

Tailings Liquefaction – What Owners/Operators Need to Know

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outline

- what is liquefaction?
- why is it important?
- but we're in a low-seismicity region?
- how is liquefaction assessed?
- how can we reduce risk?

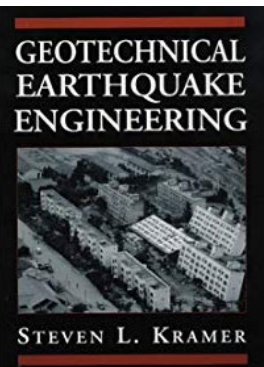
what is liquefaction?

"liquefaction is one of the most important, interesting, complex, and controversial topics" in geotechnical engineering.

-Steven L. Kraemer



2011 Christchurch earthquake (photo from: <http://www.pxl.co.nz/2011/03/christchurch-earthquake-22nd-feb-2011/>)



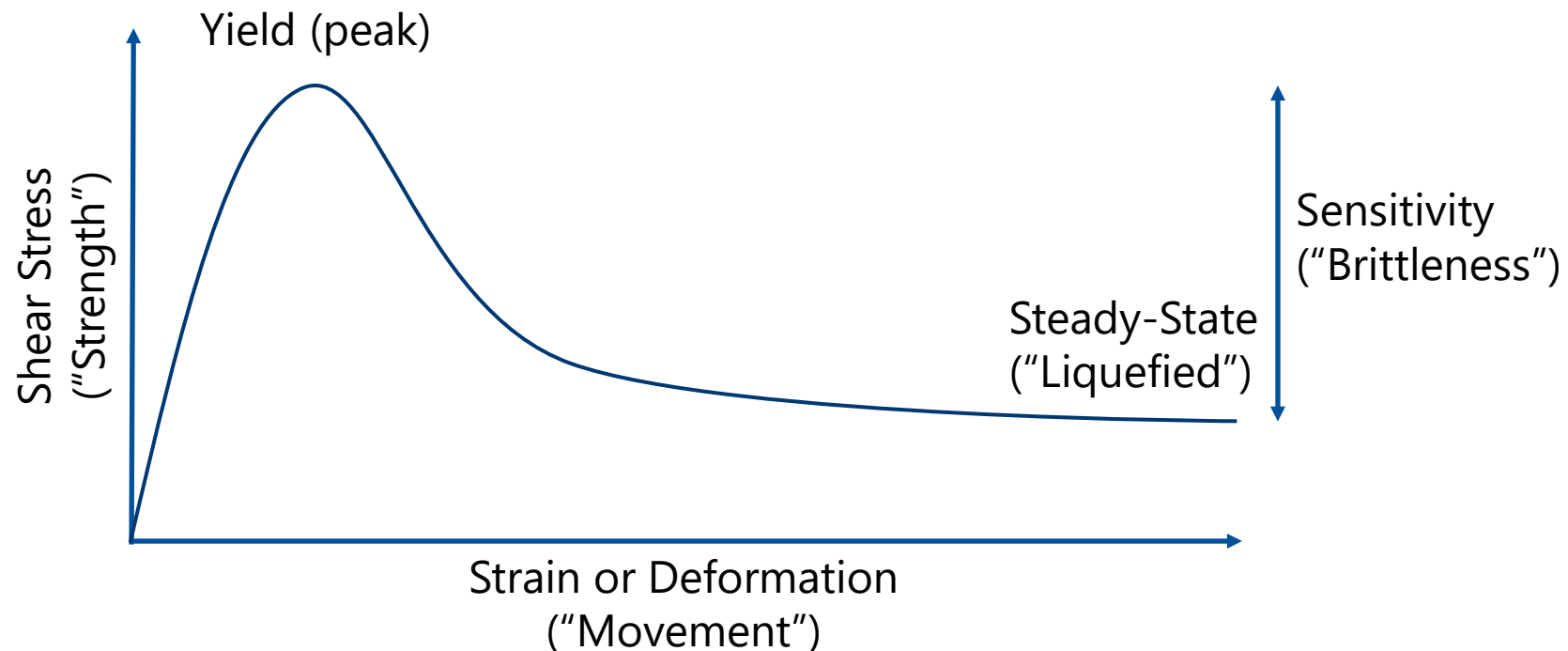
what is liquefaction?

- material temporarily assumes consistency of thick liquid
- can affect sizable portion of tailings mass
- can be triggered by seismic or static events



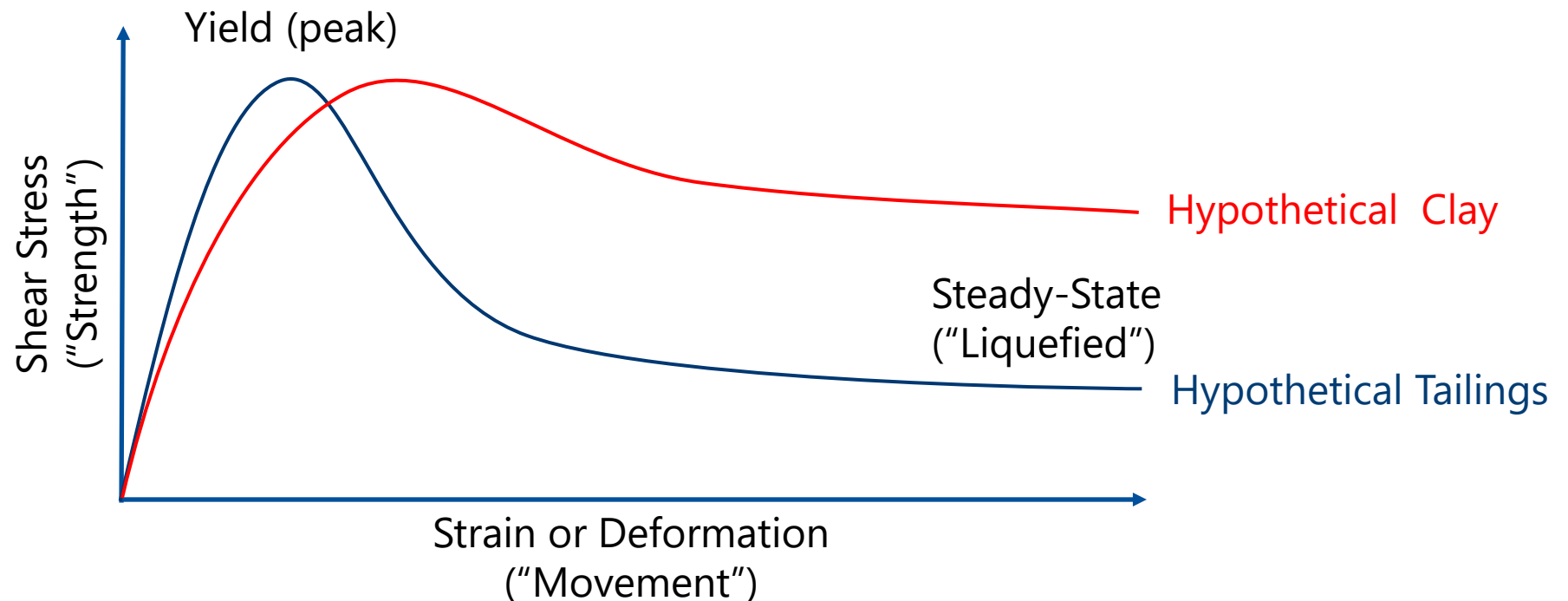
what is liquefaction?

sudden drop in shear strength from the yield (peak) undrained strength to the substantially lower steady-state undrained shear strength under undrained conditions.



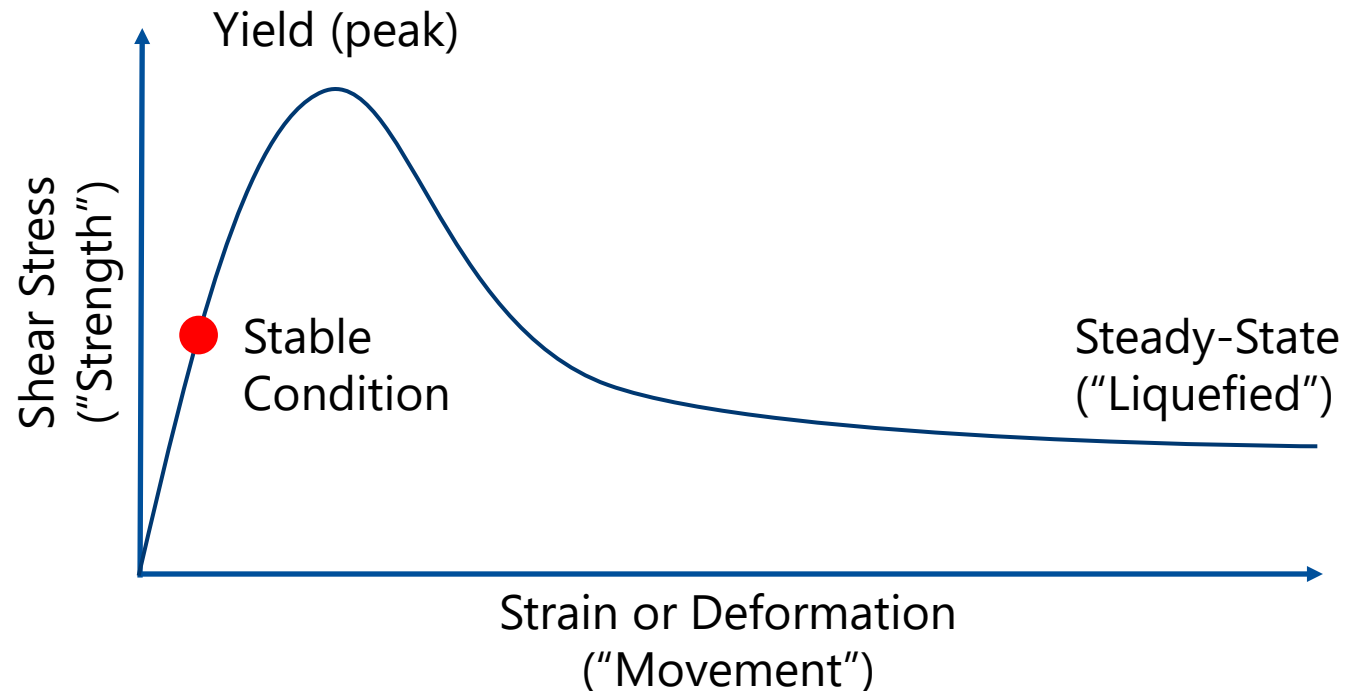
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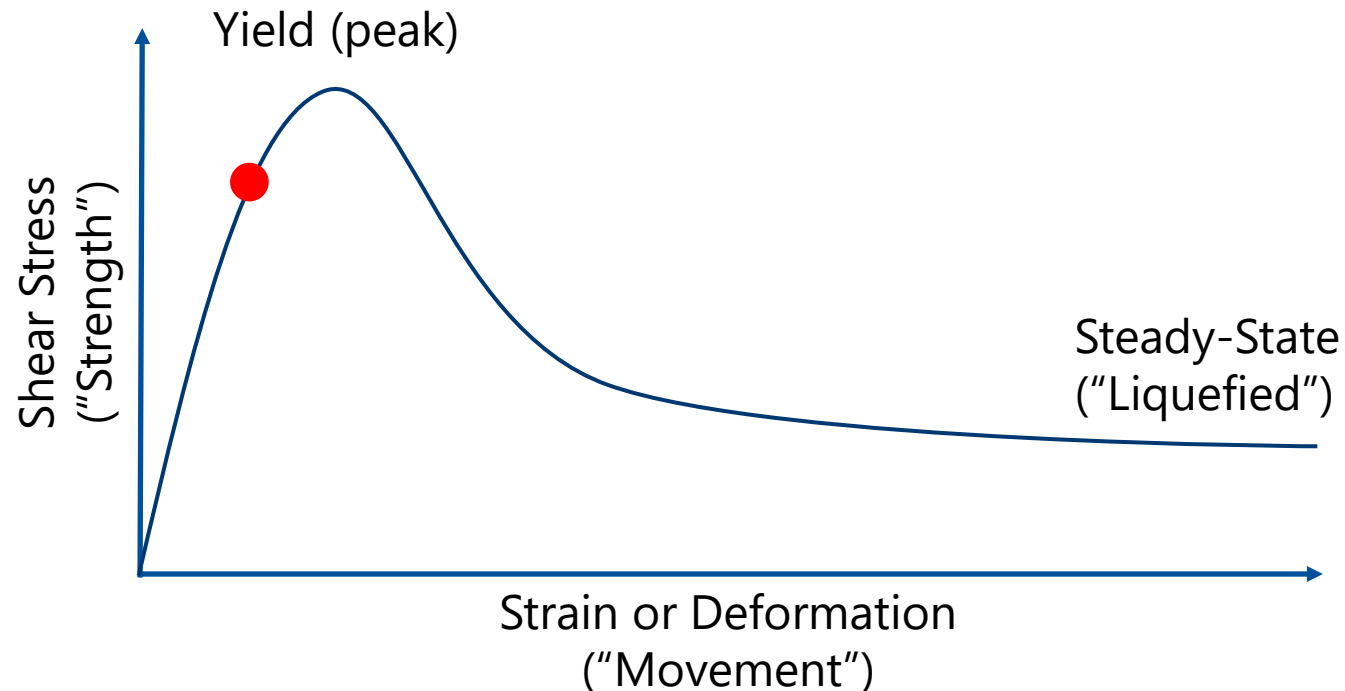
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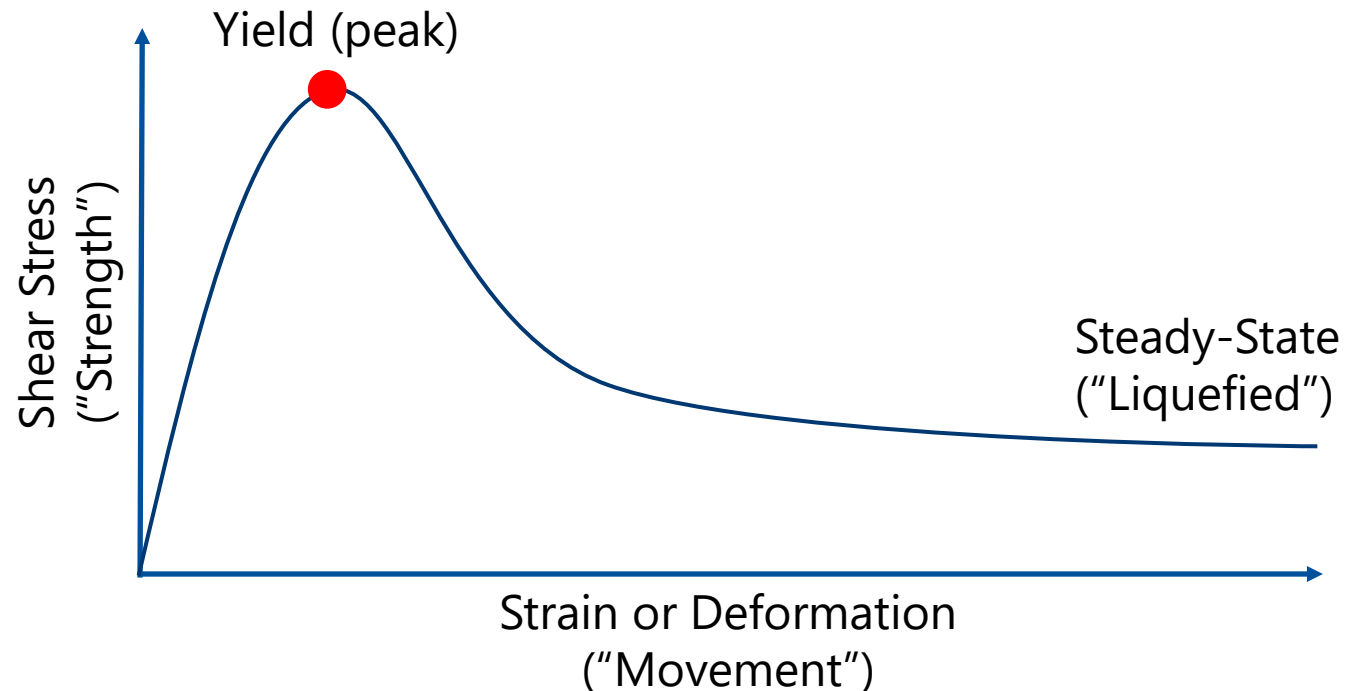
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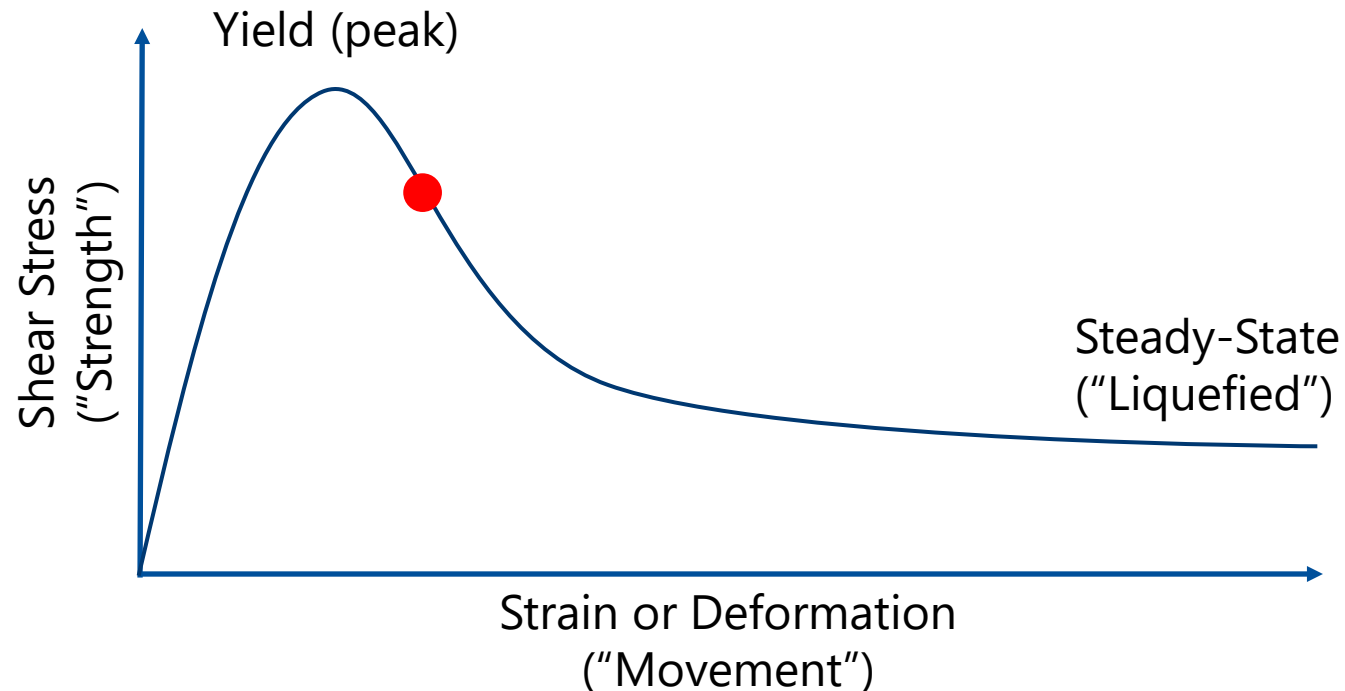
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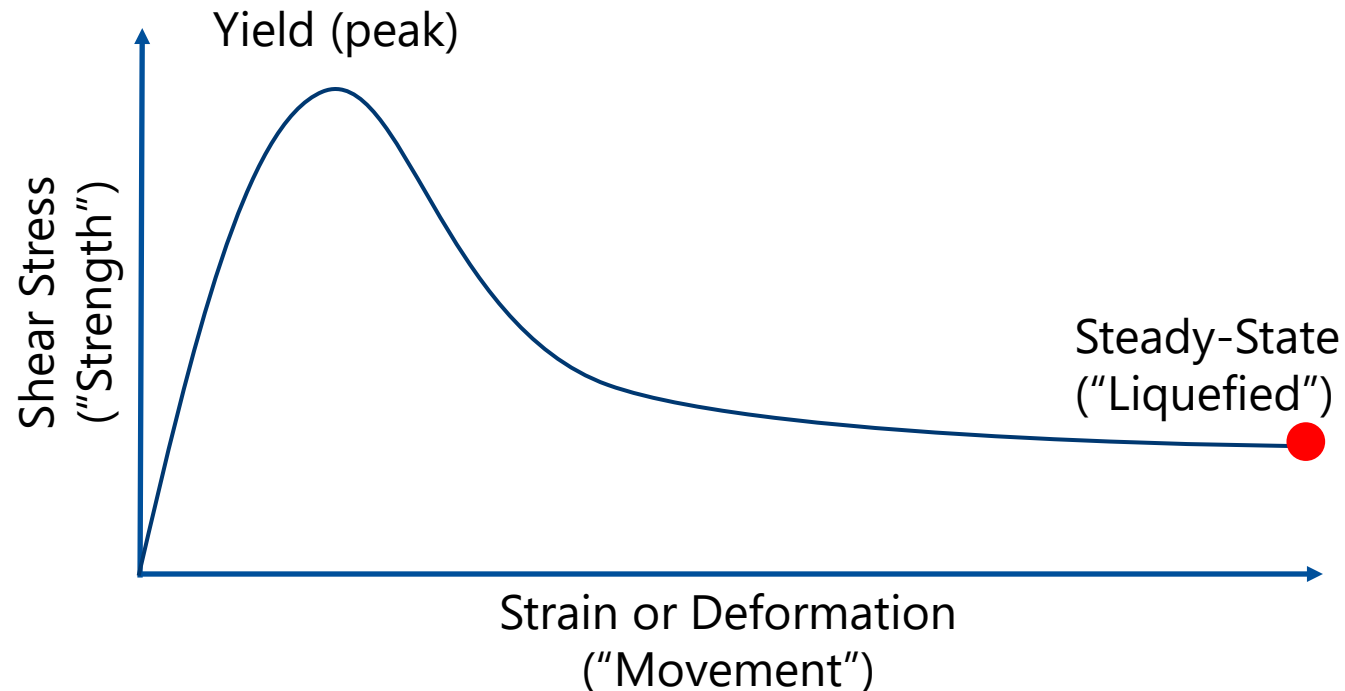
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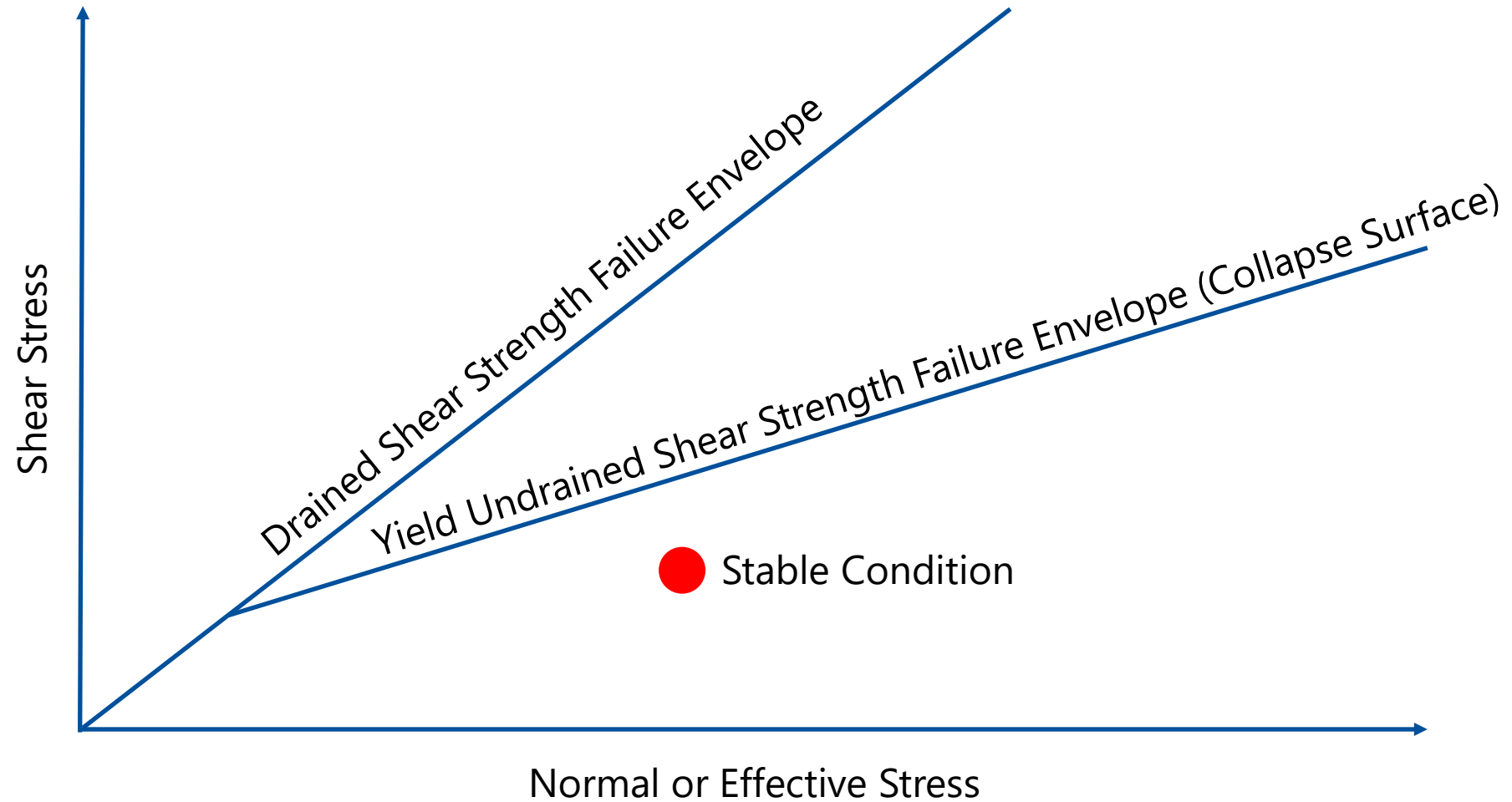


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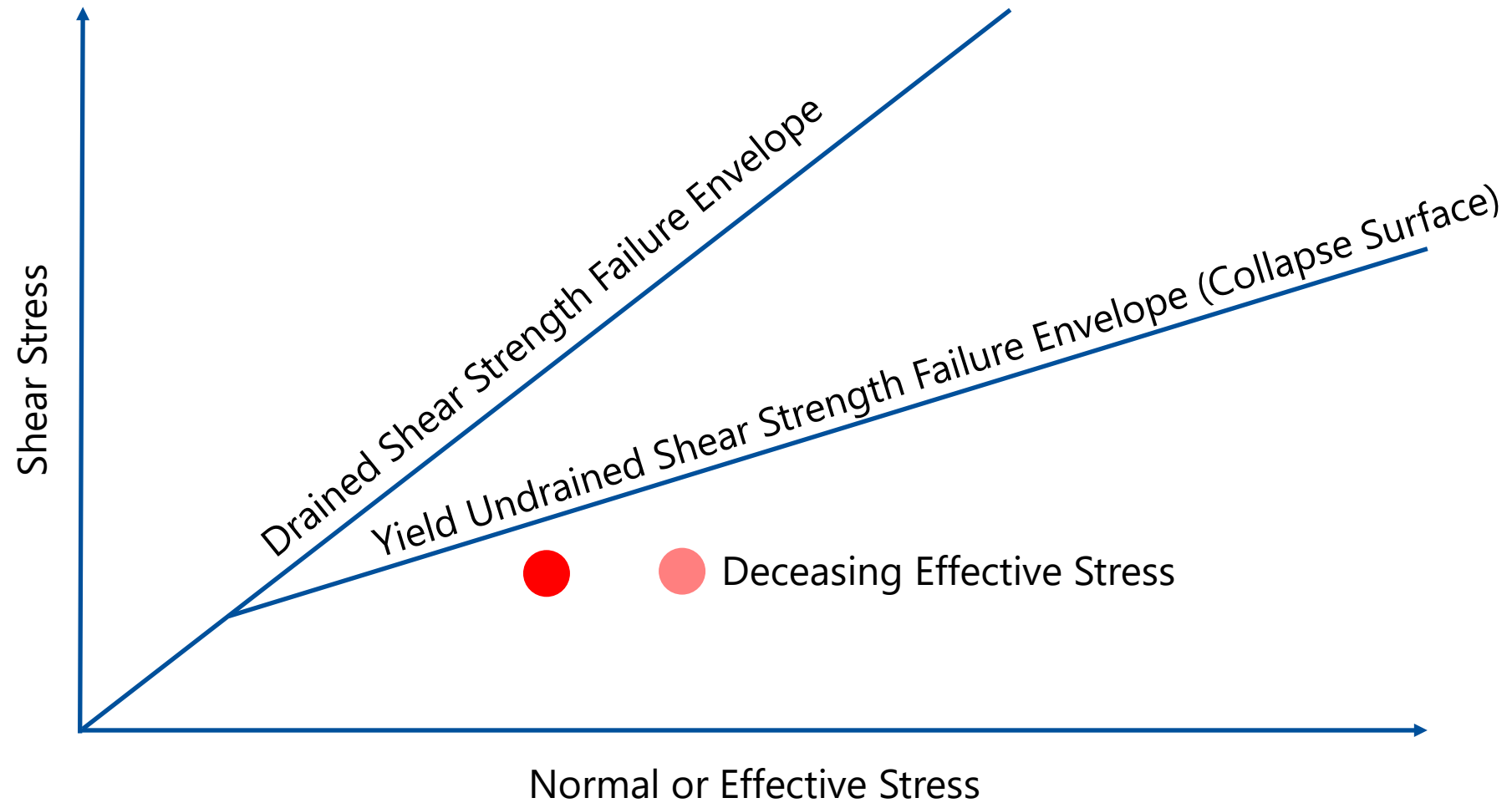
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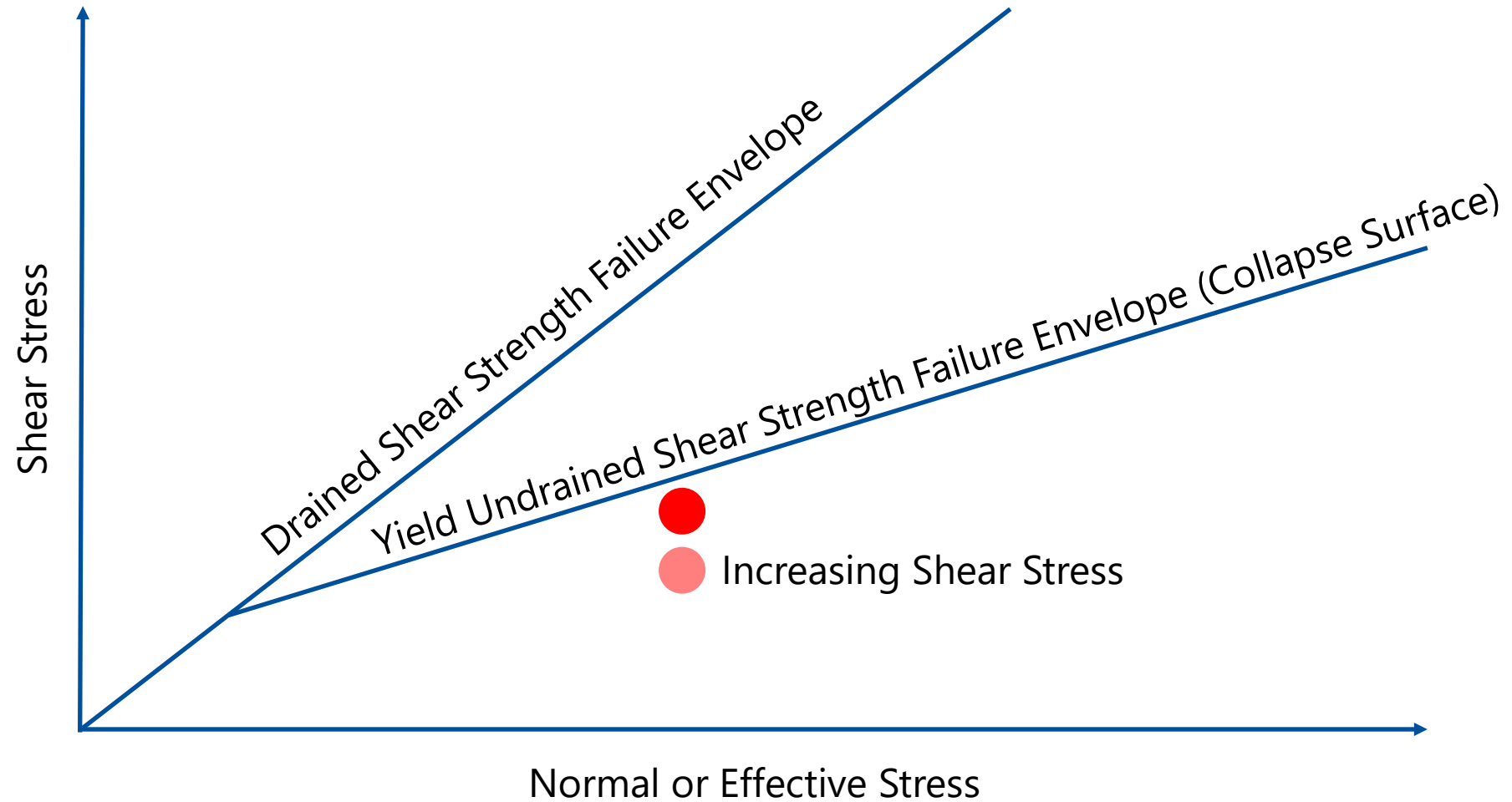
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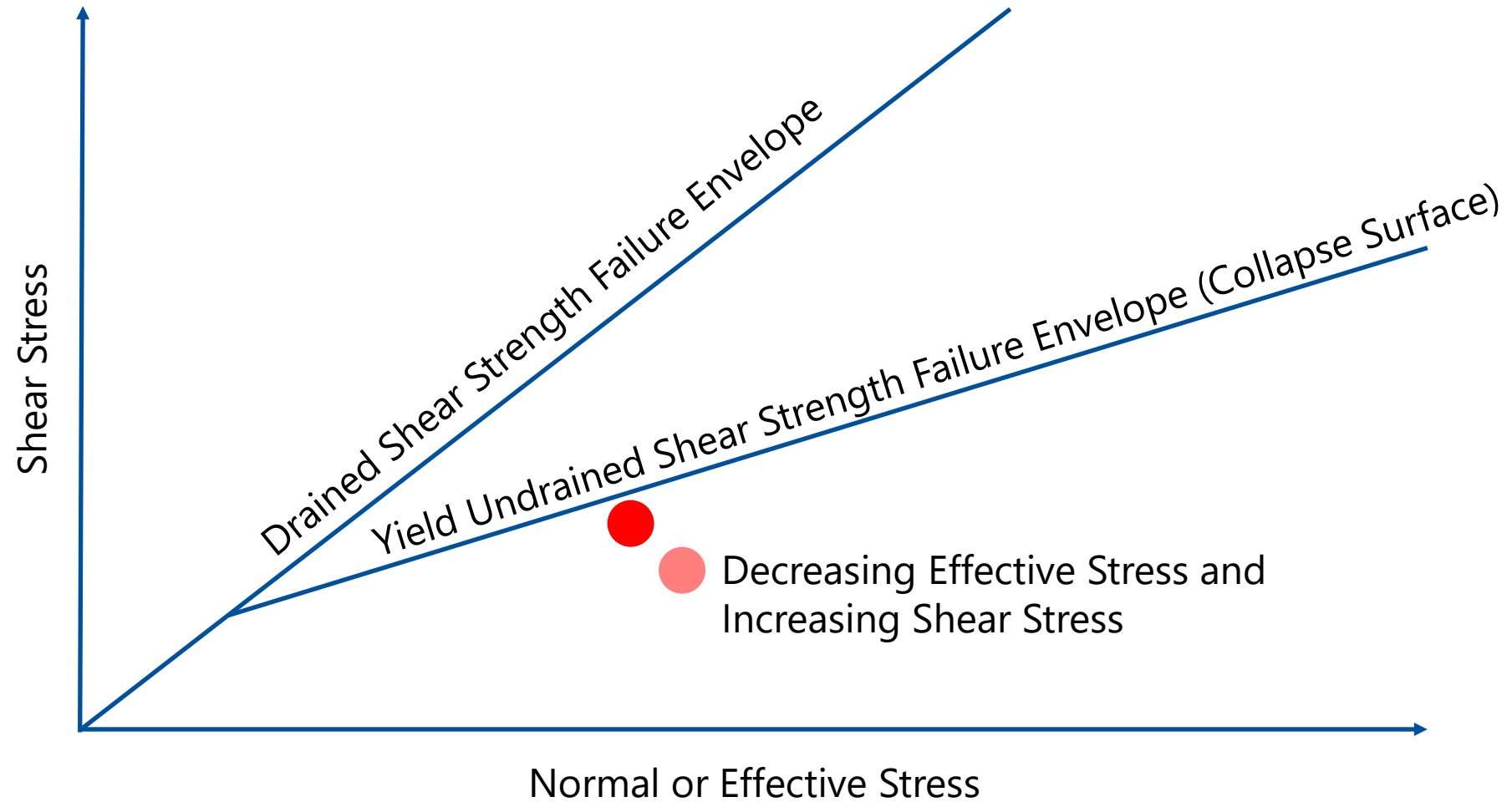
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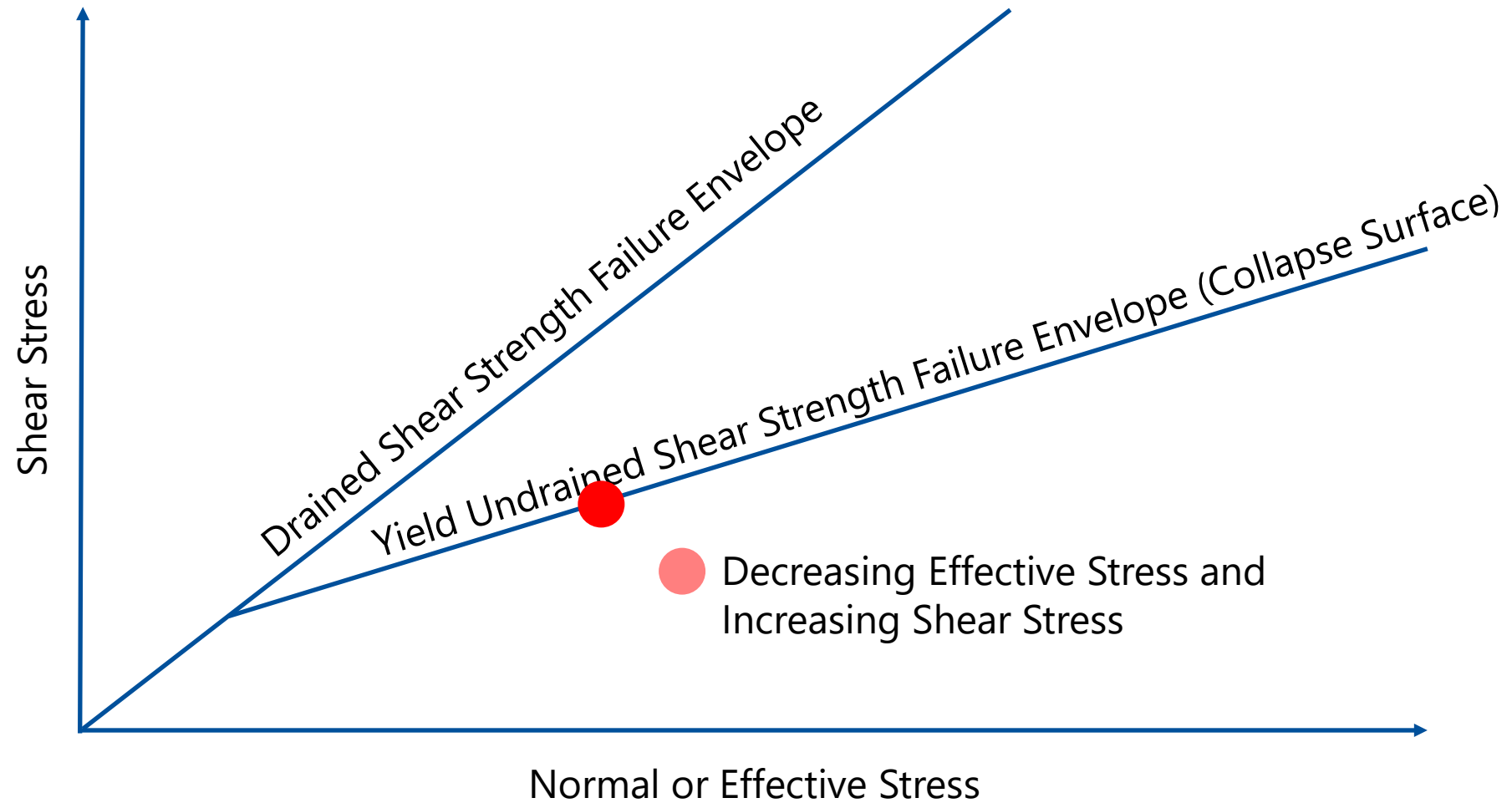
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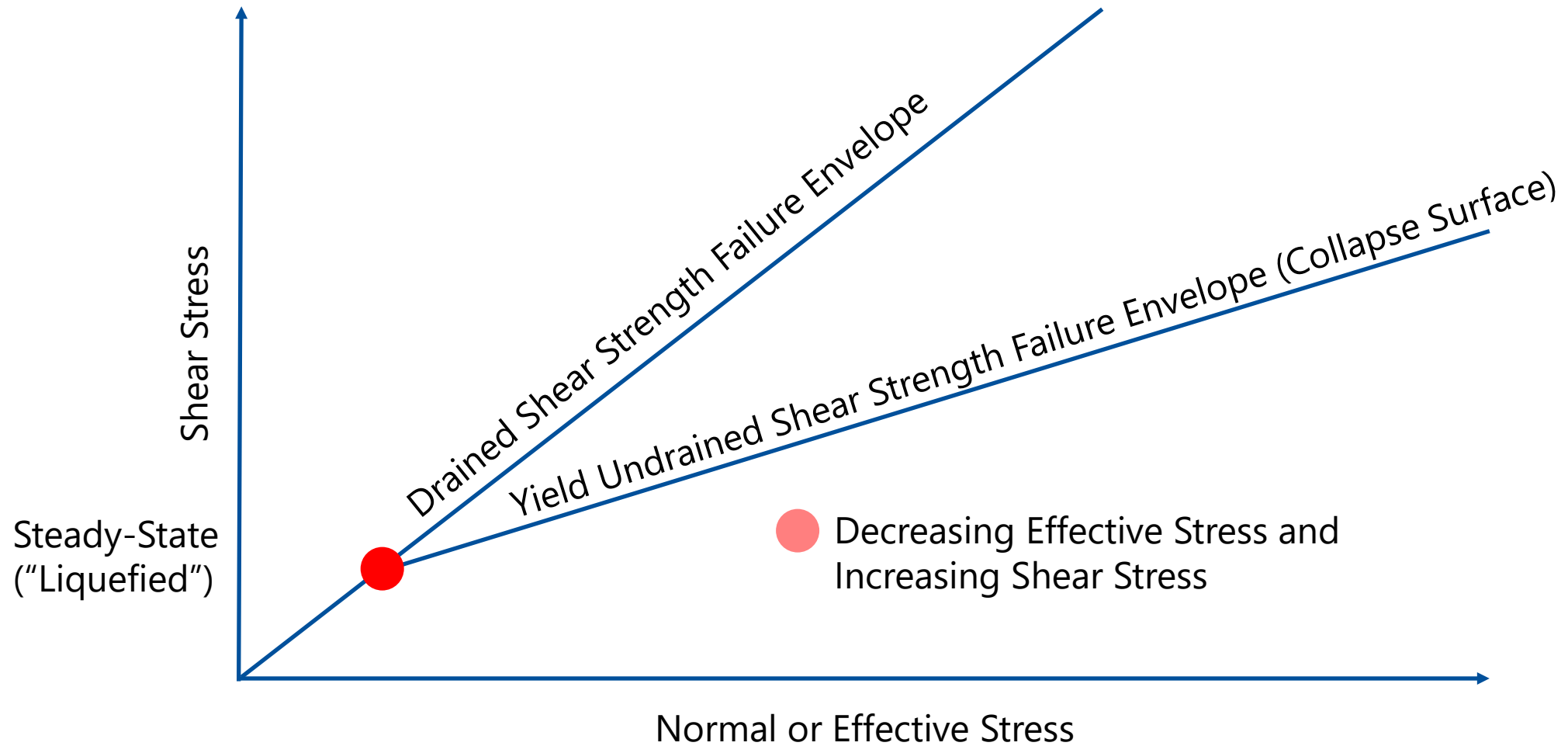
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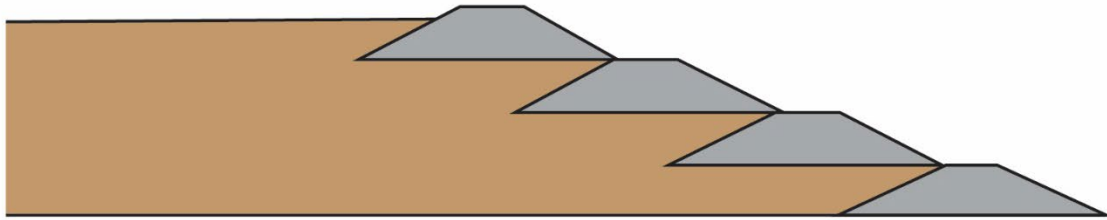
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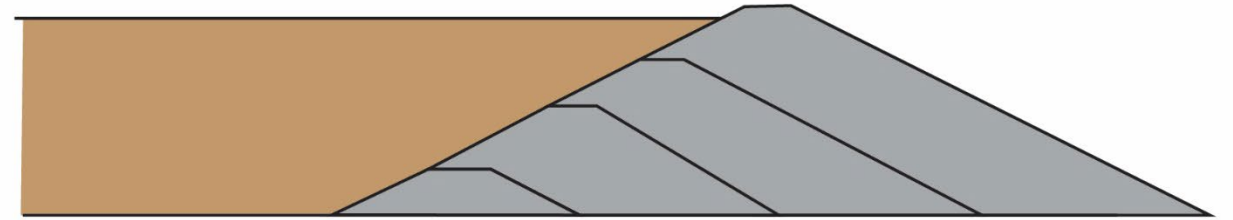
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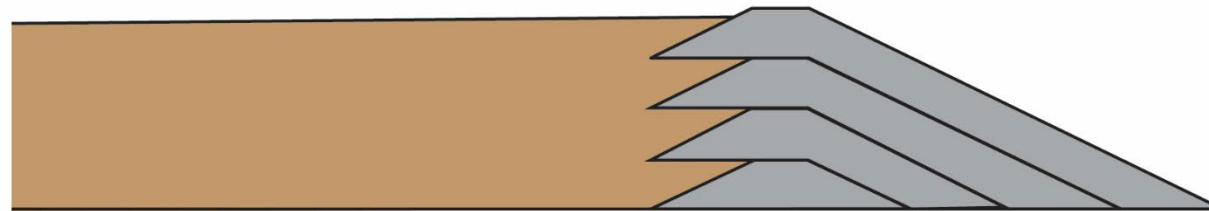
why is liquefaction important?



Upstream Construction Method



Downstream Construction Method



Centerline Construction Method

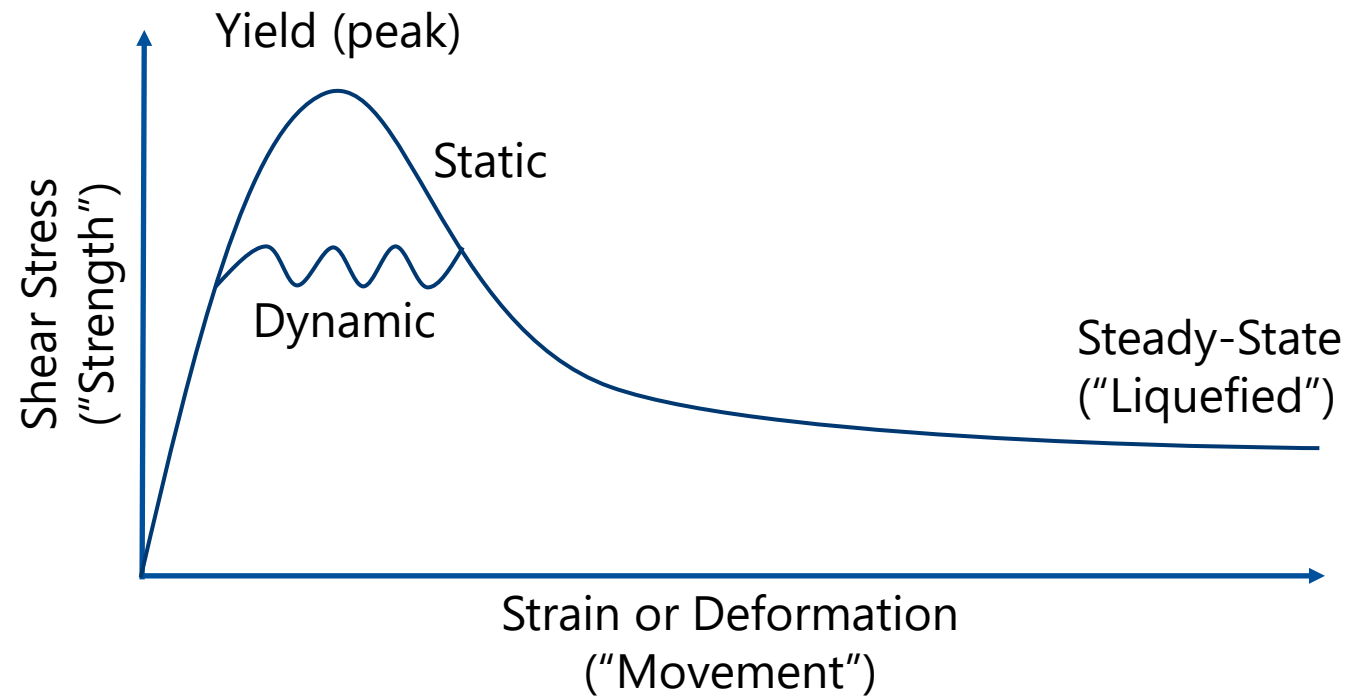
why is liquefaction important?

tailings are generally...

- young (on geologic timescale)
- saturated
- low plasticity (brittle)
- high void ratio (loose)

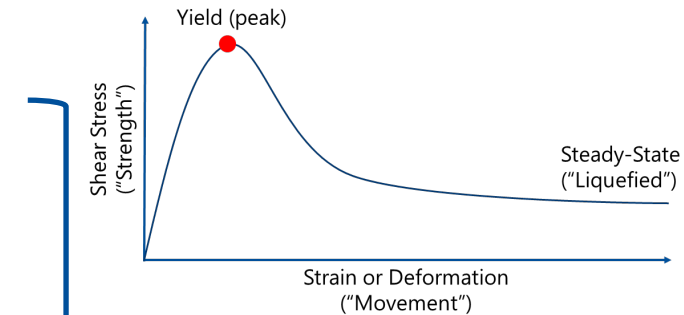
...making them susceptible to liquefaction.

but we're in a low seismicity region?



but we're in a low-seismicity region?

Triggering Mechanism	Potential Cause
Over-Steepening at Toe	• Erosion (intense storm runoff, pipeline break causing washout) • Construction activities or "housekeeping" (excavation)
Overloading of Slope/Foundation	• Rapid rate of impoundment raising • Steepening of slope near crest • Construction activities at crest
Changes in Pore Pressures	• Seepage breakout on face of dam • Deterioration in performance of under drainage measures • Concentrated tailings discharge from one location for an extended period • Accelerated rate of construction • Foundation or embankment movement • Intense rainstorms • Increased pond levels
Overtopping of Dam	• Severe storm runoff • Failure of diversion dams/ditches • Blockage and failure of spillways/decants • Embankment settlement/deformation and loss of freeboard
Acceleration/Vibration	• Earthquakes • Construction traffic • Blasting

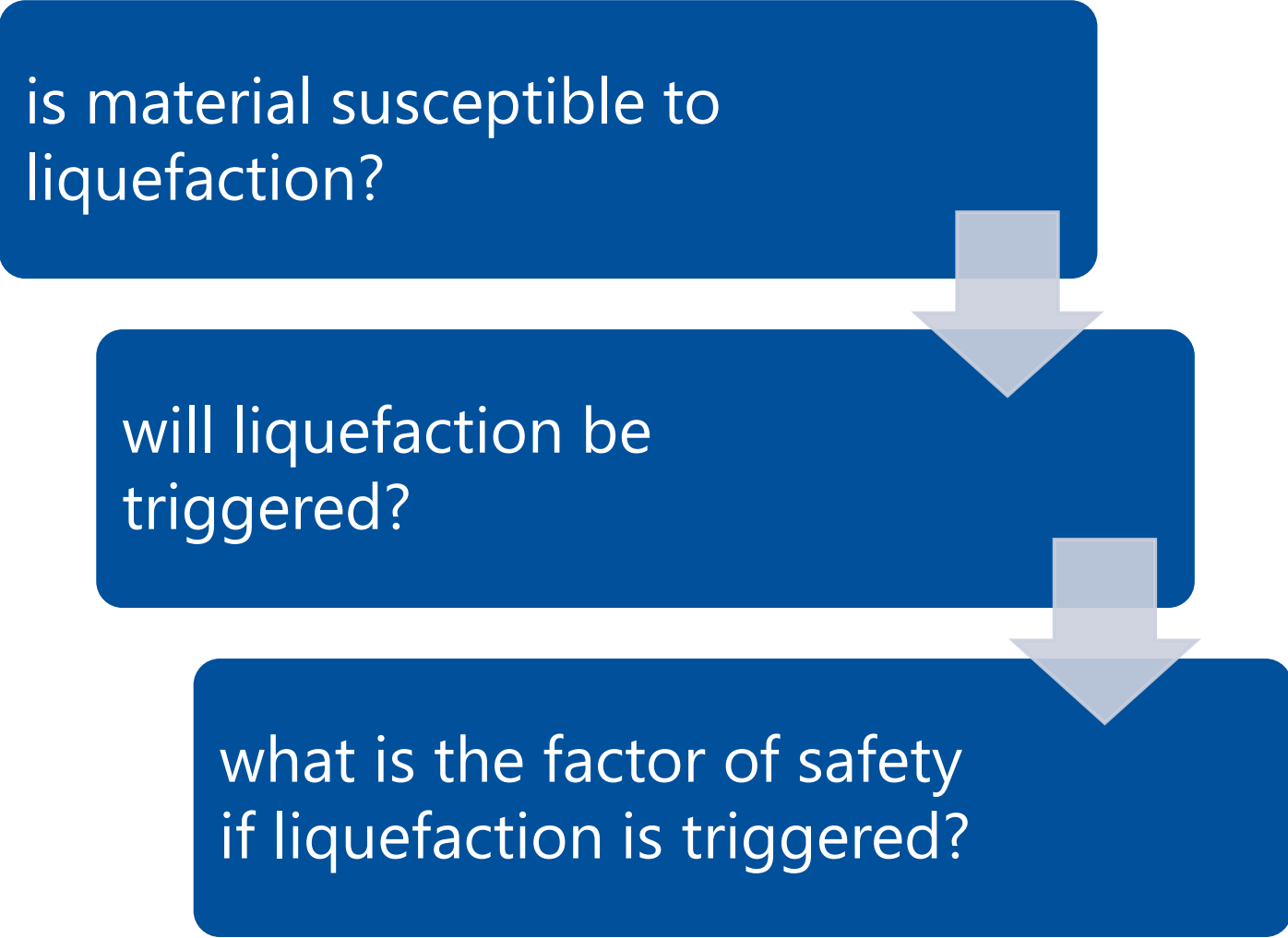


static triggers

dynamic triggers

how is liquefaction assessed?

is material susceptible to
liquefaction?



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graph TD; A[is material susceptible to liquefaction?] --> B[will liquefaction be triggered?]; B --> C[what is the factor of safety if liquefaction is triggered?];
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will liquefaction be
triggered?

what is the factor of safety
if liquefaction is triggered?

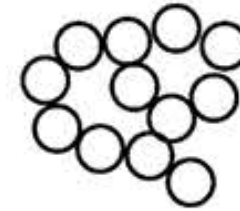
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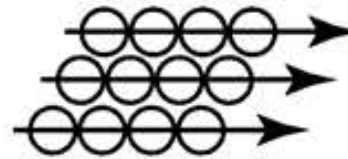
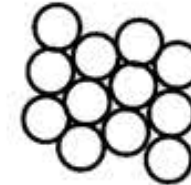
Loose, contractive soil



Shear

Shear

Dense, dilative soil

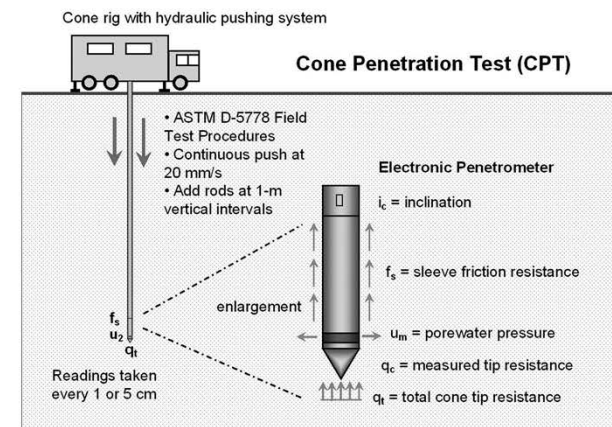
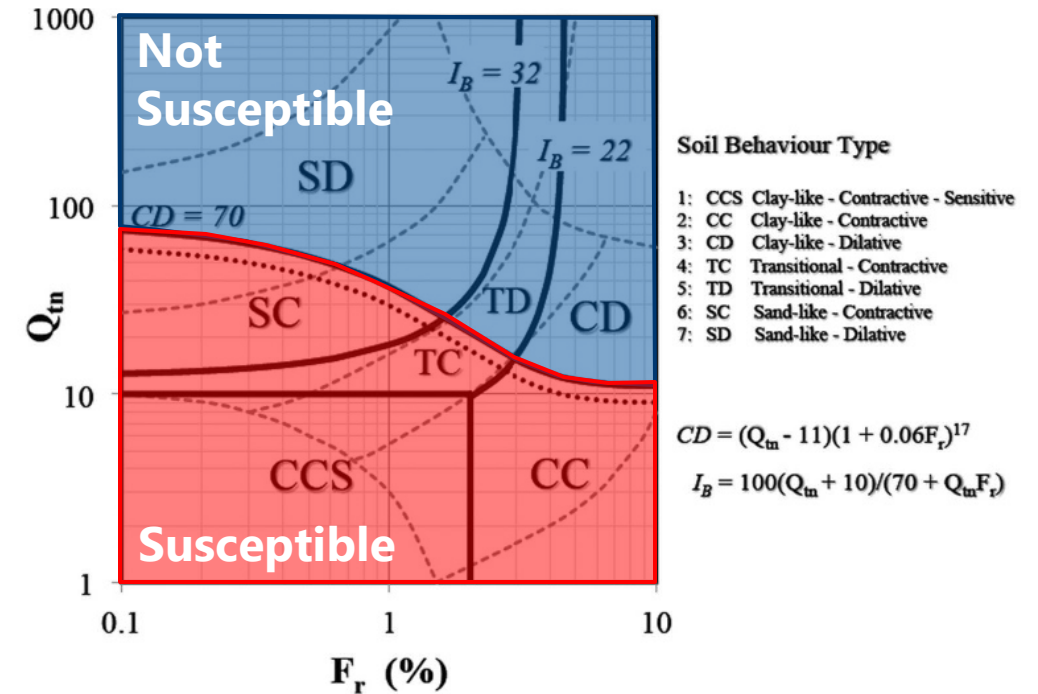


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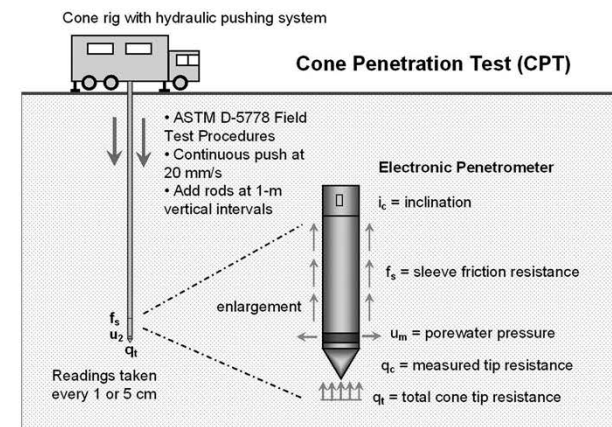
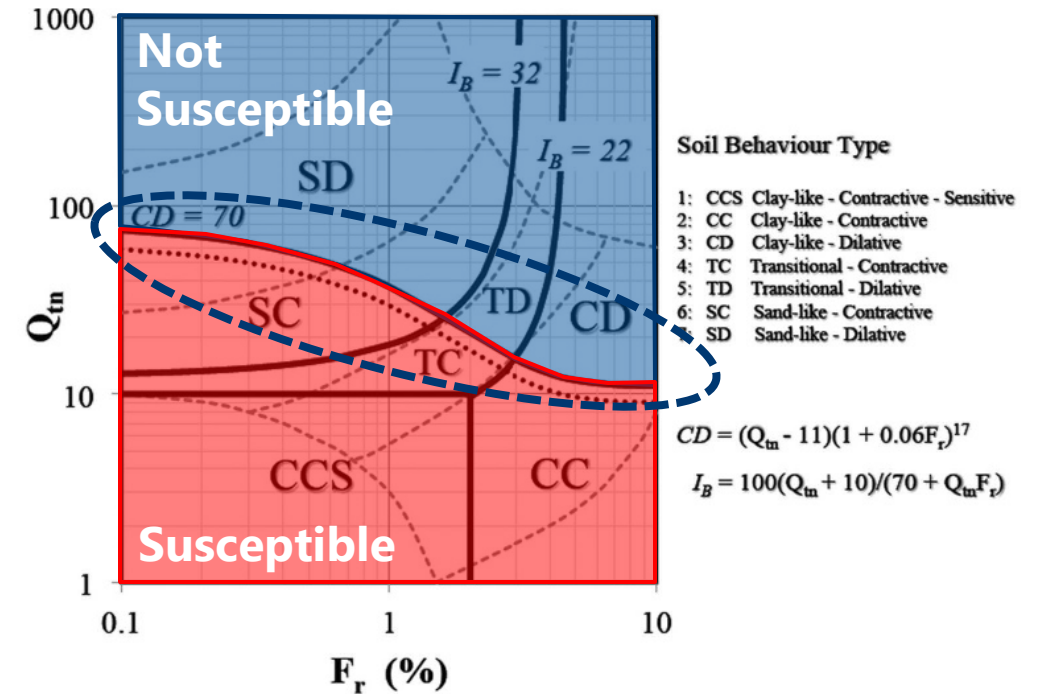


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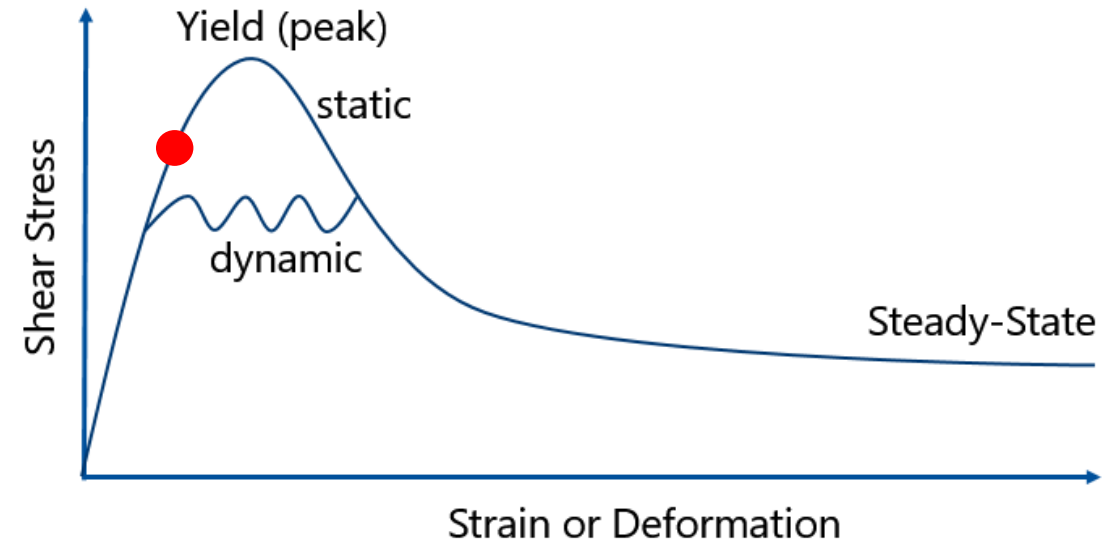
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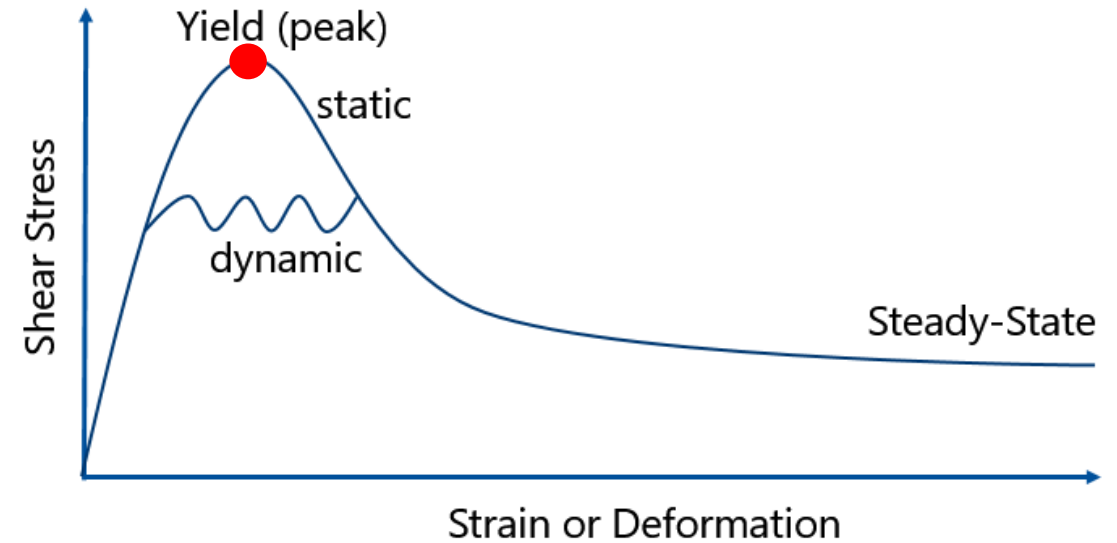
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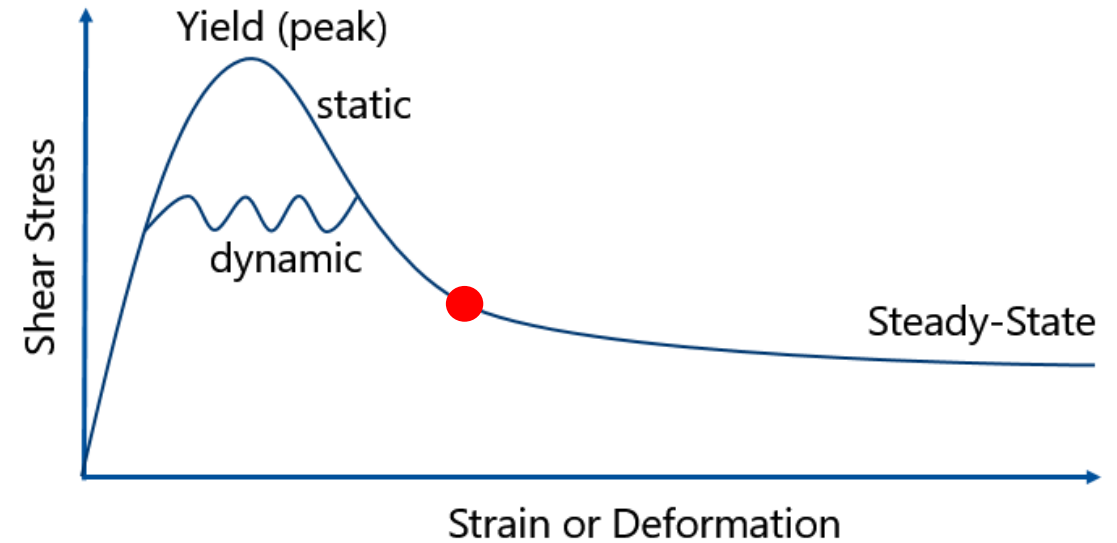
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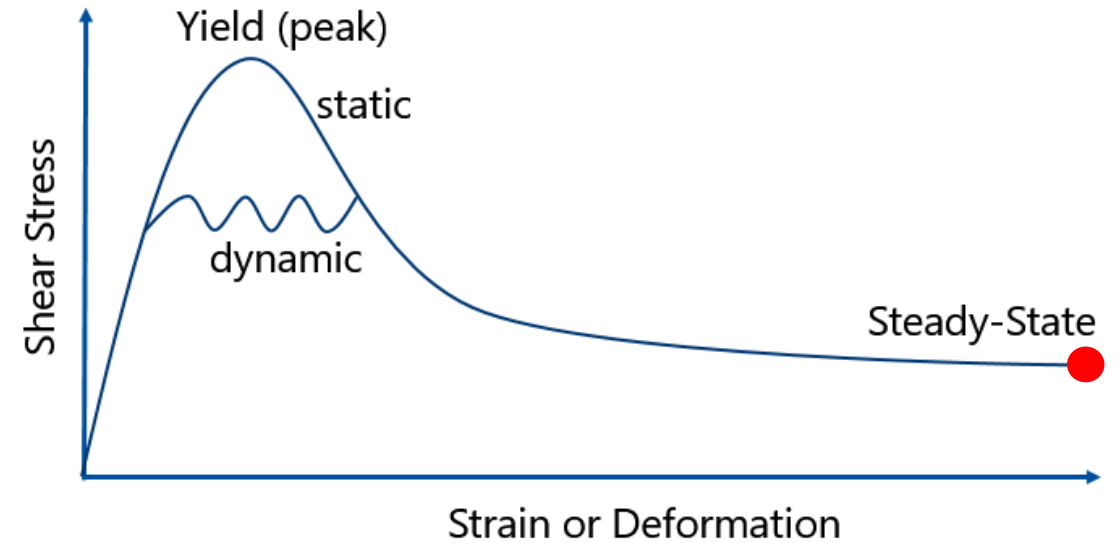
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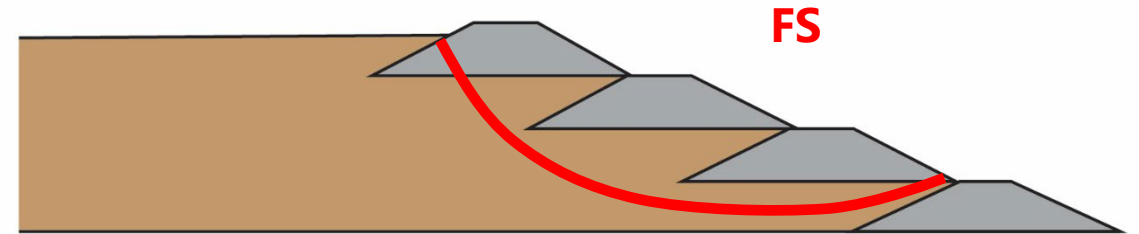
is material susceptible to liquefaction?

YES

will liquefaction be triggered?

YES

what is the factor of safety if liquefaction is triggered?



how can we reduce risk?

analysis and design

- properly characterize tailings
- analyze drained, undrained, and liquefied conditions
- incorporate conservatism when analyzing undrained conditions
- assume tailings will fully liquefy

how can we reduce risk?

construction and operations

- dewater tailings
- utilize relatively flat downstream slope
- limit rate of rise
- densify impoundment dam
- reduce amount of impounded water
- maintain appropriate beach lengths
- keep phreatic surface low within dam

how can we reduce risk?

instrumentation monitoring and surveillance

- monitor and limit excess pore-water pressures
- regularly inspect dams for signs of distress
- recognize that instrumentation monitoring and site surveillance may not warn of brittle failure

thank you



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