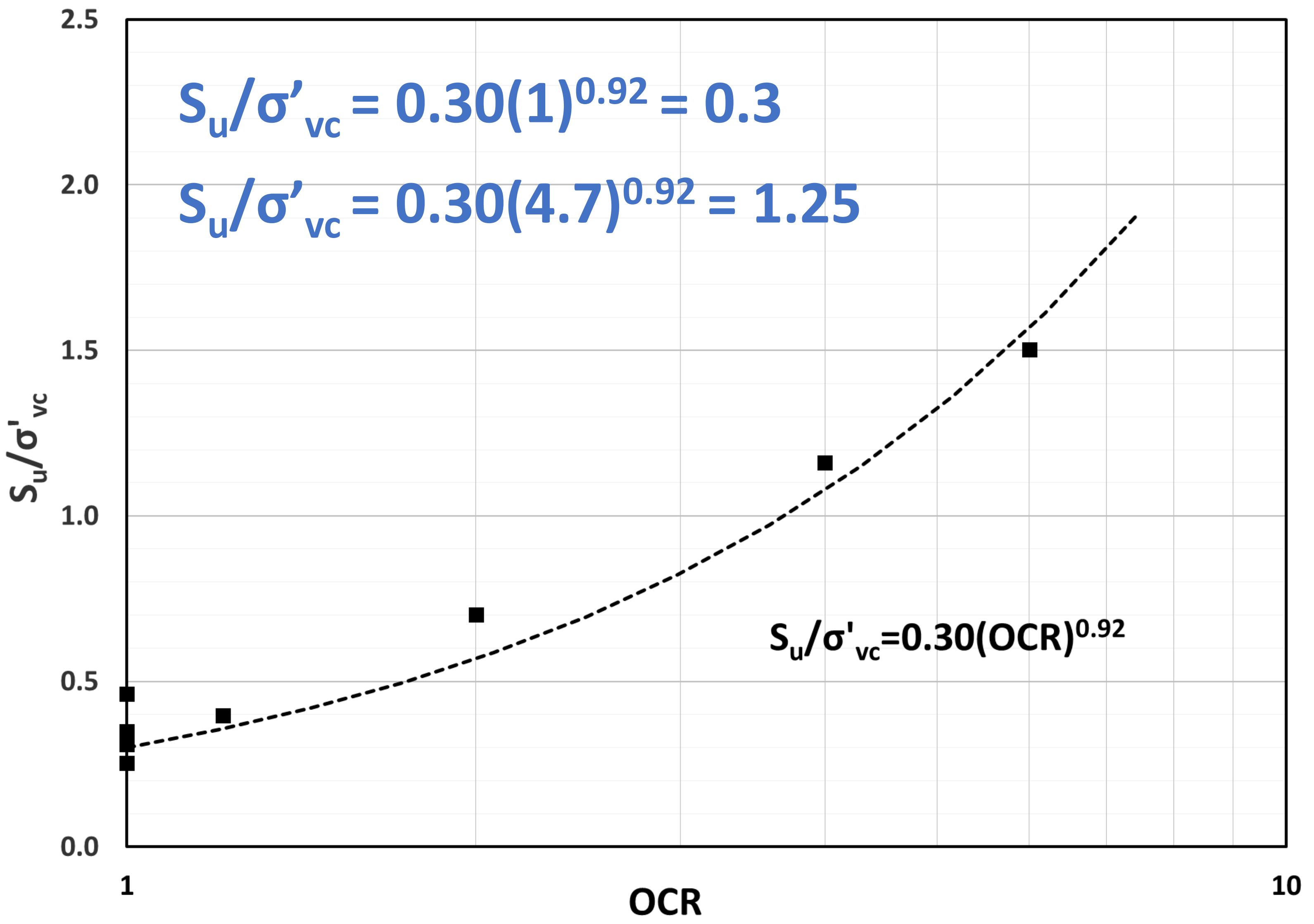
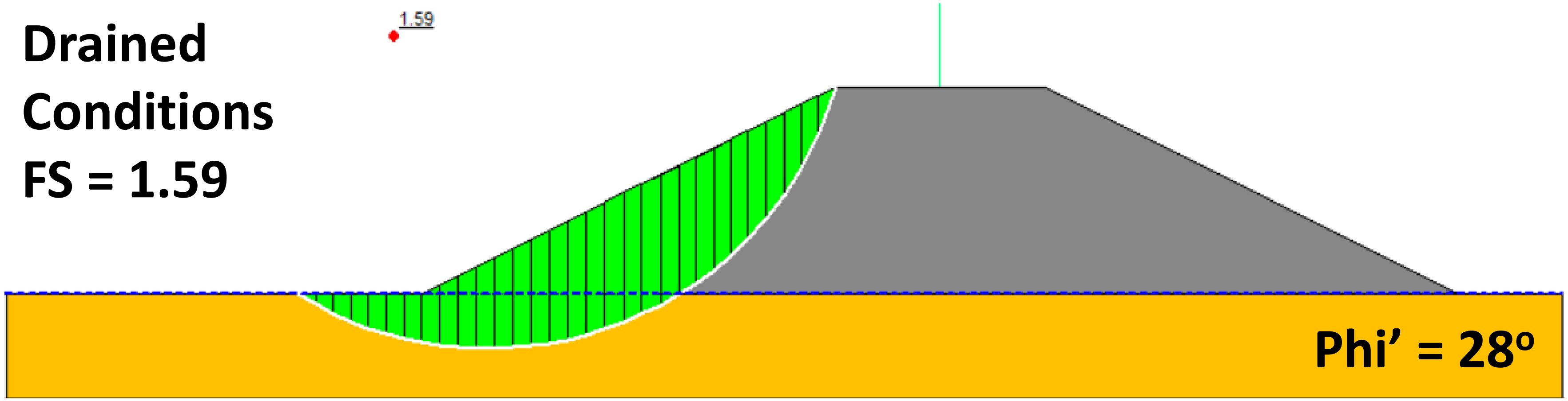


Hypothetical Example (cont.)

Drained Conditions
FS = 1.59



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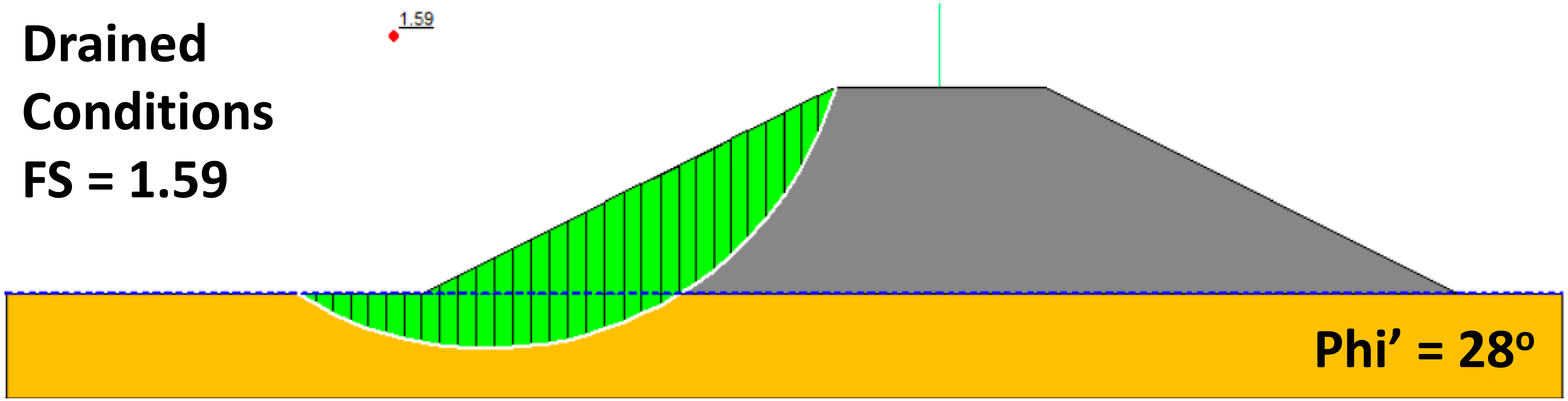
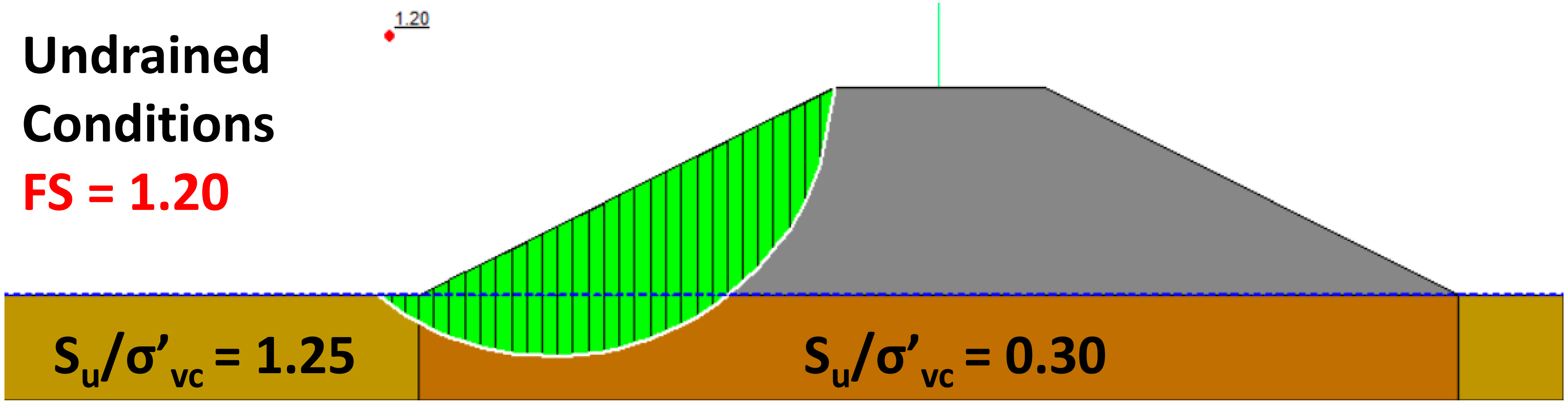


Undrained Conditions
FS = 1.20



Summary

- Much of northern Minnesota is underlain by stiff clay due to glaciation

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Summary (cont.)

- Much of northern Minnesota is underlain by stiff clay due to glaciation
- As clay is loaded, its behavior changes
- Stress history influences strength
- Failure to account for change in strength due to loading may result in unconservative designs
- SHANSEP is a convenient approach for inter-relating strength and stress history

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Thank You

Kurt J. Schimpke, PE

Senior Geotechnical Engineer
Minneapolis, MN office: 952.832.2897
cell: 612.387.0504
kurt.schimpke@barr.com
www.barr.com

resourceful. naturally.