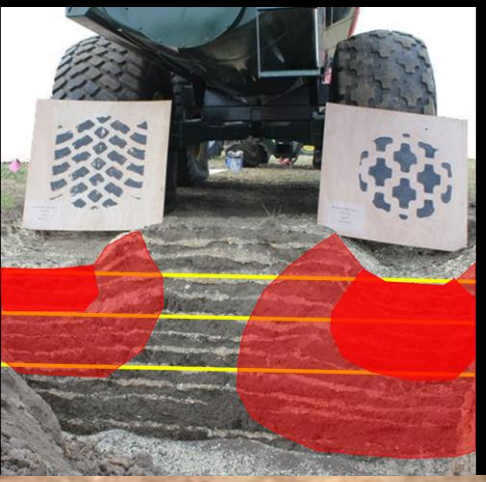
Physics of Soil Compaction and its Remediation



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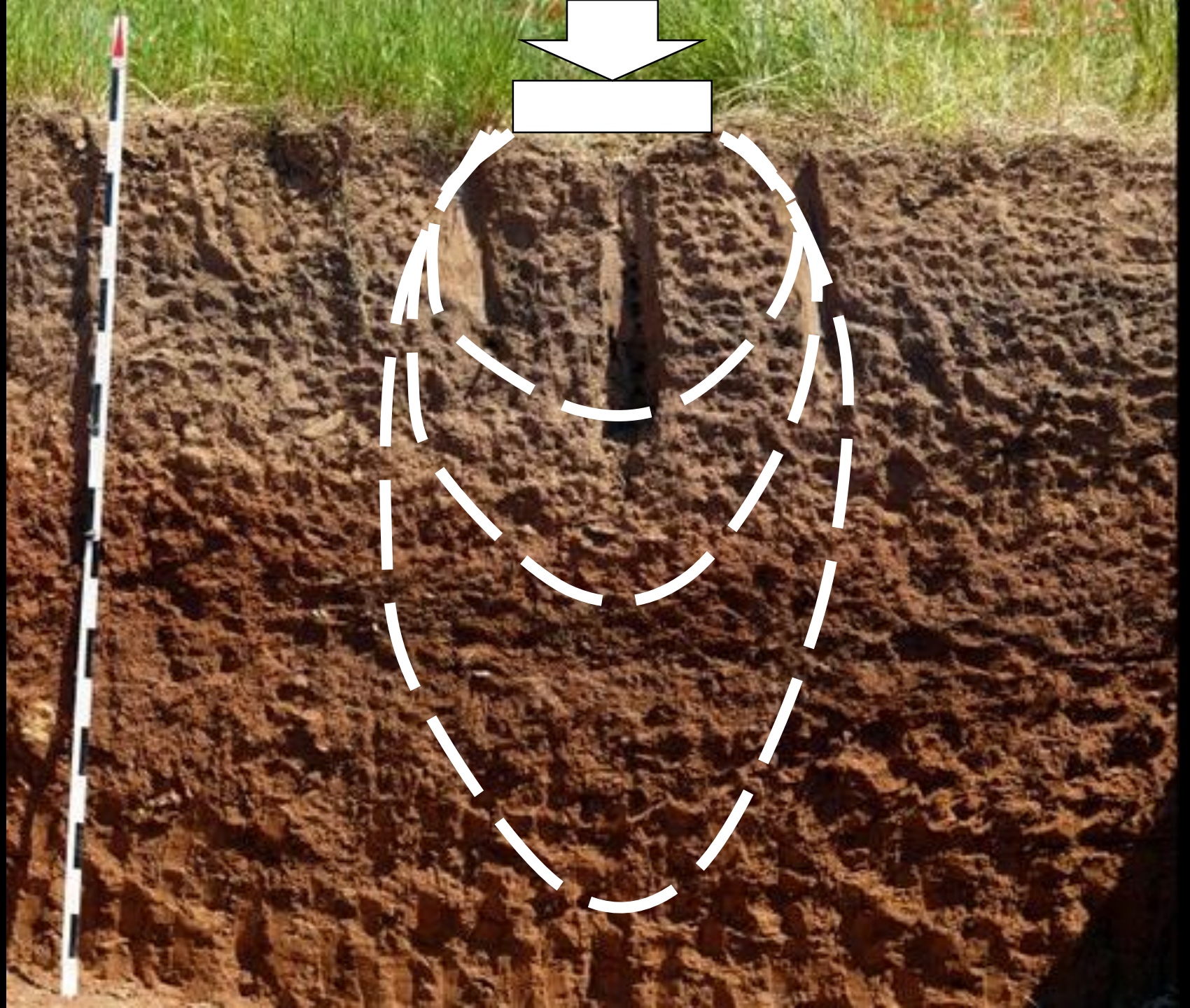
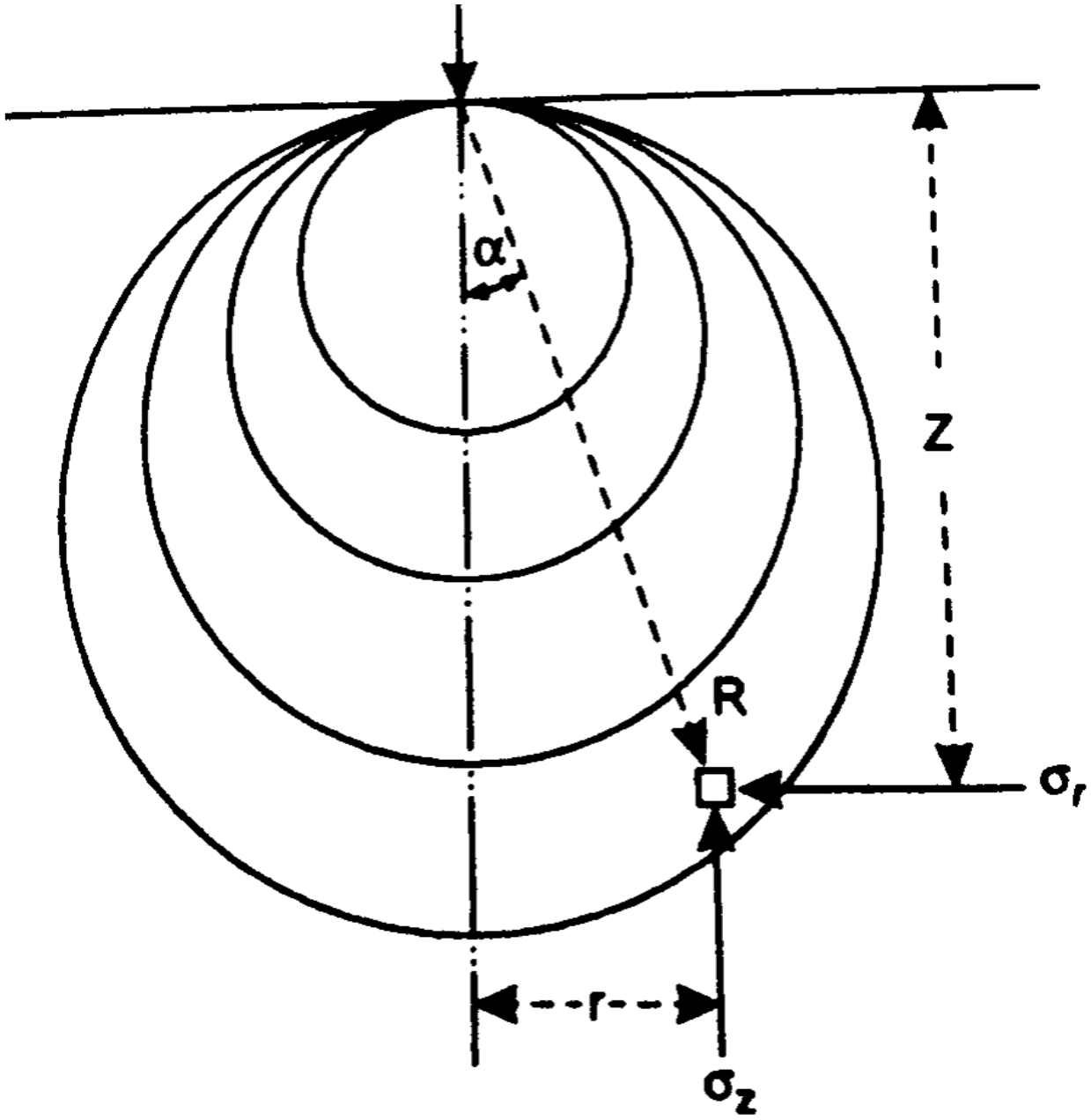
Compaction… How does it work?

Stress, Stain, and Strength



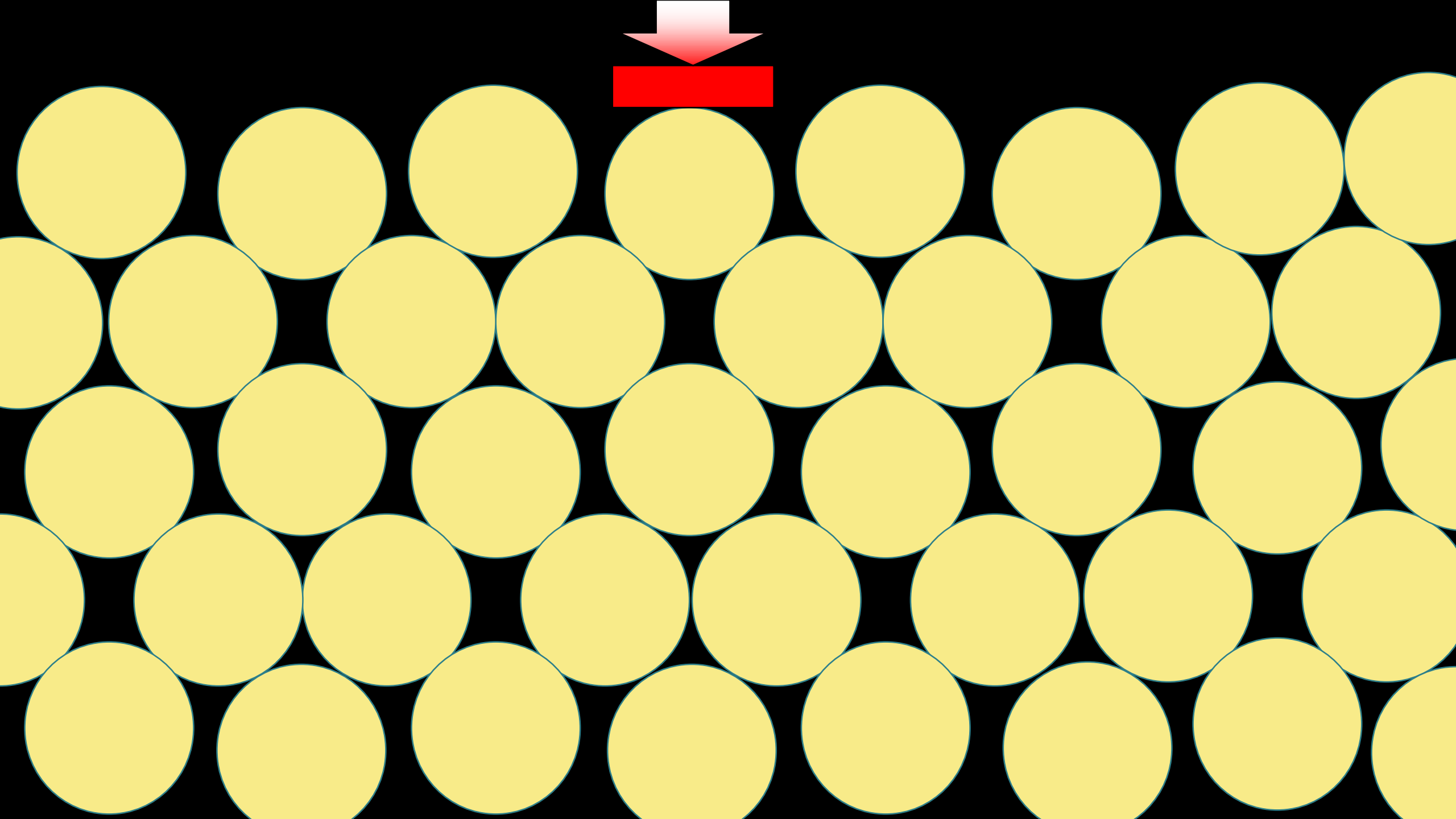
Distribution of vertical shear stress under a concentrated vertical load

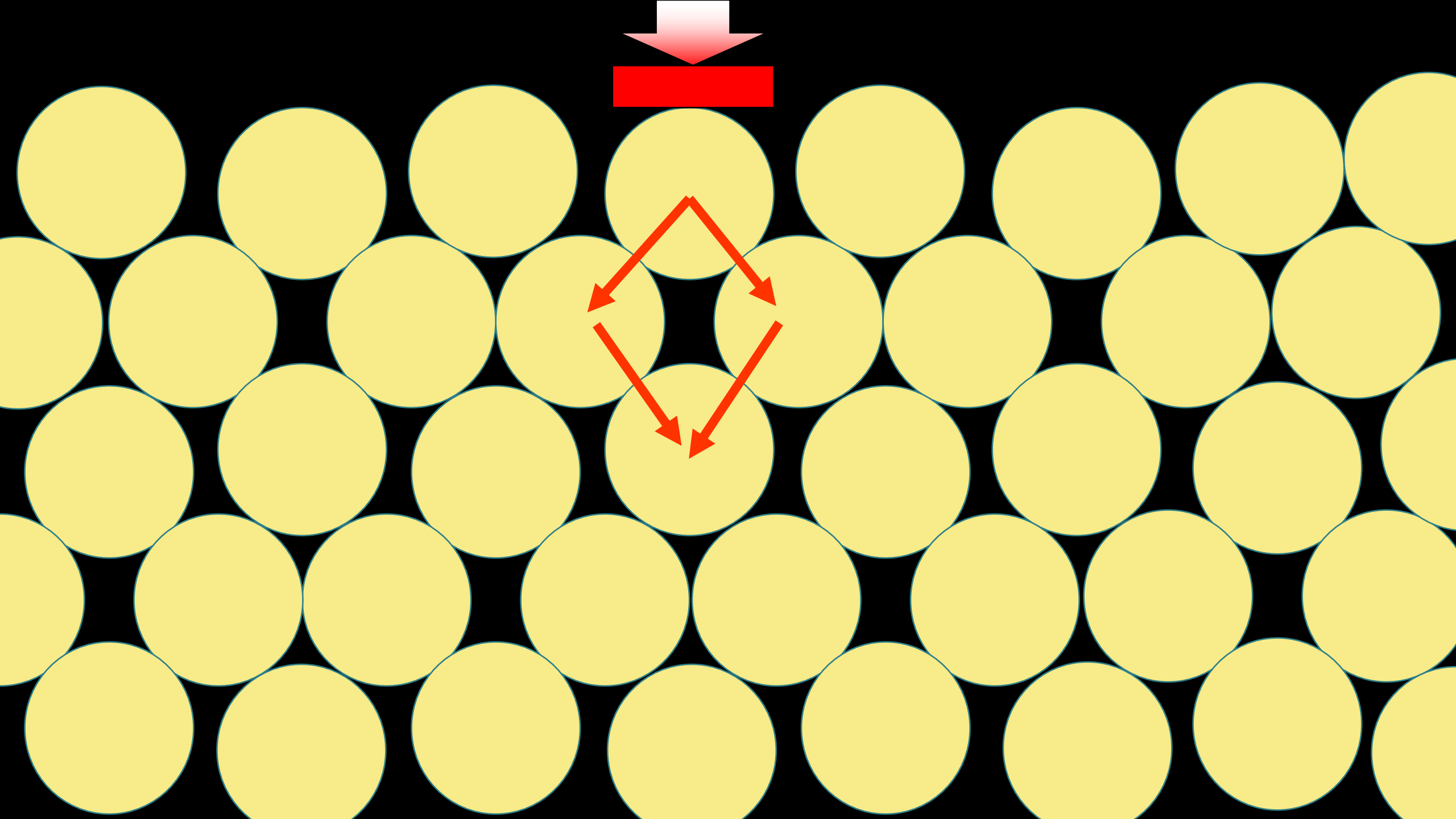


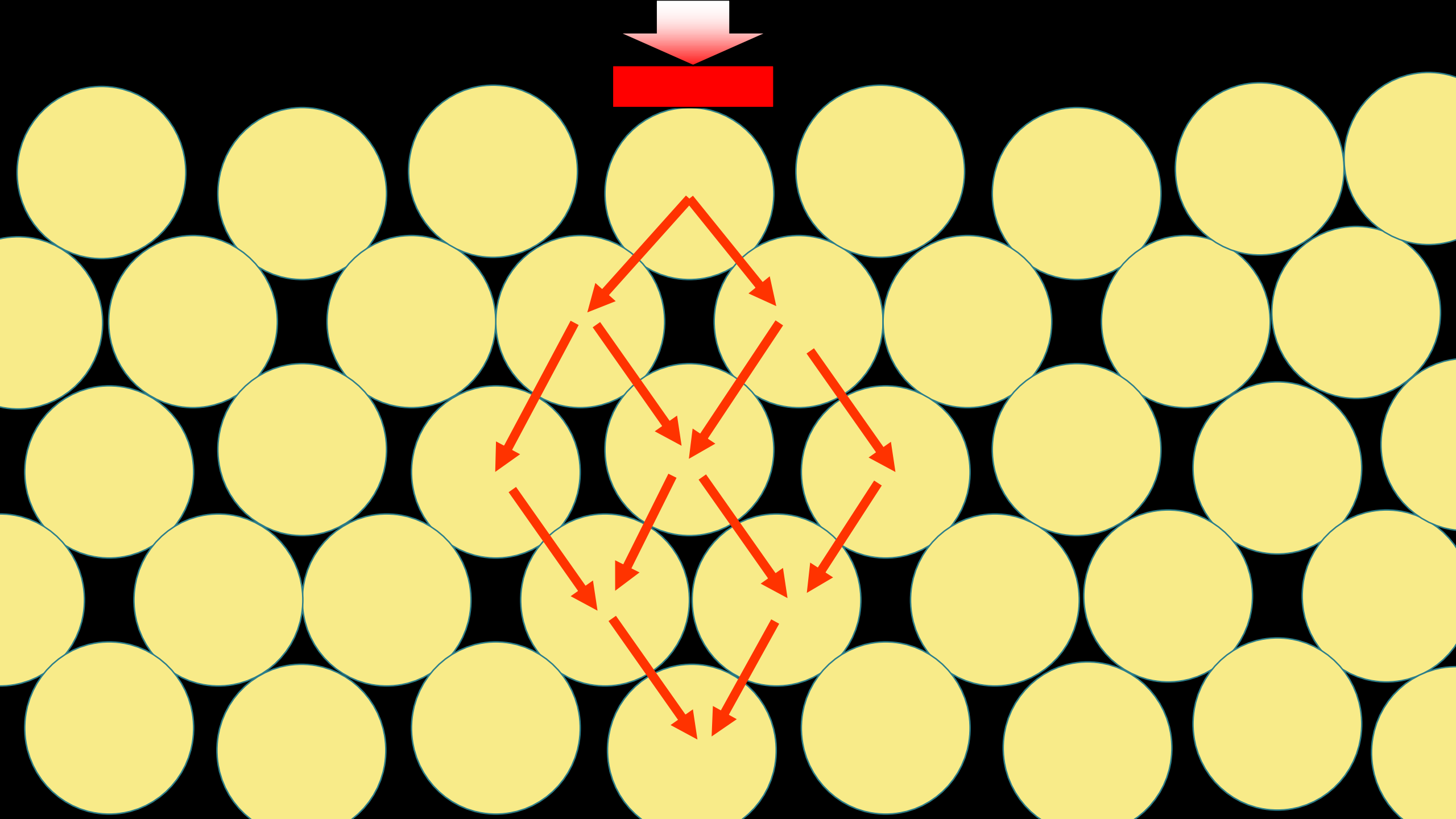
Boussinesq theory

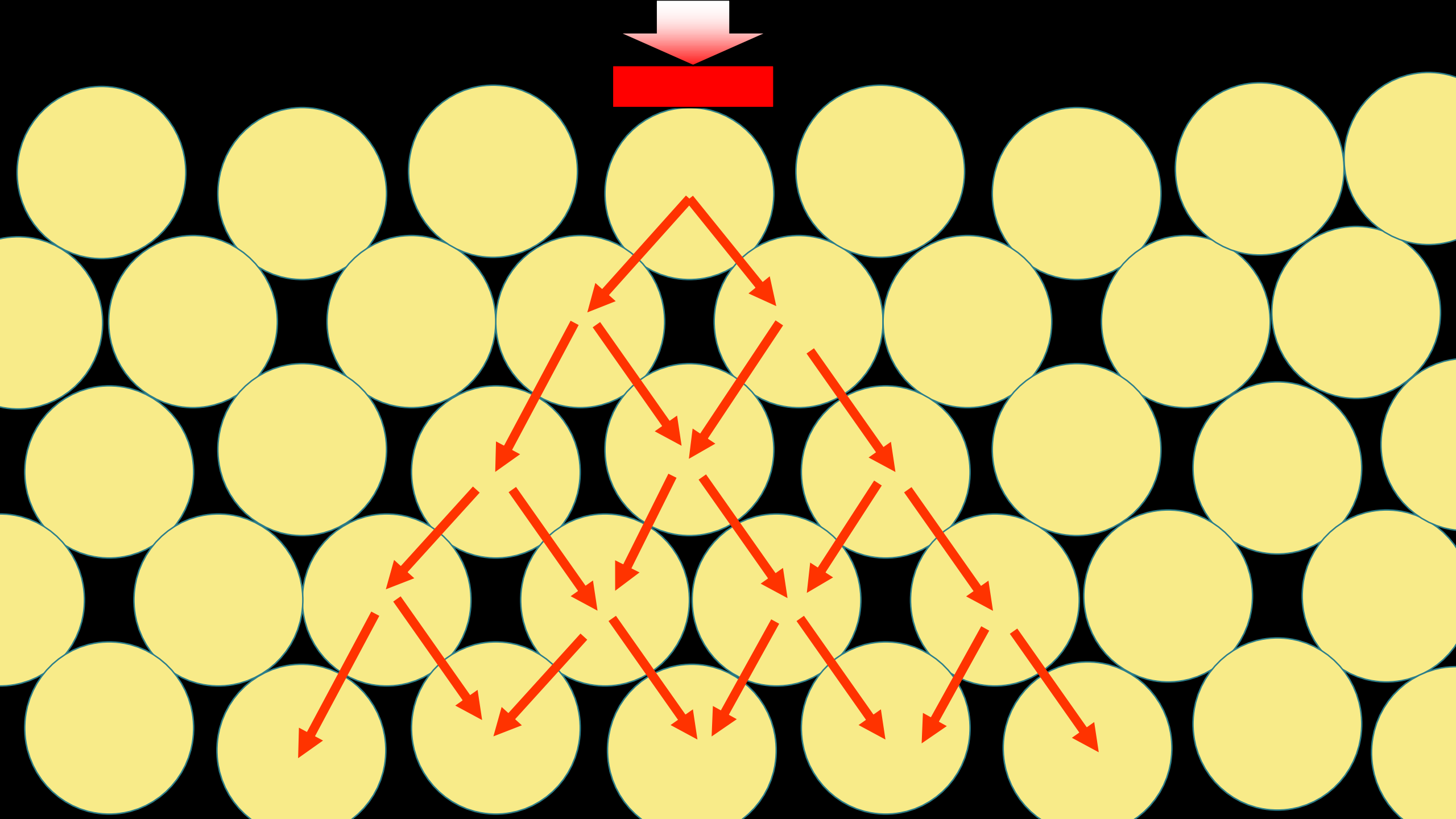
$$\sigma_z = L * \frac{3}{2\pi} * \frac{z^3}{(r^2 - z^2)^{5/2}}$$

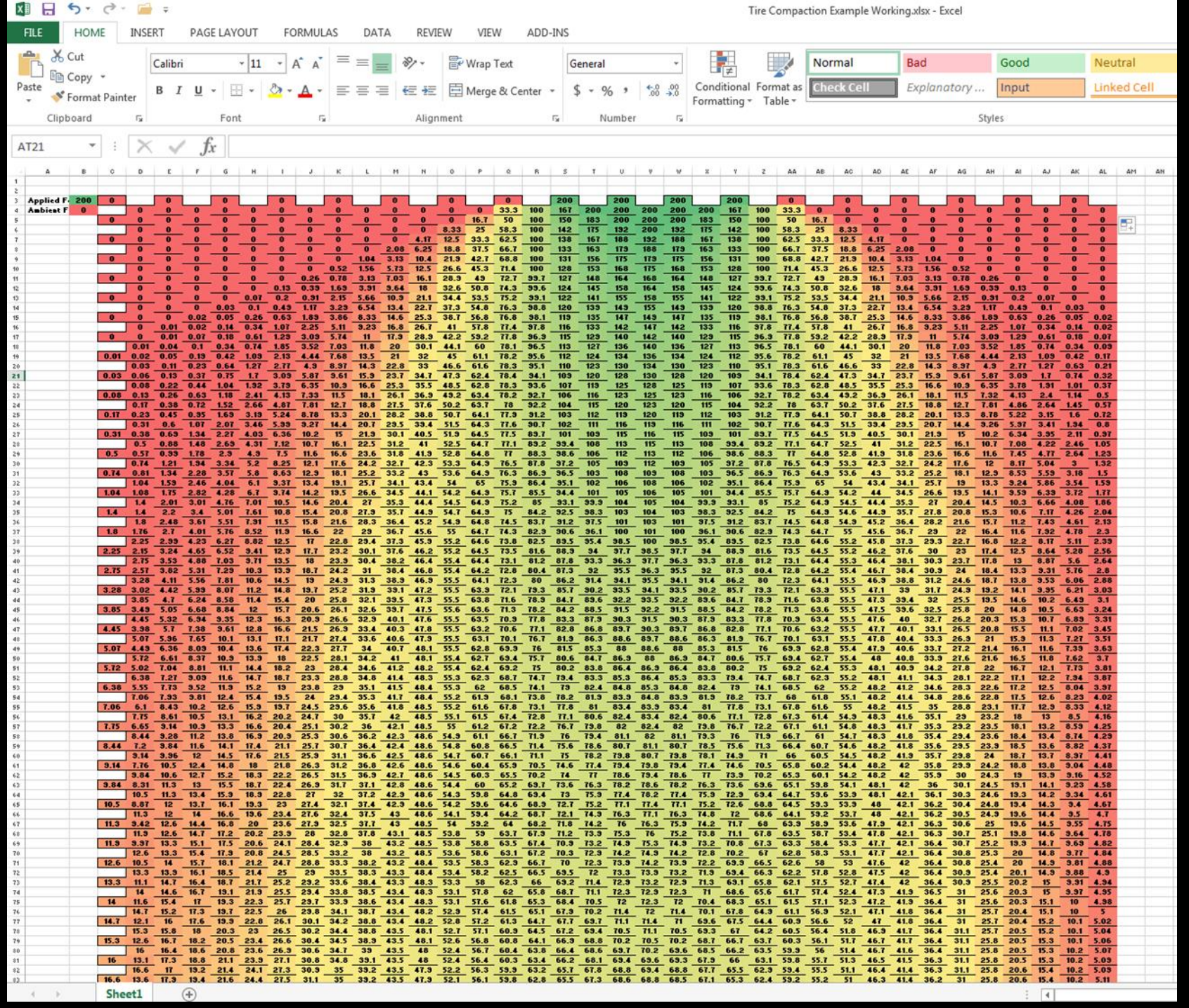
Nesting of Tangent Circles










Tire Compaction Example Working.xlsx - Excel
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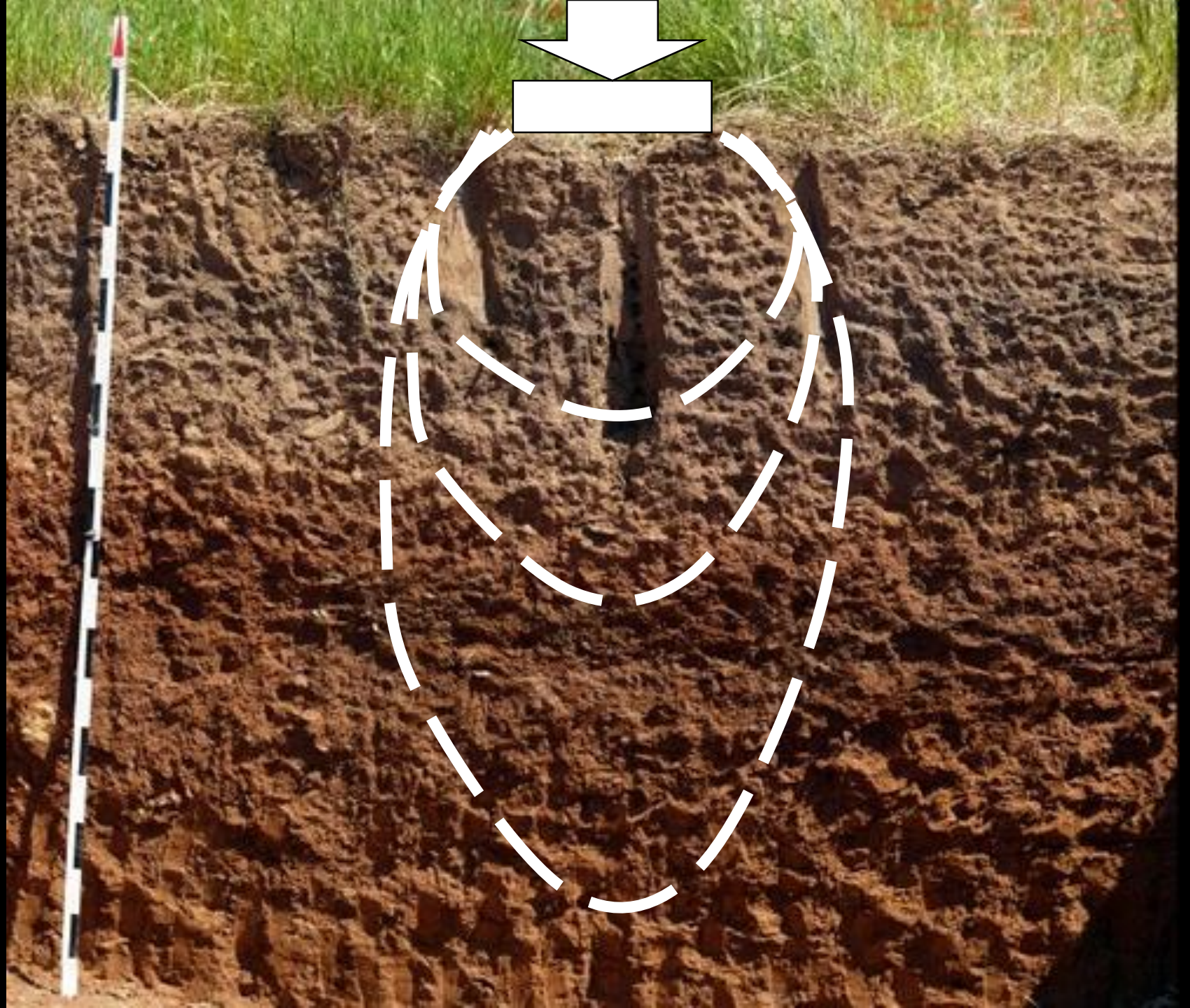
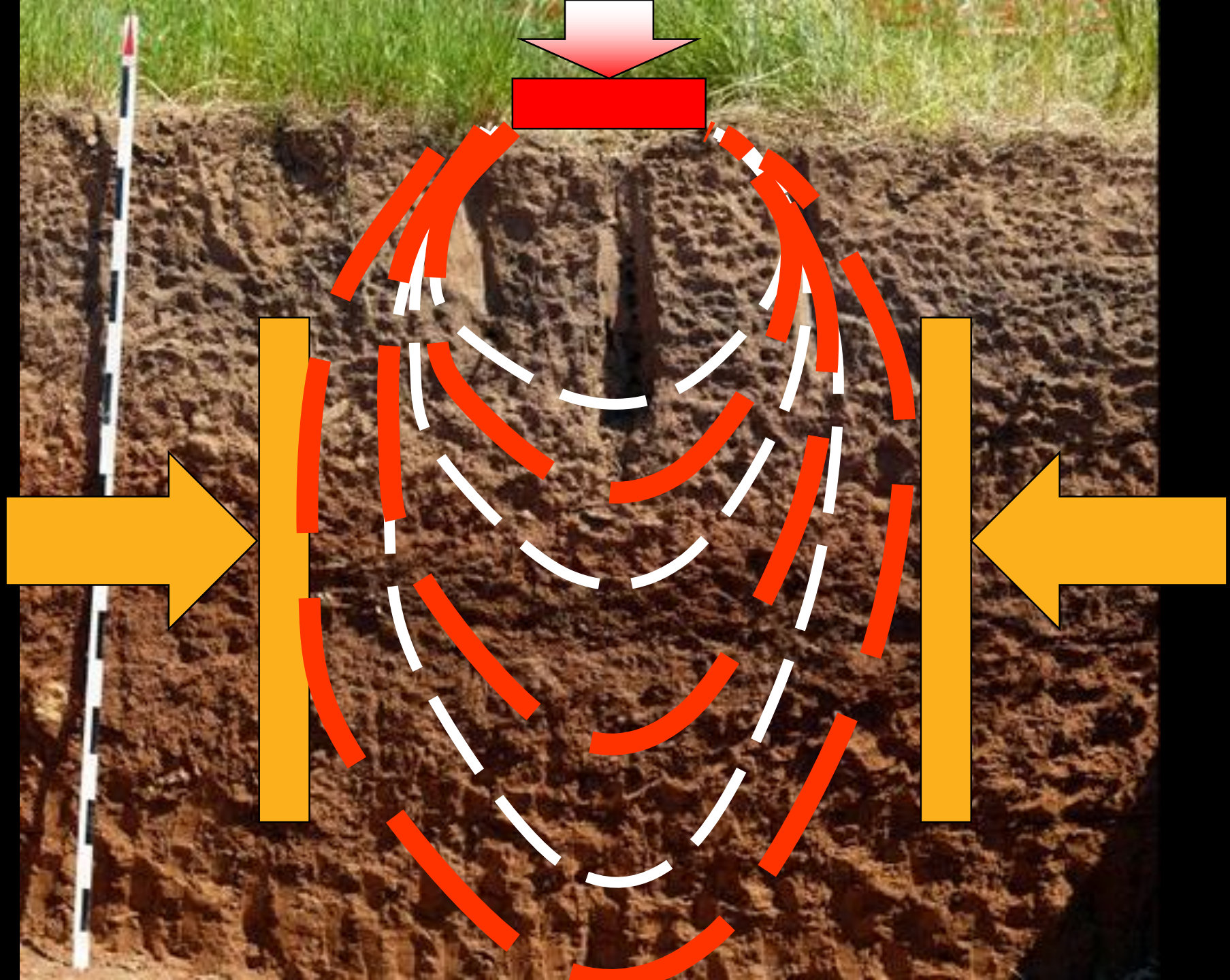
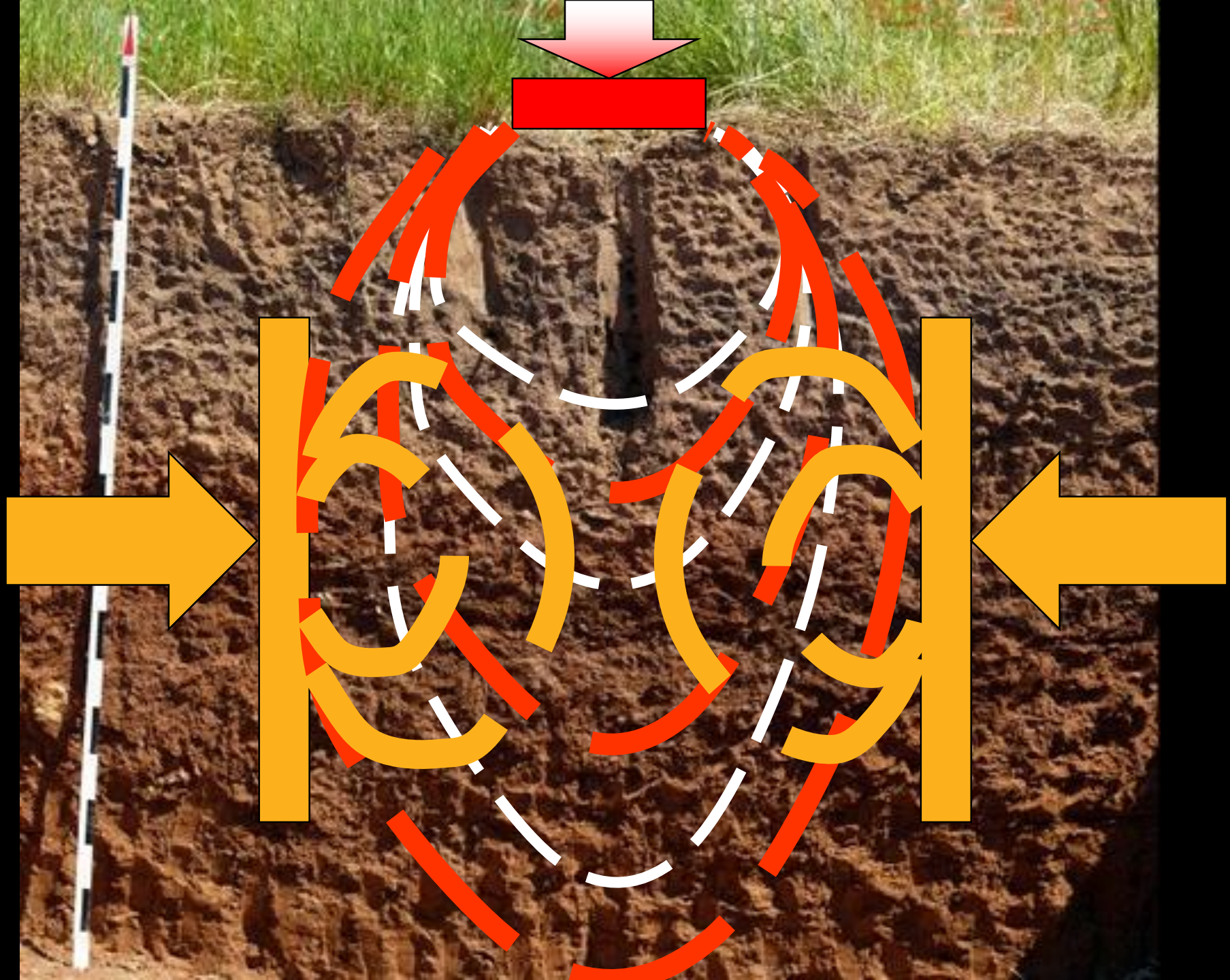
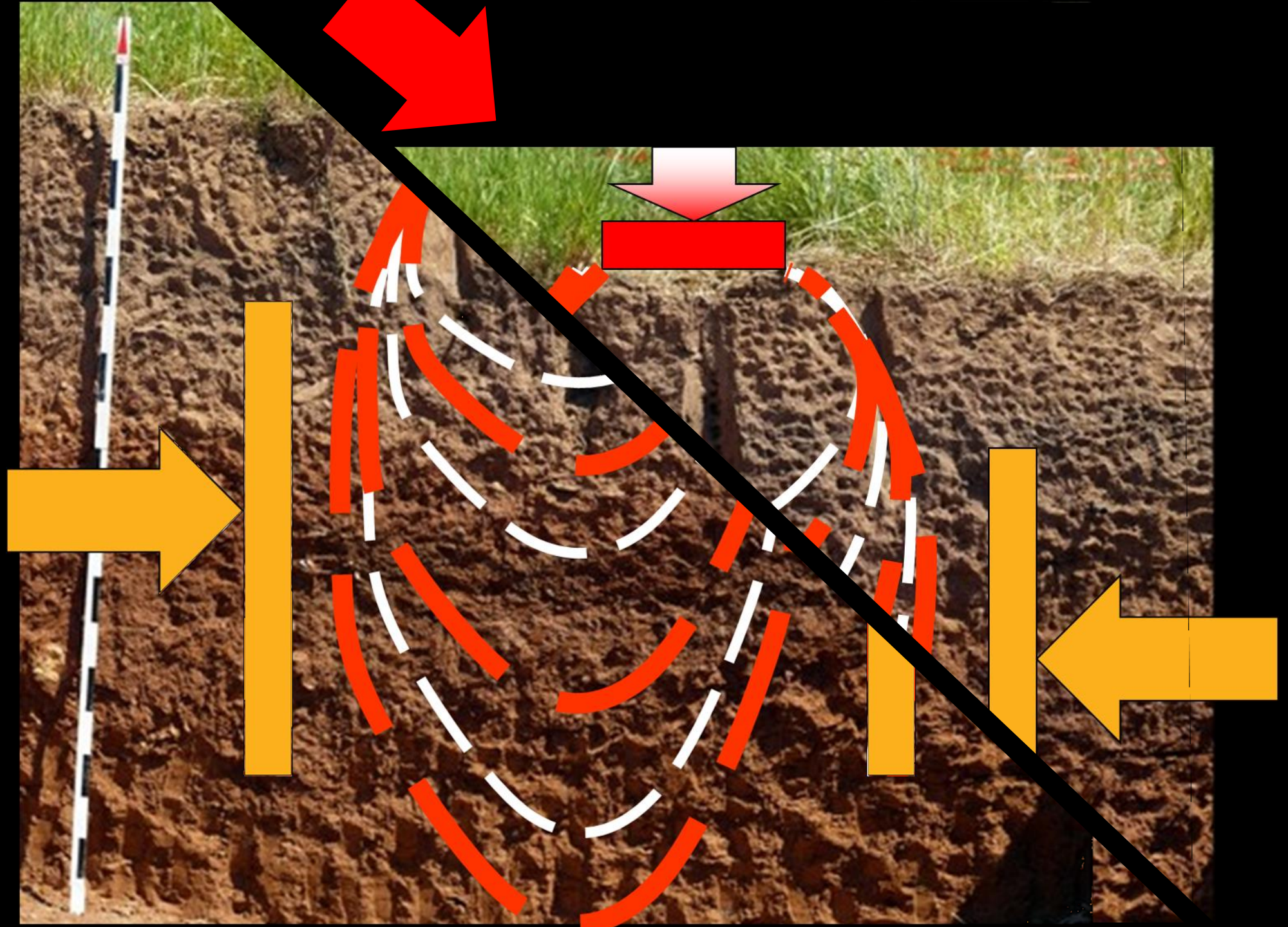
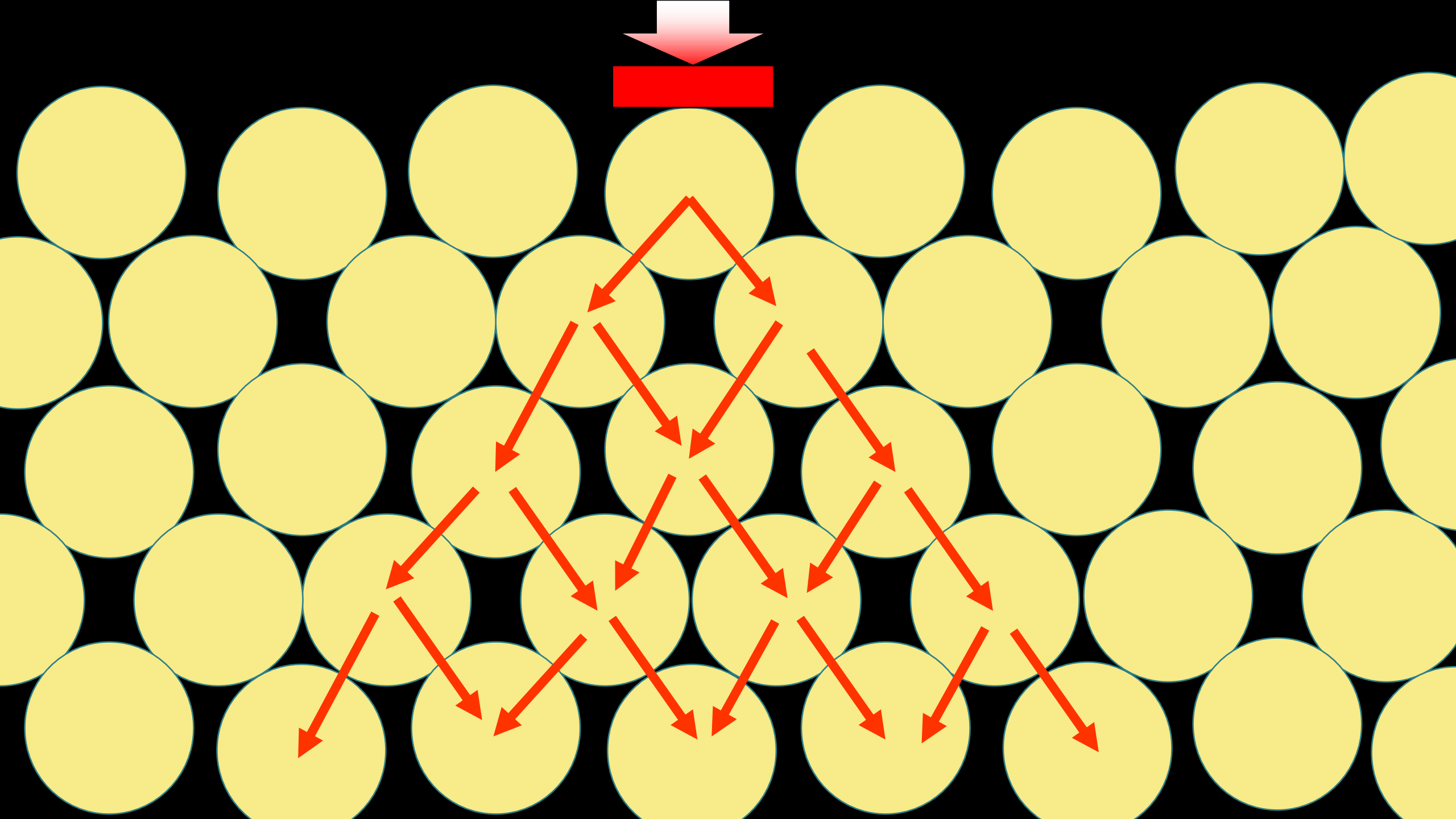
PAGE LAYOUT
FORMULAS
DATA
REVIEW
VIEW
ADD-INS
Cut
Copy
Format Painter
Paste
Calibri
11
Wrap Text
Merge & Center
General
Conditional Formatting
Format as Table
Normal
Bad
Good
Neutral
Check Cell
Explanatory ...
Input
Linked Cell
Clipboard
Font
Alignment
Number
Styles
AT21
Applied F
Ambient F
Sheet1

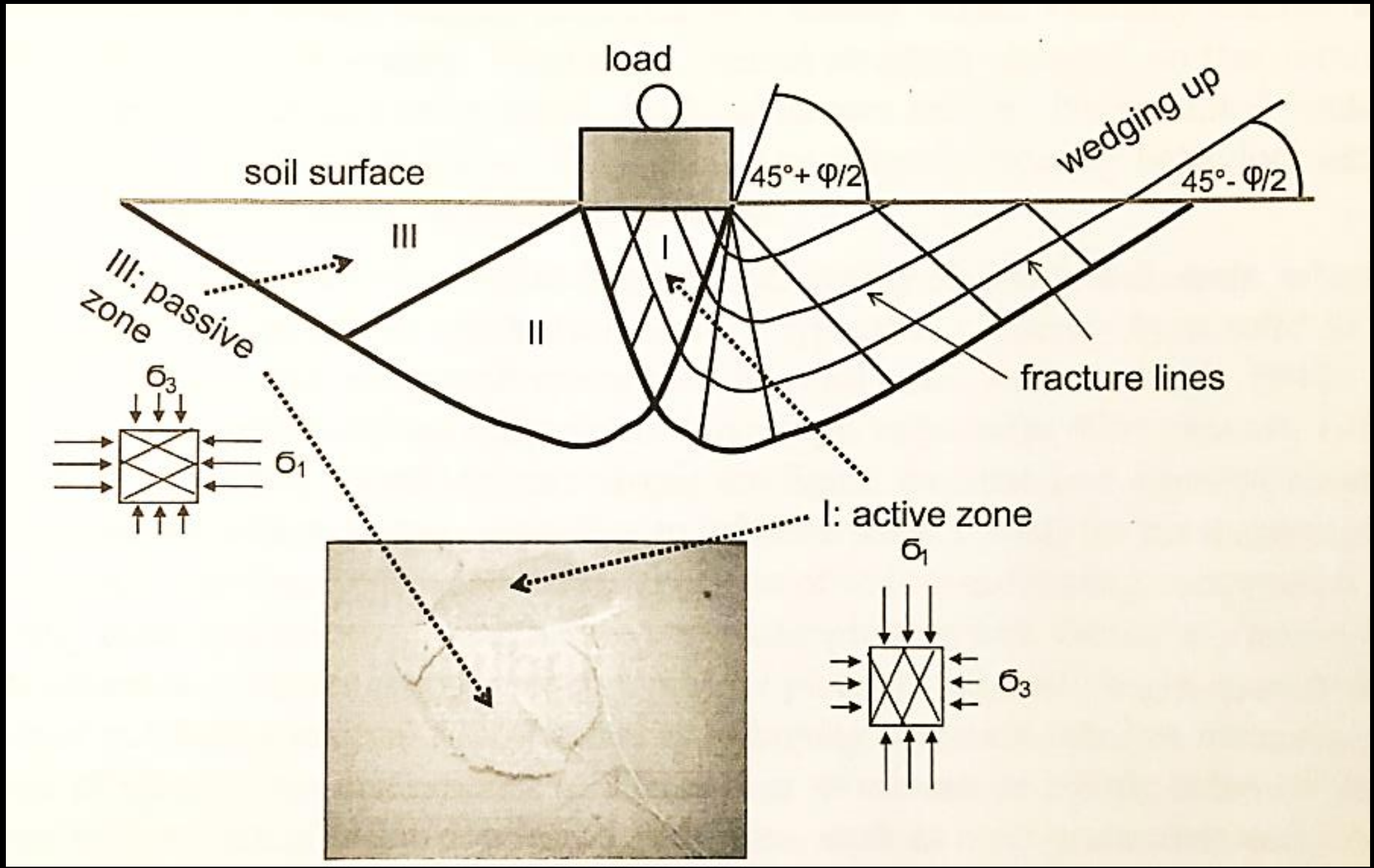


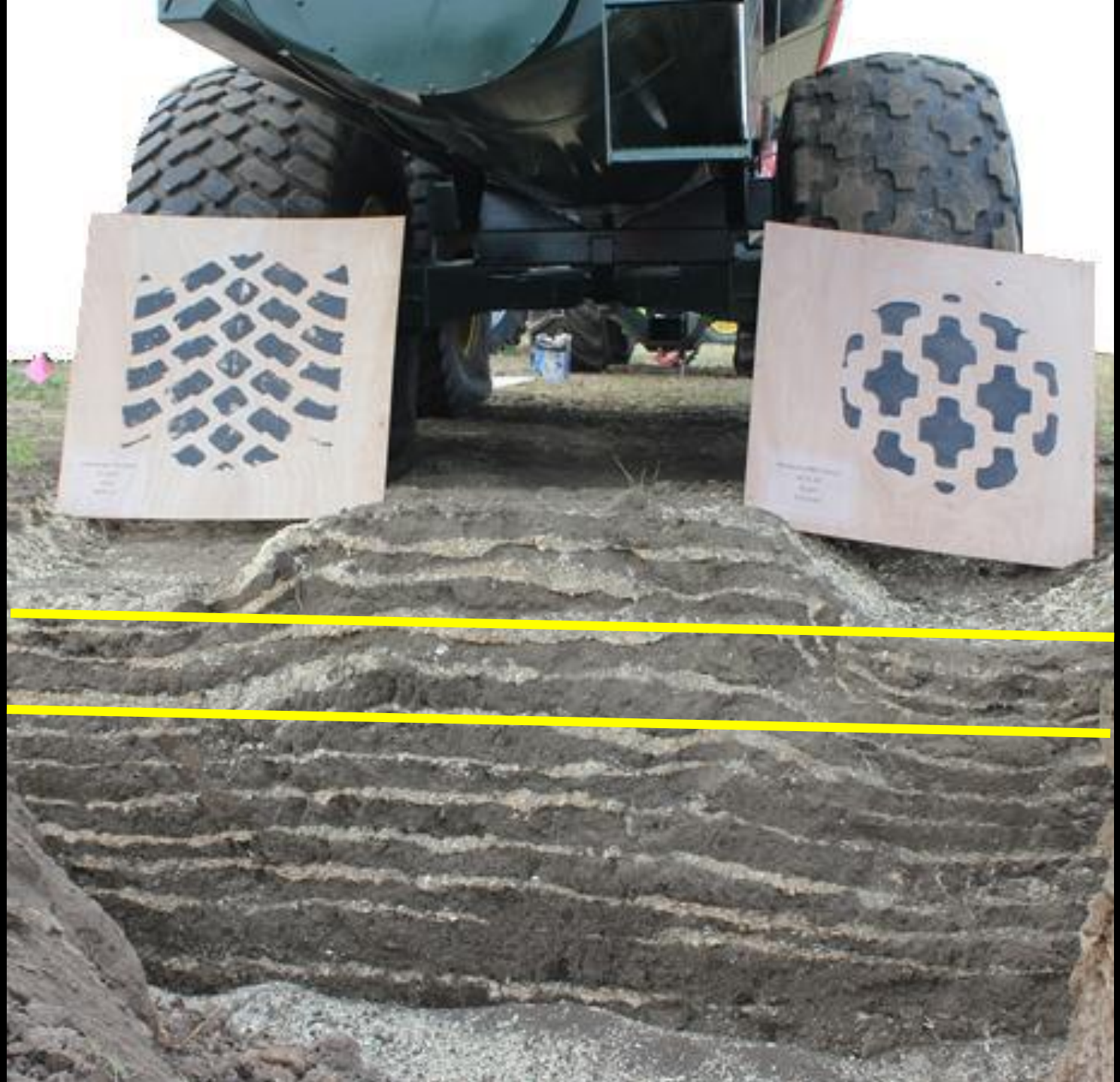


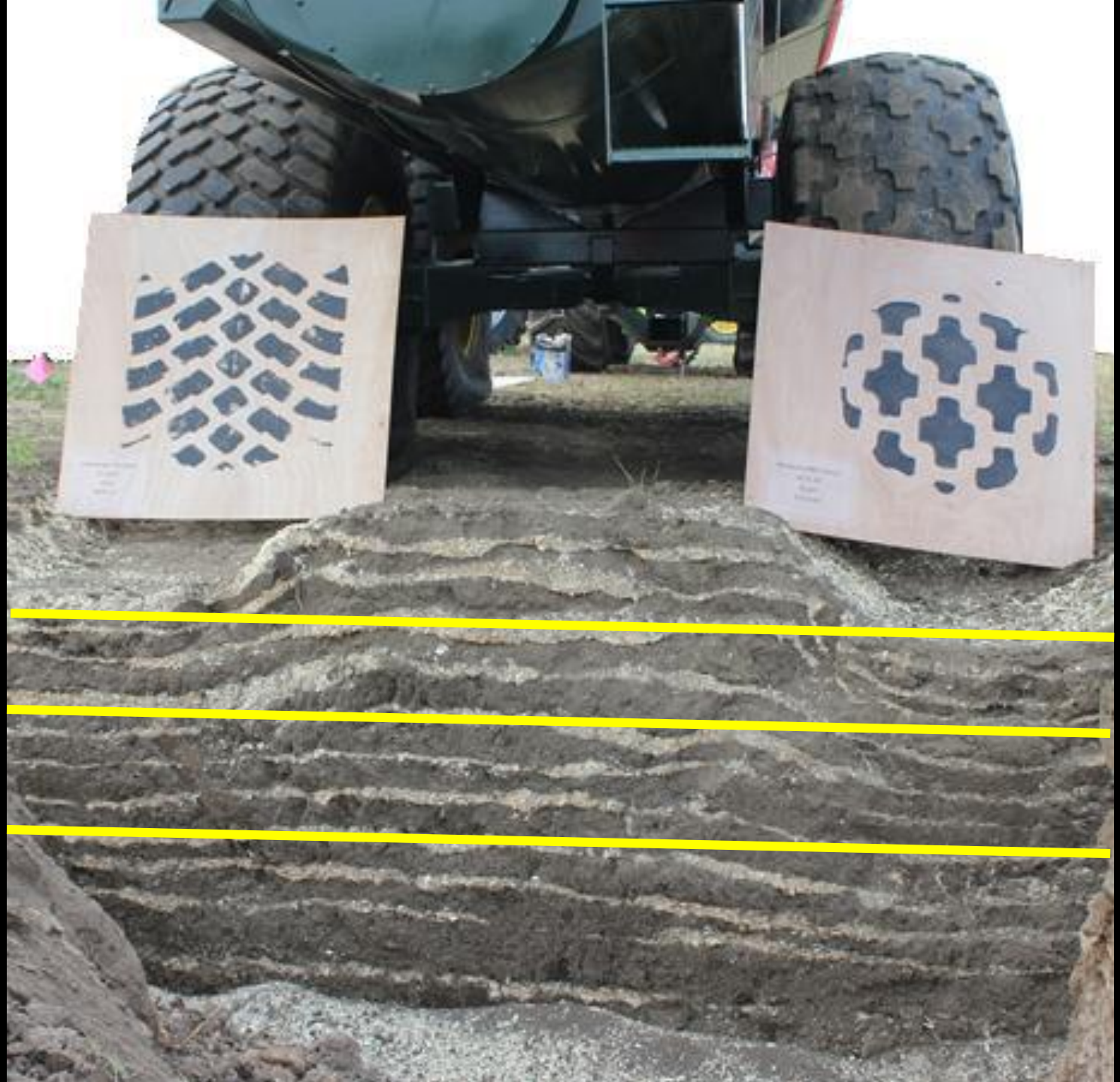


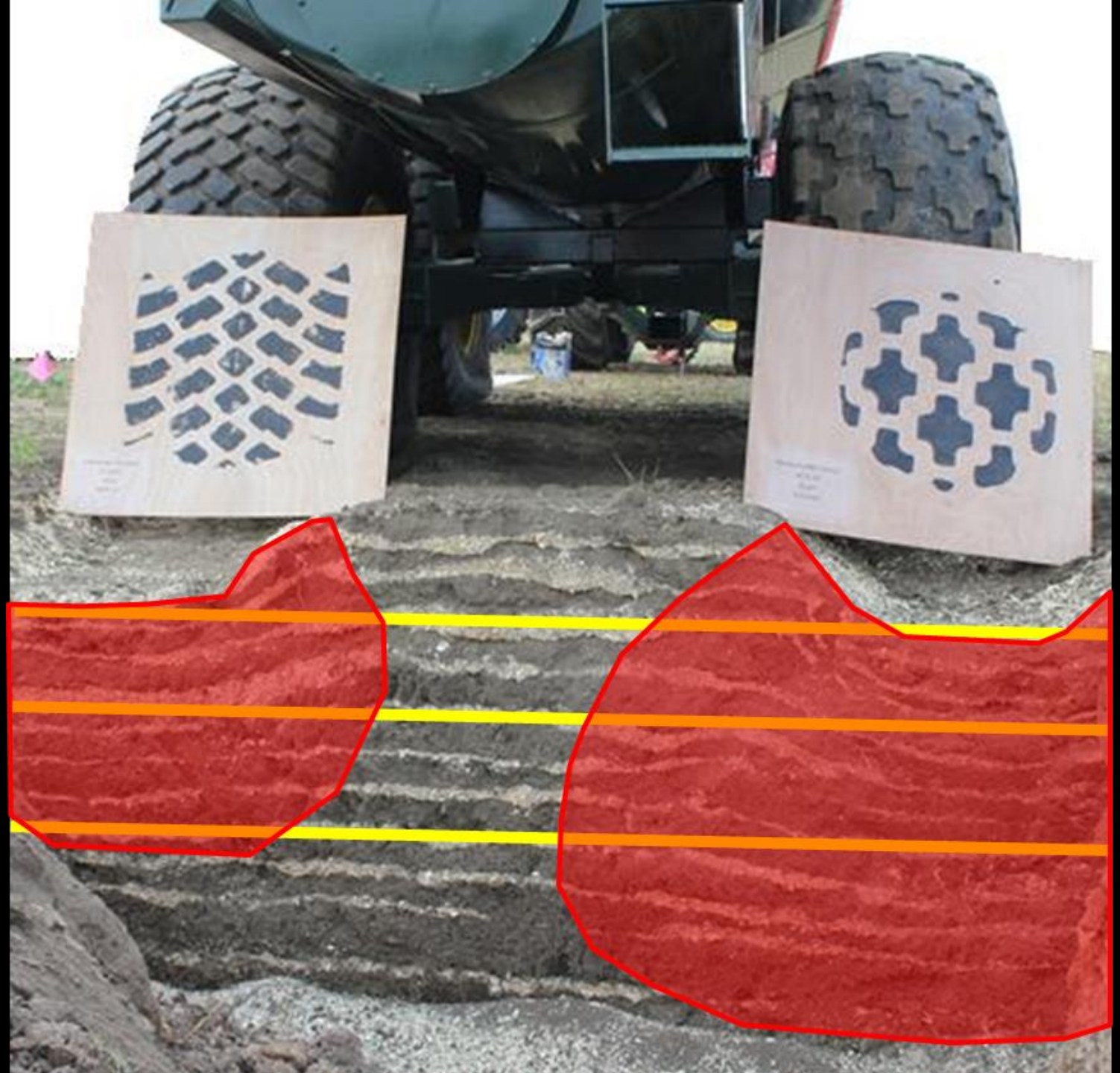


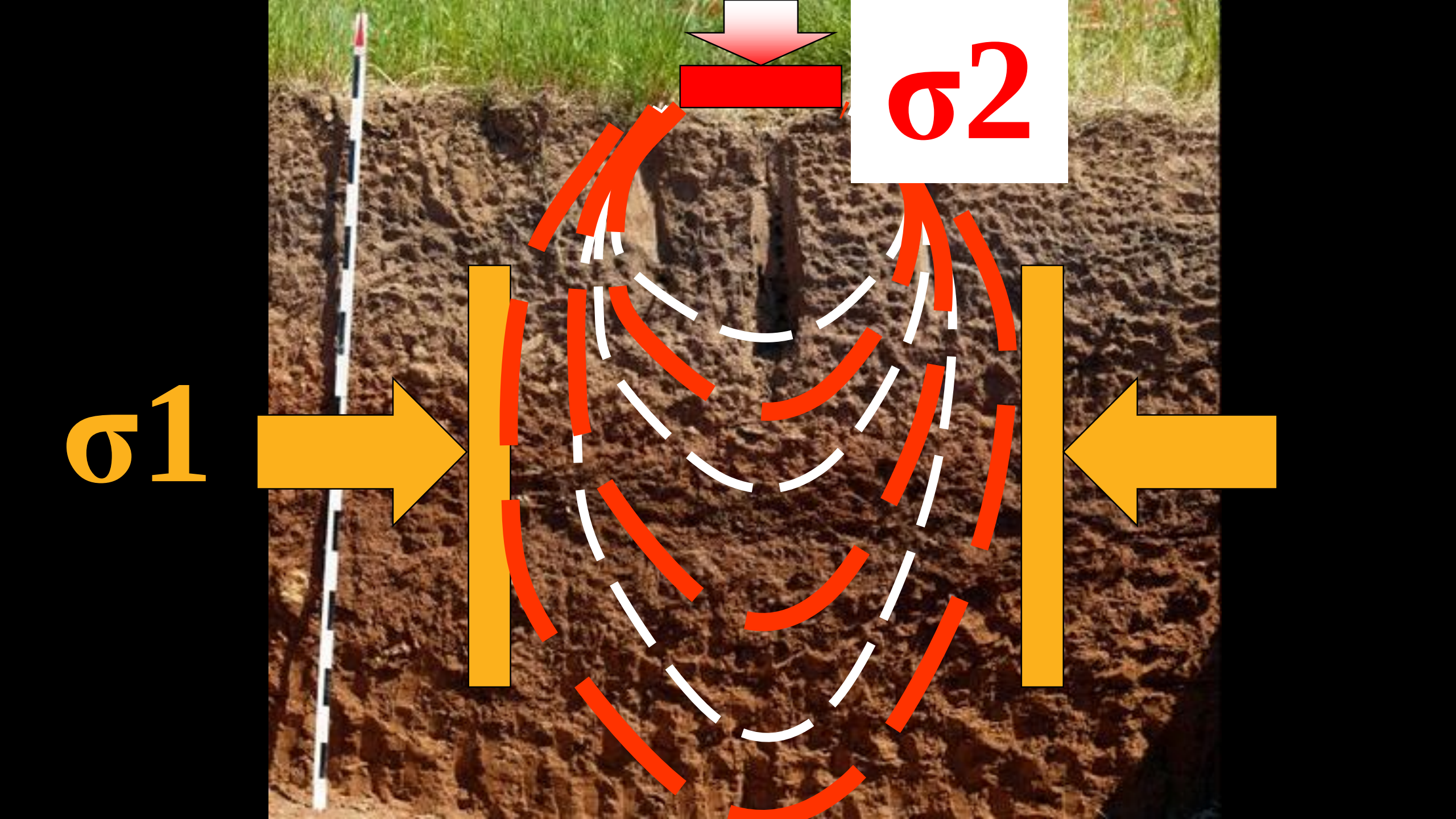


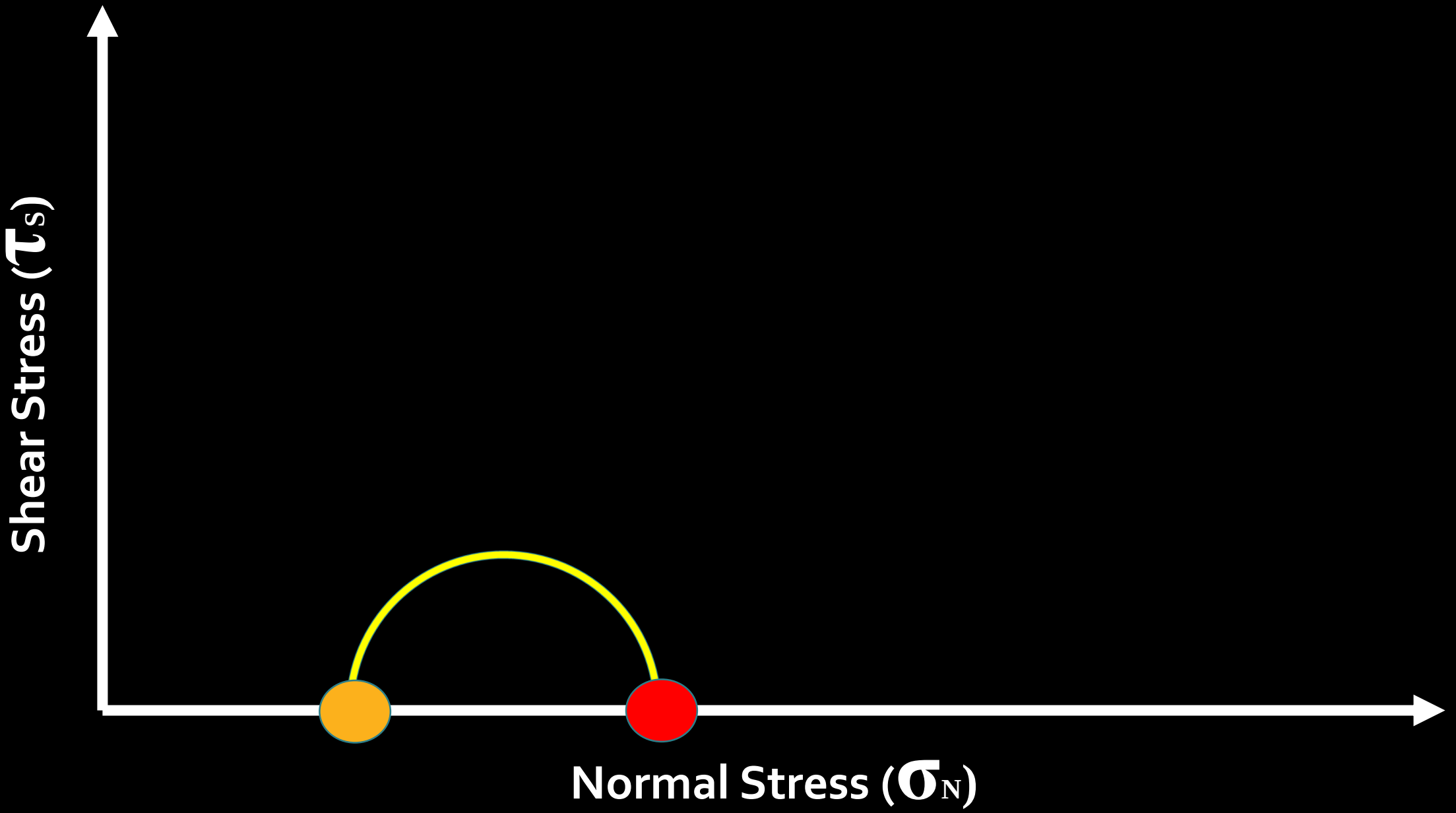

load
soil surface
45°+ φ/2
wedging up
45°- φ/2
III
I
II
III: passive zone
fracture lines
σ3
σ1
I: active zone
σ1
σ3



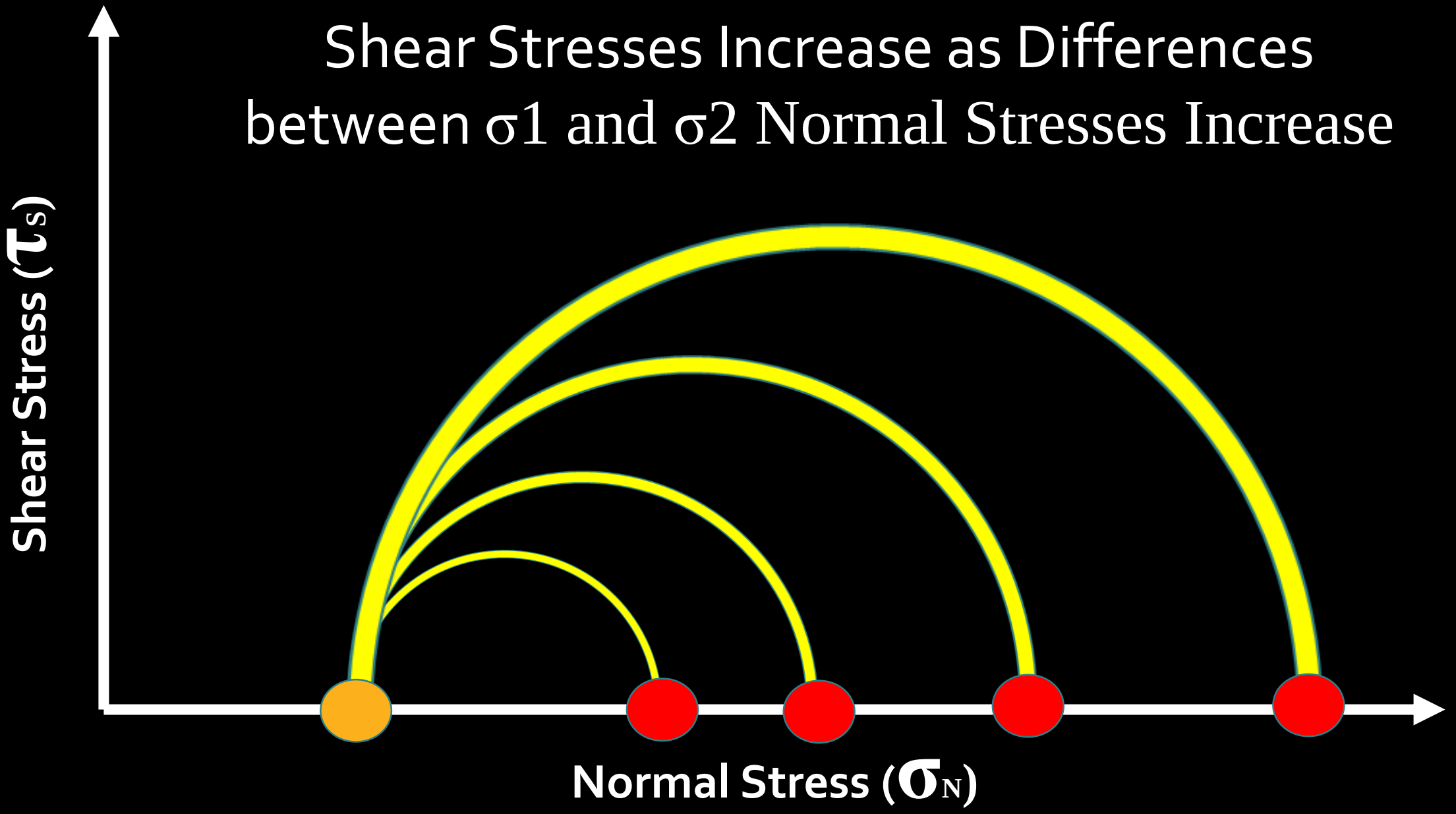


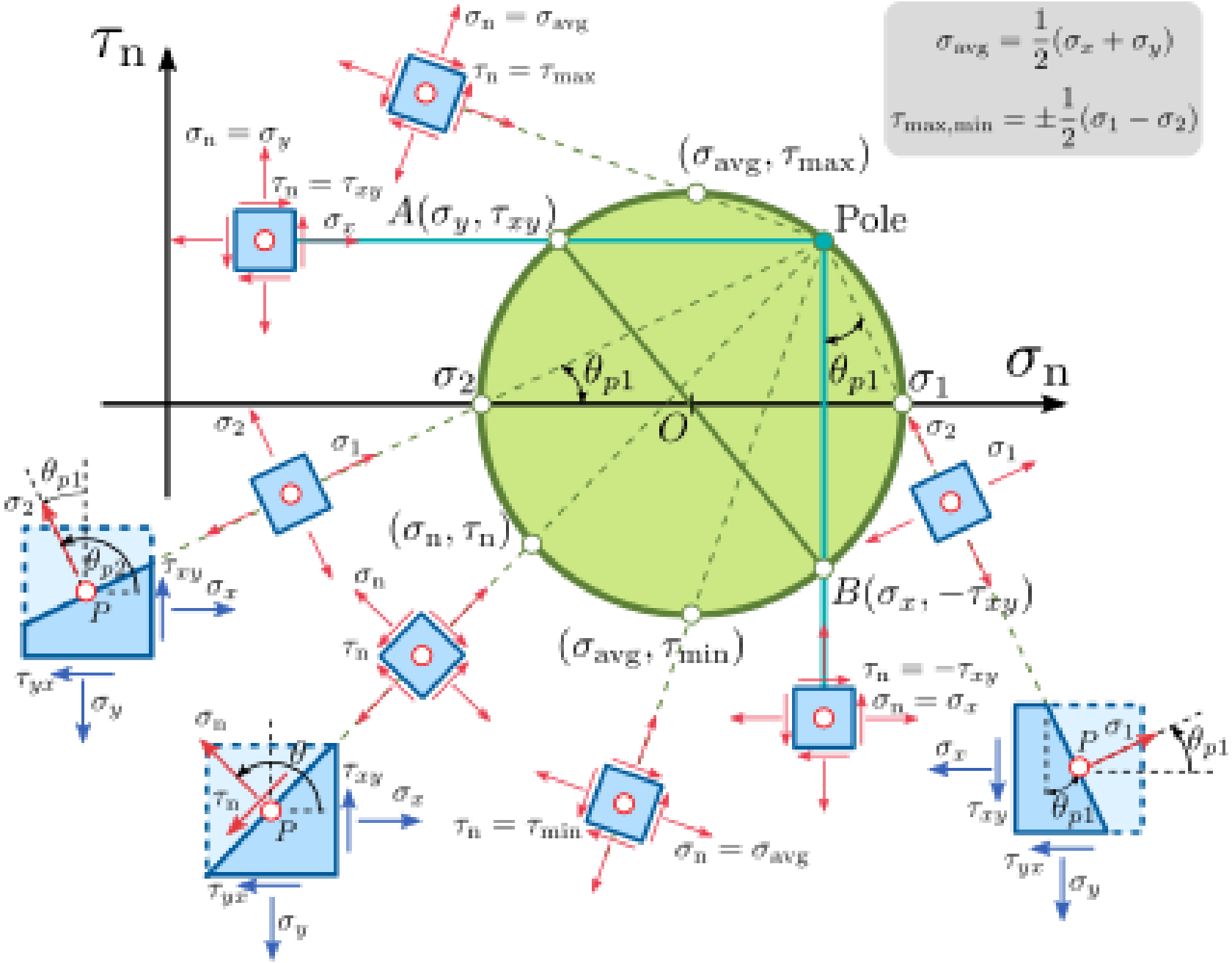


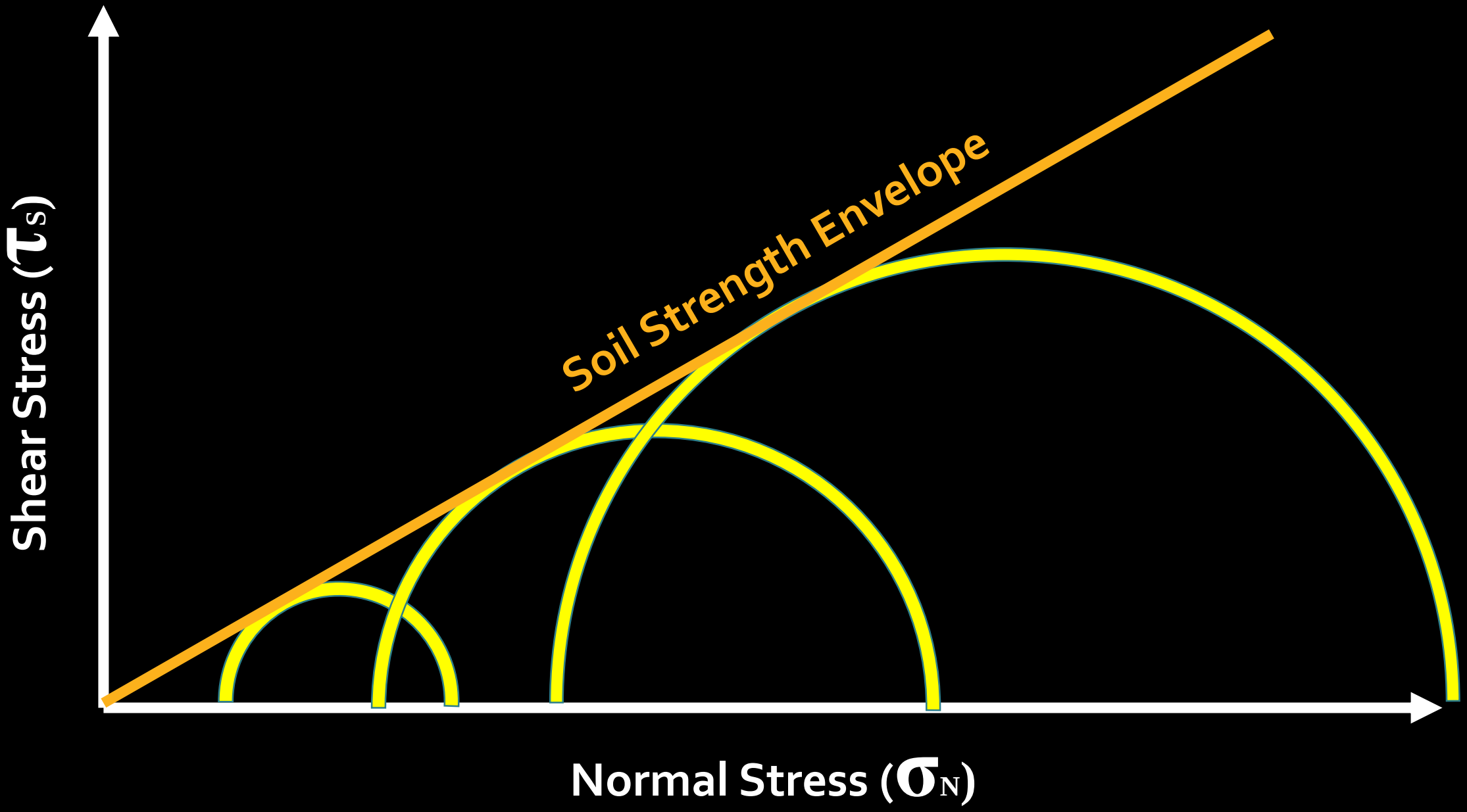

σ2
σ1


Shear Stress (τ_S)
Normal Stress (σ_N)

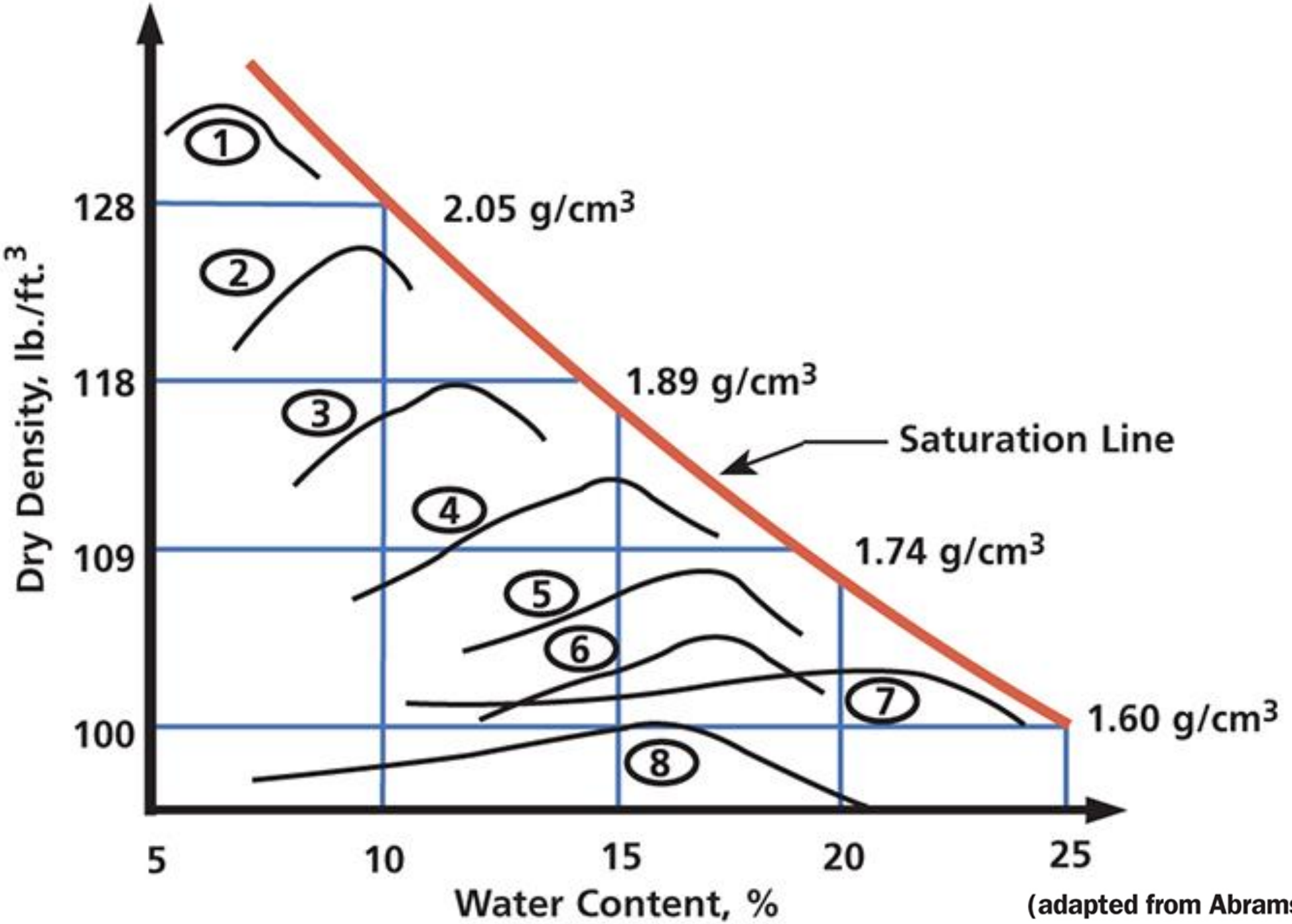
Shear Stresses Increase as Differences between σ1 and σ2 Normal Stresses Increase



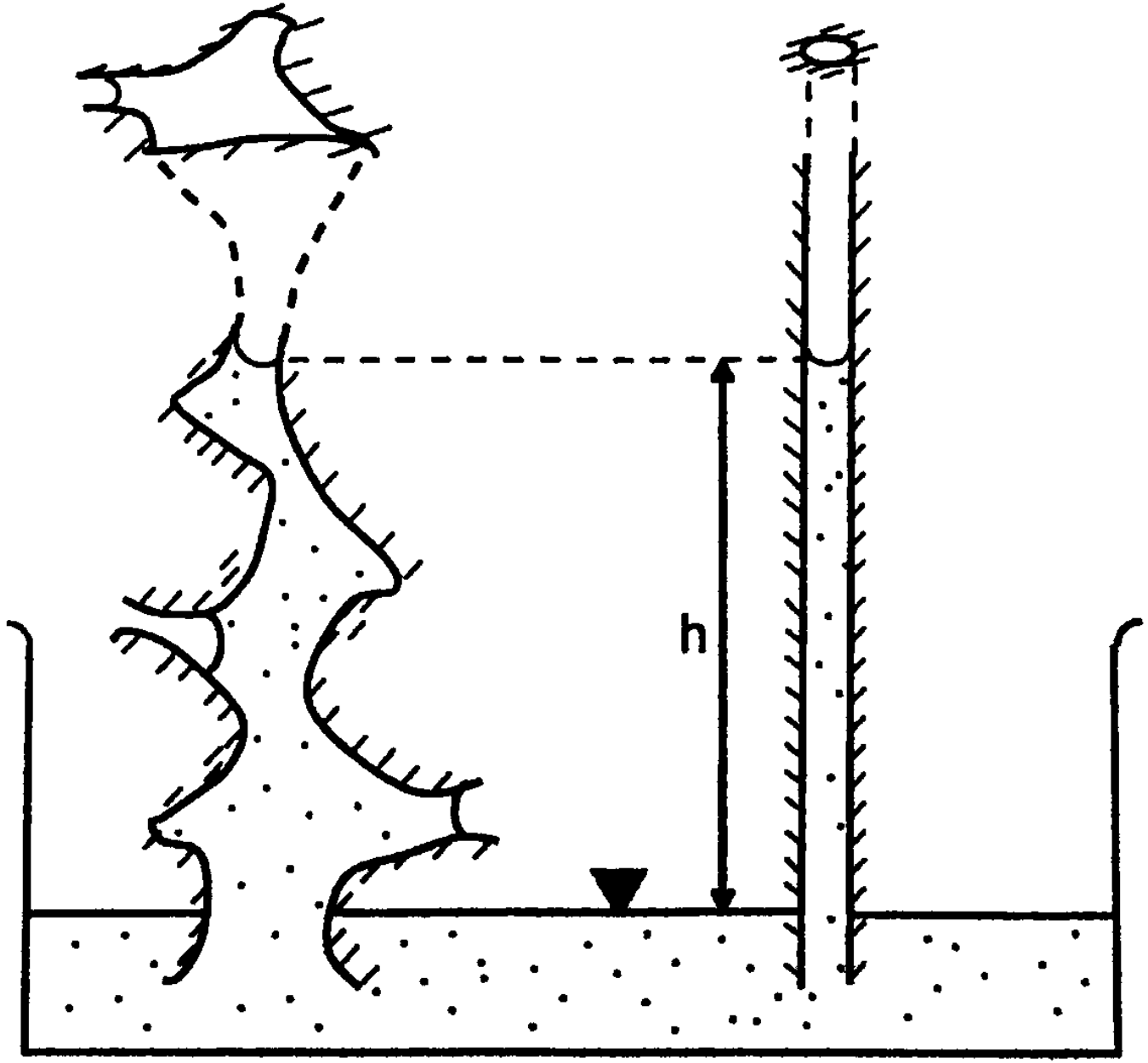

τ_n
σ_n
$\sigma_{avg} = \frac{1}{2}(\sigma_x + \sigma_y)$
$\tau_{max,min} = \pm\frac{1}{2}(\sigma_1 - \sigma_2)$
$\sigma_n = \sigma_{avg}$
$\tau_n = \tau_{max}$
$\sigma_n = \sigma_y$
$\tau_n = \tau_{xy}$
σ_x
$(\sigma_{avg}, \tau_{max})$
$A(\sigma_y, \tau_{xy})$
Pole
σ_2
θ_{p1}
O
σ_1
(σ_n, τ_n)
$B(\sigma_x, -\tau_{xy})$
$(\sigma_{avg}, \tau_{min})$
$\tau_n = -\tau_{xy}$
$\sigma_n = \sigma_x$
$\tau_n = \tau_{min}$
$\sigma_n = \sigma_{avg}$
τ_{xy}
τ_{yx}
σ_y
P


Soil Strength Envelope
Shear Stress (τ_S)
Normal Stress (σ_N)

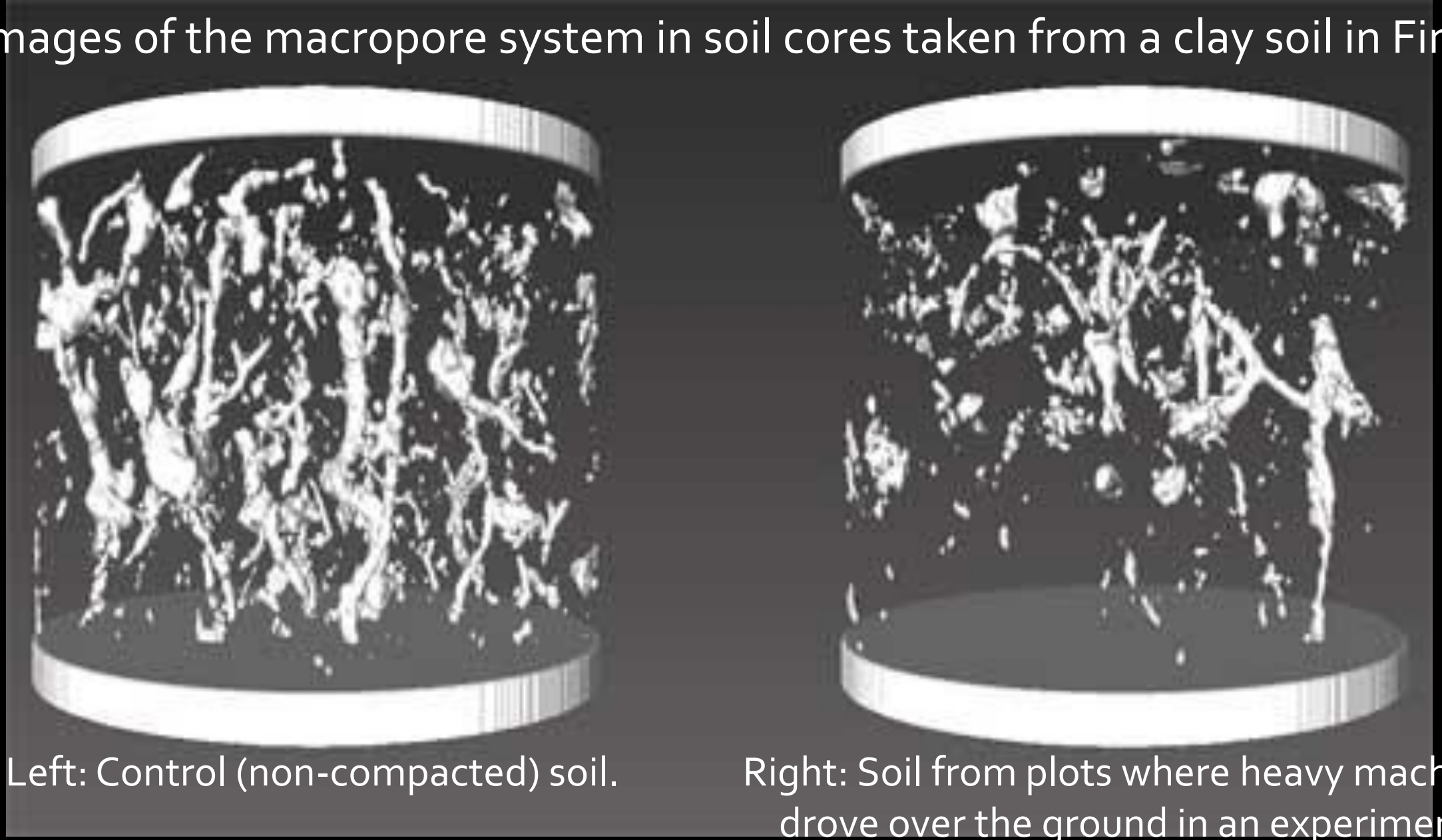

Taken by Abbey Wick



(adapted from Abramson et al., 1995)


h

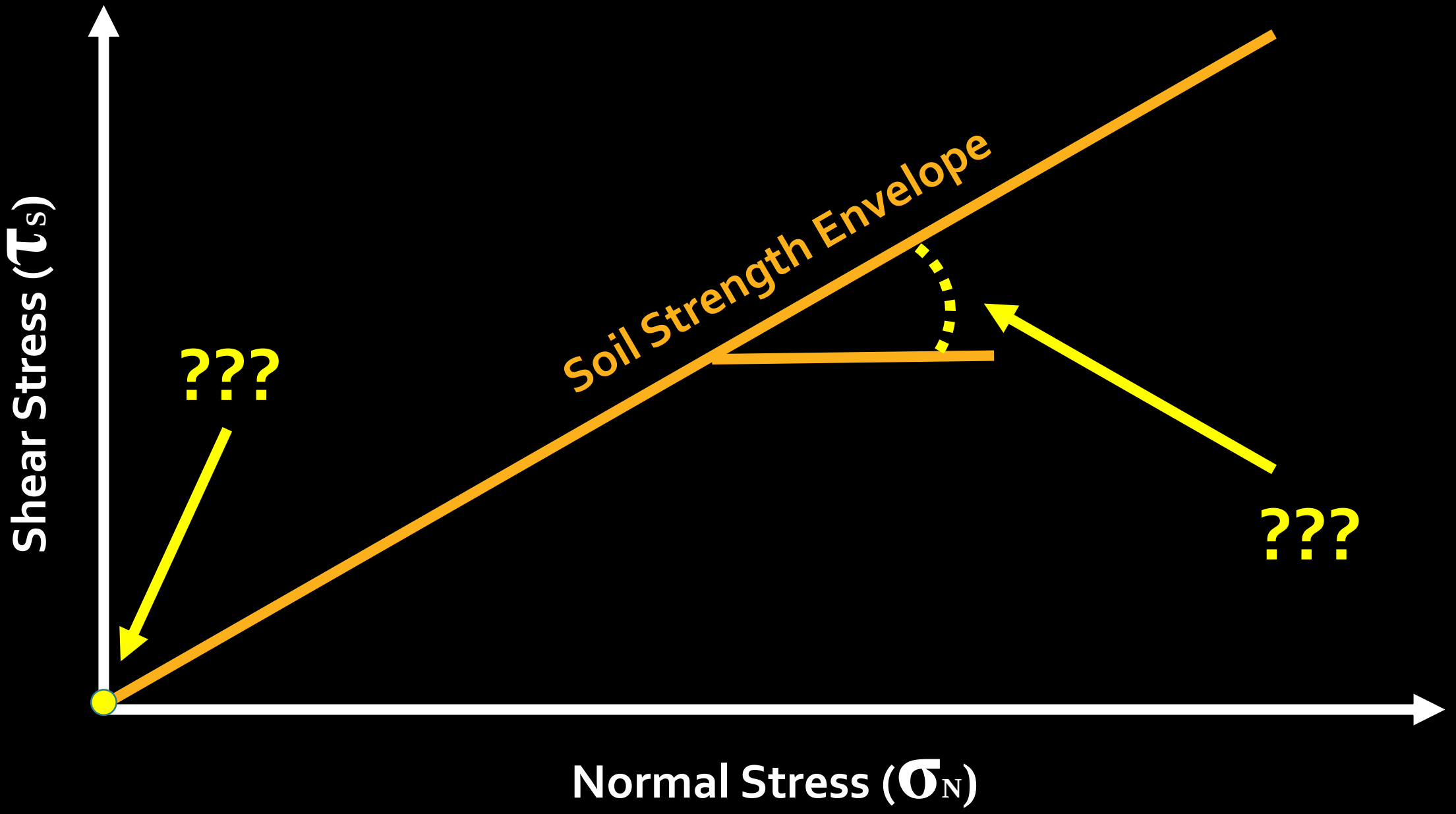
3-D images of the macropore system in soil cores taken from a clay soil in Finland.

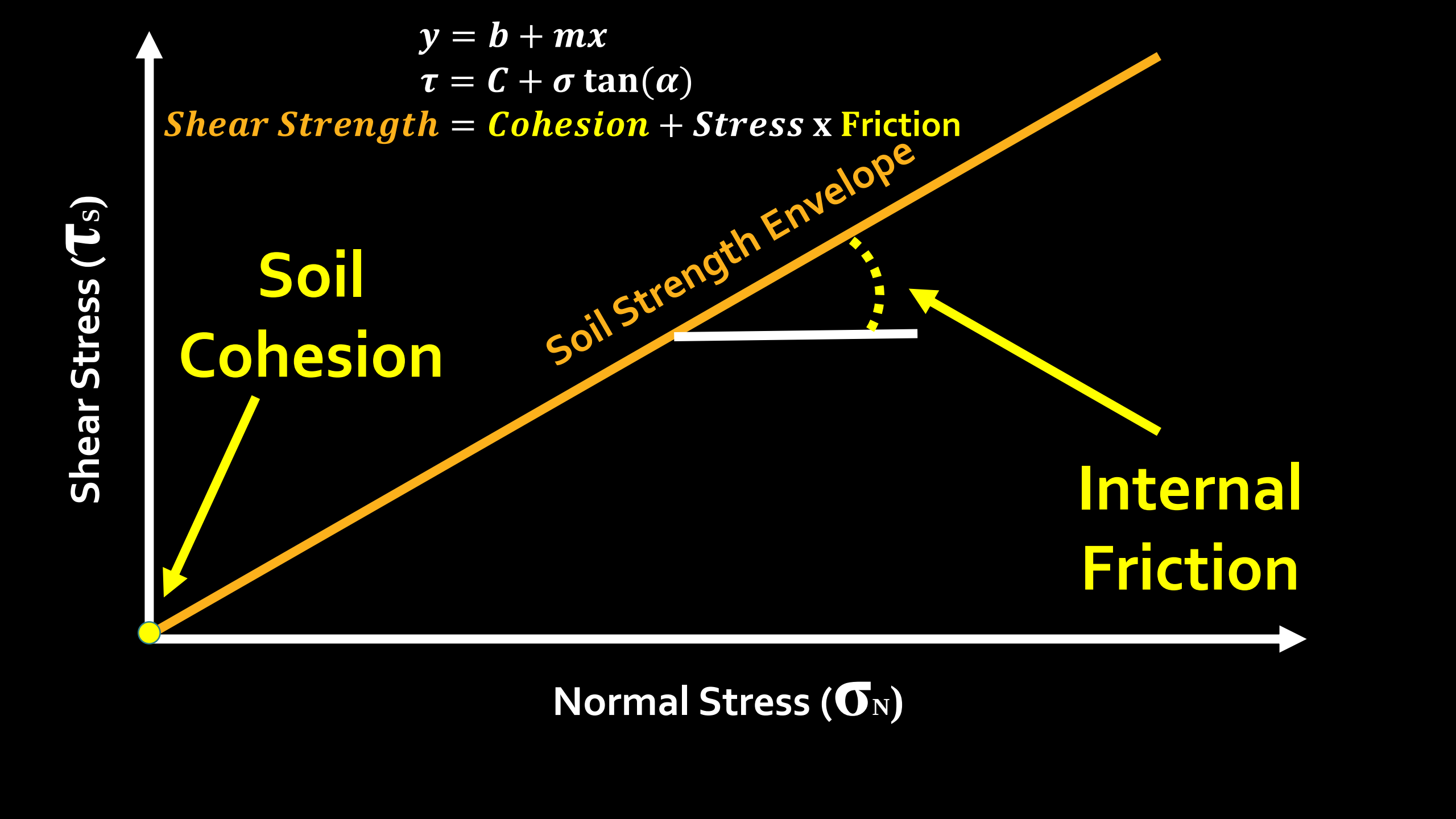


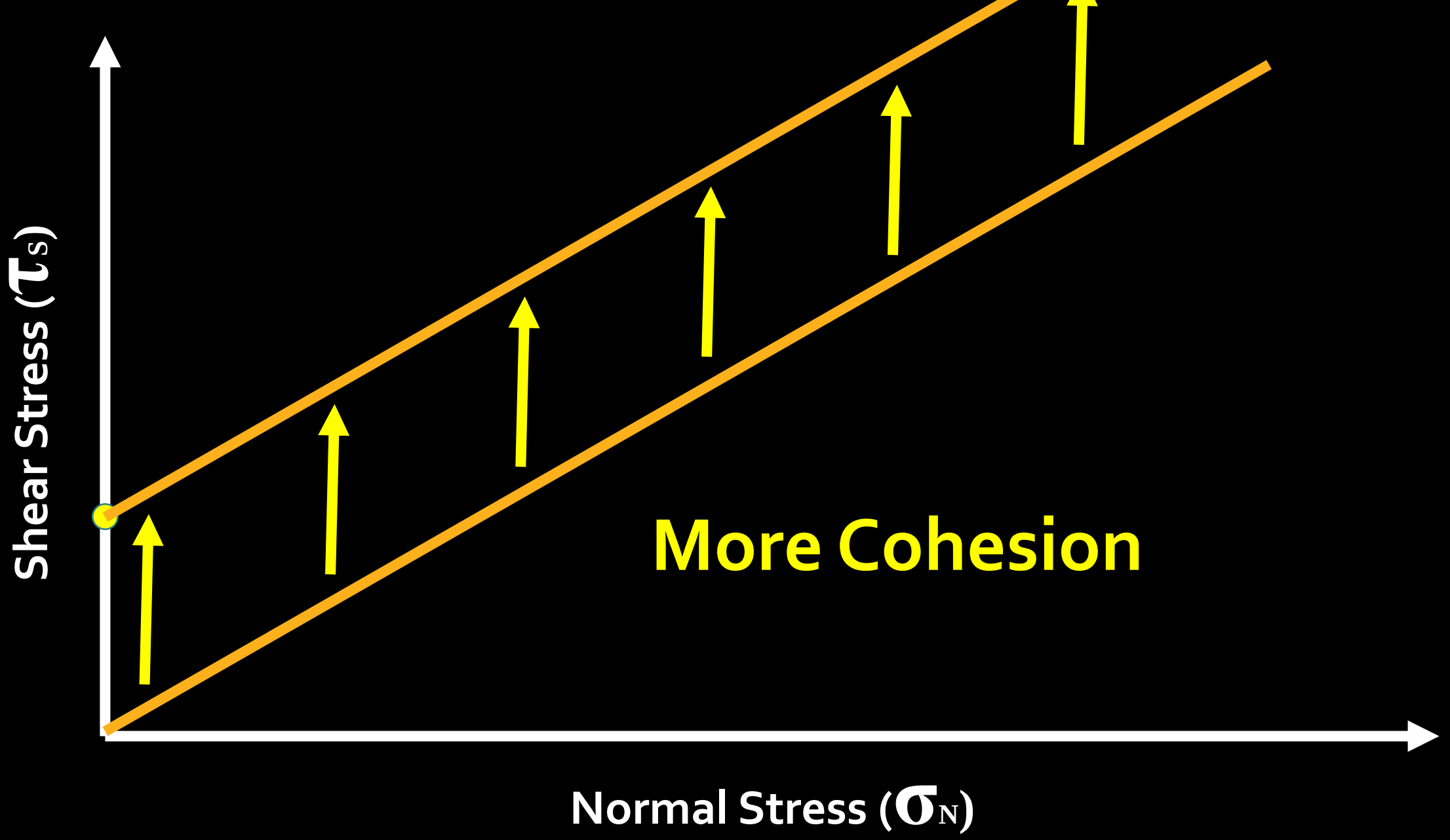
Left: Control (non-compacted) soil.

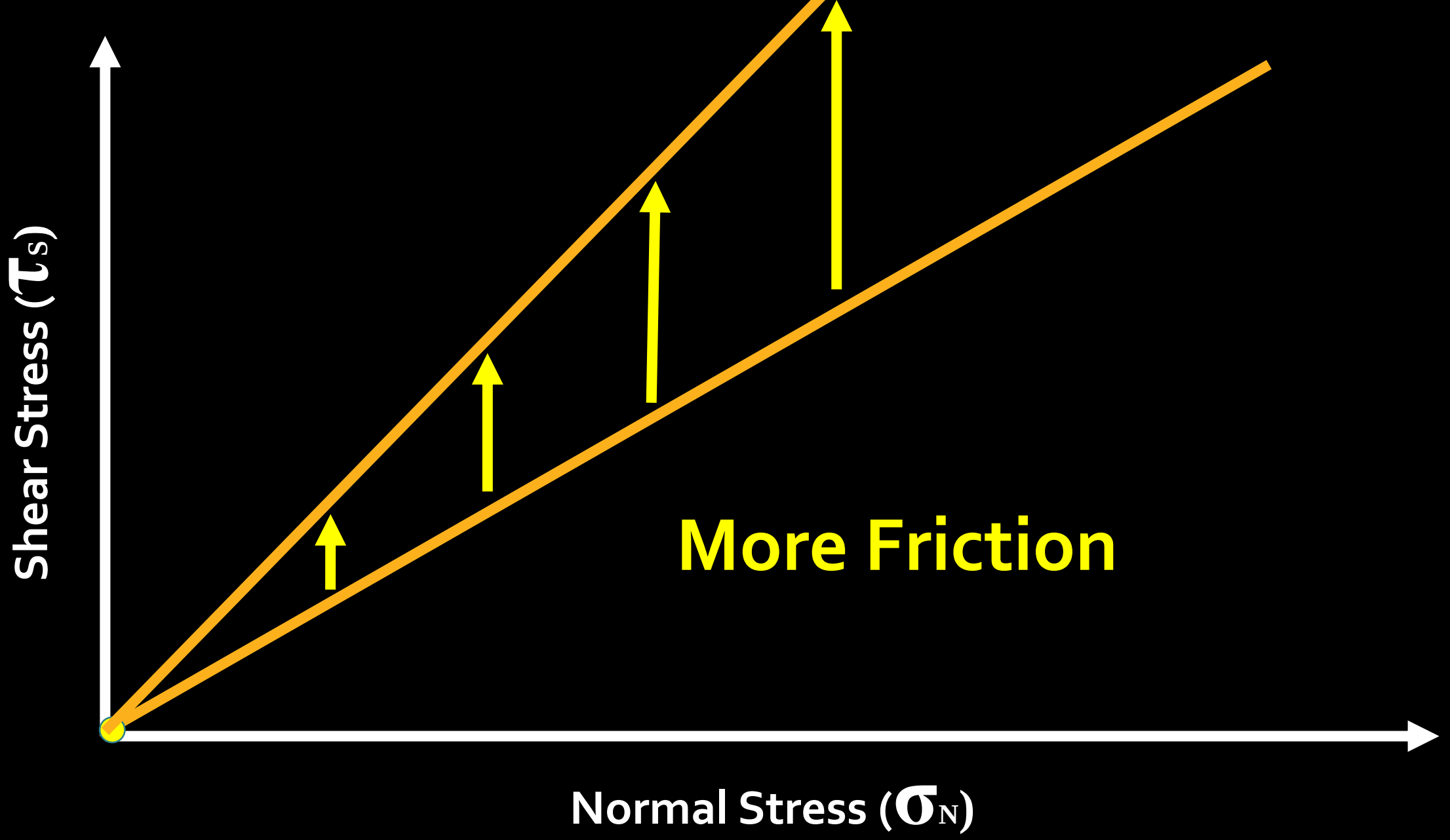
Right: Soil from plots where heavy machinery drove over the ground in an experimental treatment 29 years earlier.

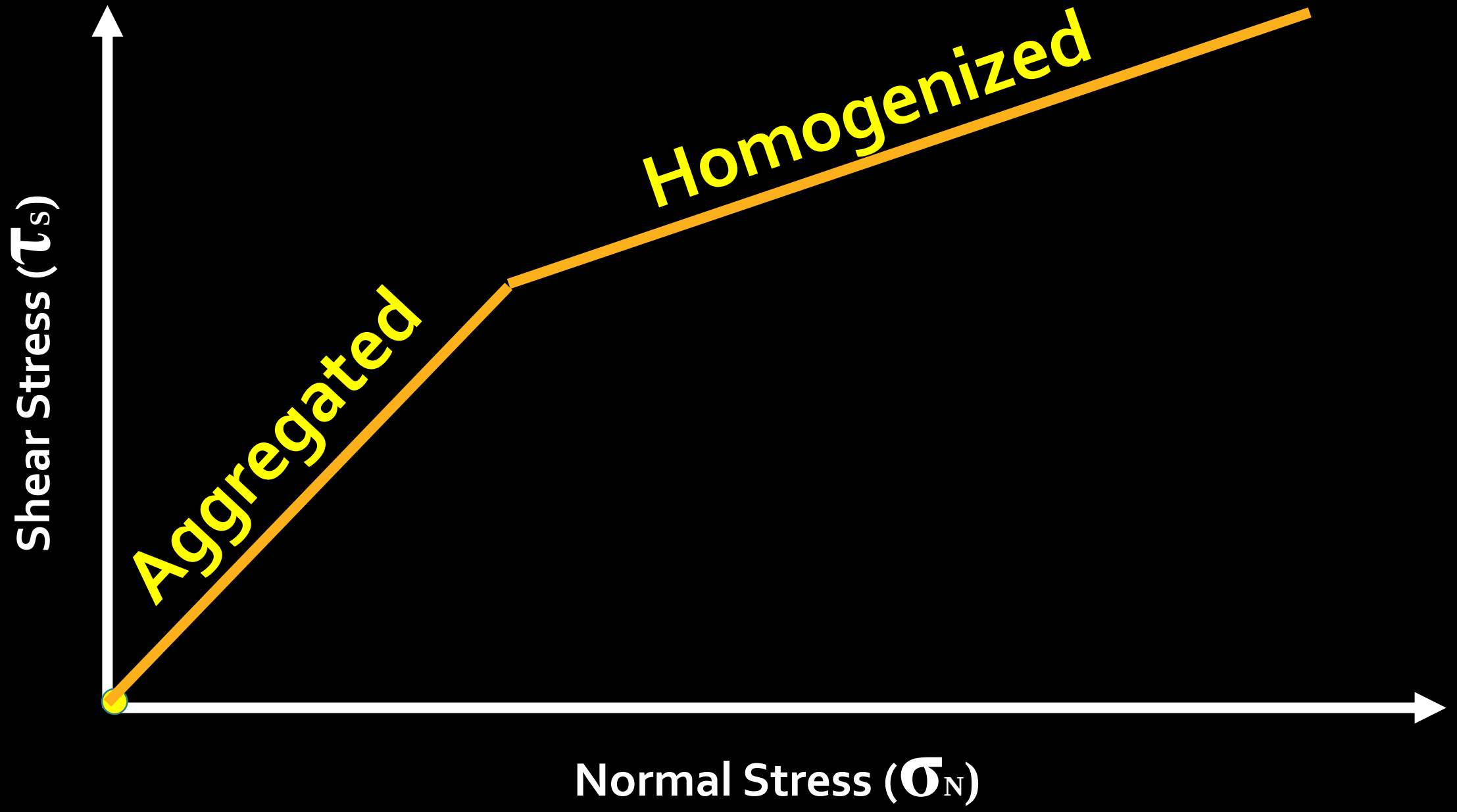
X-ray, computed tomography (CT) scans by Mathieu Lamandé.
https://www.soils.org/discover-soils/story/medical-imaging-helps-reveal-lasting-impacts-soil-compaction


Shear Stress (τ_S)
???
Soil Strength Envelope
???
Normal Stress (σ_N)


$y = b + mx$
$\tau = C + \sigma \tan(\alpha)$
$Shear\ Strength = Cohesion + Stress$ x Friction
Shear Stress (τ_S)
Soil Cohesion
Soil Strength Envelope
Internal Friction
Normal Stress (σ_N)


Shear Stress (τ_S)
More Cohesion
Normal Stress (σ_N)


Shear Stress (τ_S)
More Friction
Normal Stress (σ_N)

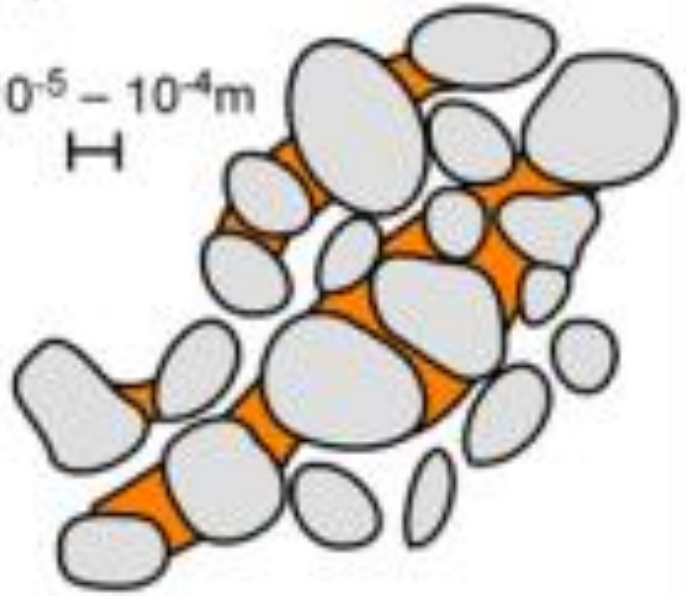

Homogenized
Aggregated
Shear Stress (τ_S)
Normal Stress (σ_N)

What Influences Cohesion and Friction?

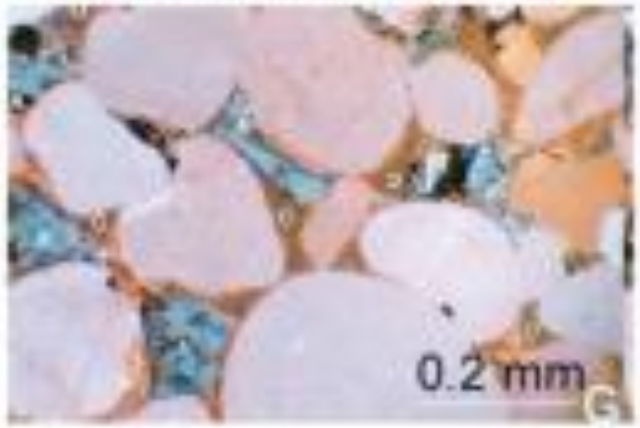
- WATER… tension, W-D & F-T cycles
- Precompression… contact points, aggregation
- Roots & other biomass… elongation, entanglement, adhesion
- Chemical precipitants… cementation

(a) Cements

$10^{-5} - 10^{-4}$m

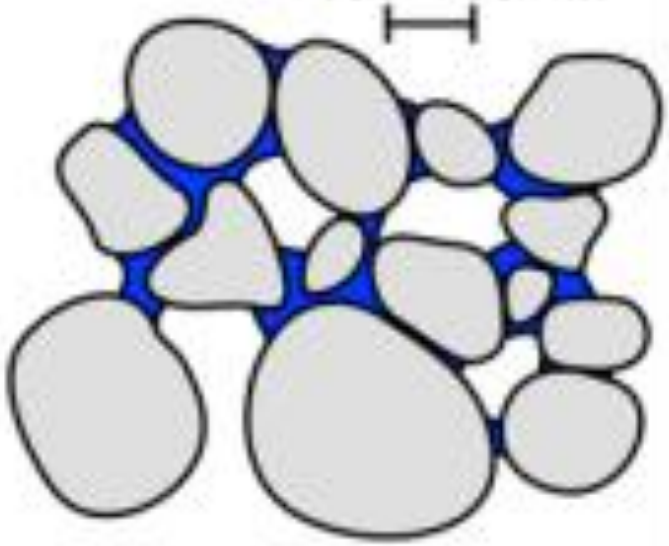


Cement between sand particles (from Houseknecht [1991])

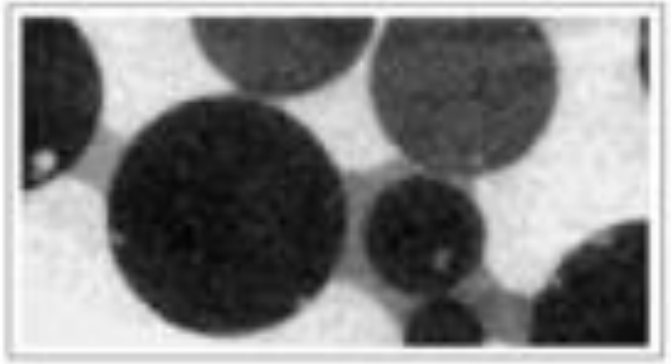


(b) Water bridges

$10^{-4} - 10^{-3}$ m

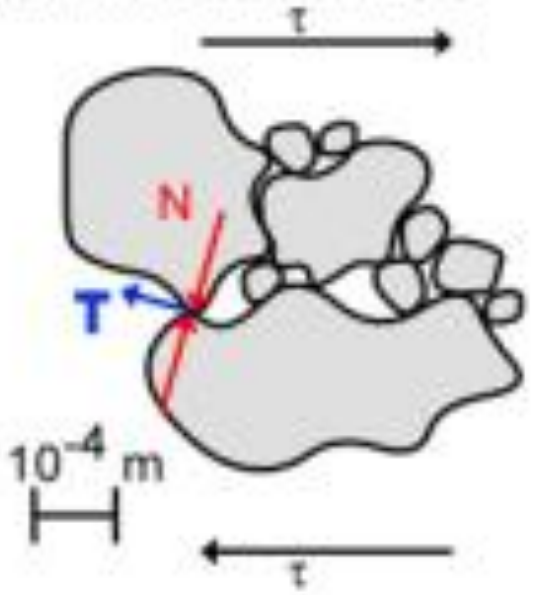


Water bridges across glass spheres

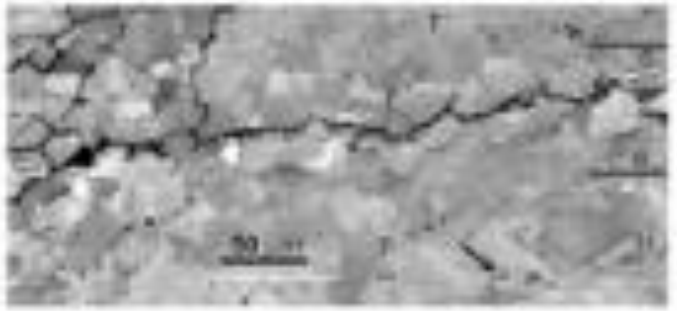


Cohen et al. 2009

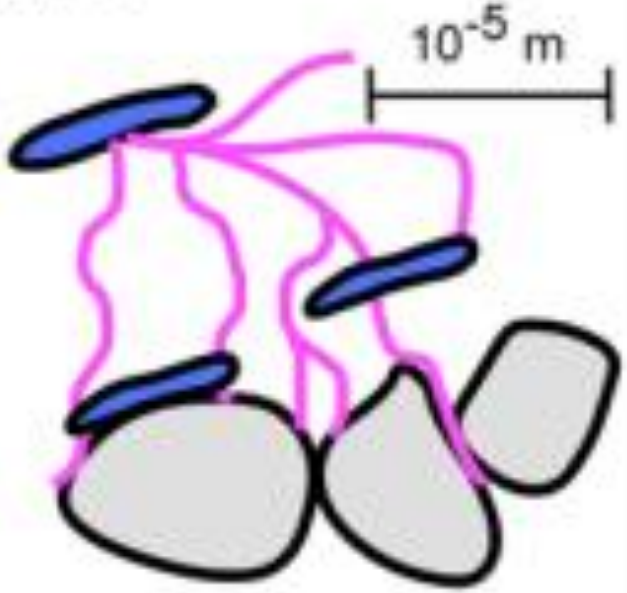
(c) Frictional contacts



Granular contacts along a fracture in marble (modified from Bestmann and Prior [2003])



(d) EPS



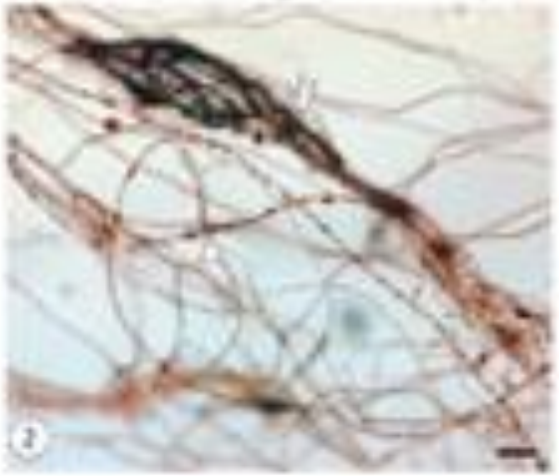
Bridging of kaolinite particles by microbial scleroglucan (EPS) strands (from Chenu and Stotsky [2002]).

Cohen et al. 2009

(e) Hyphae

$10^{-1} - 10^{-4}$ m

Fungal endophyte (from Peterson et al. [2008]). Scale bar in lower right is 20 μm.

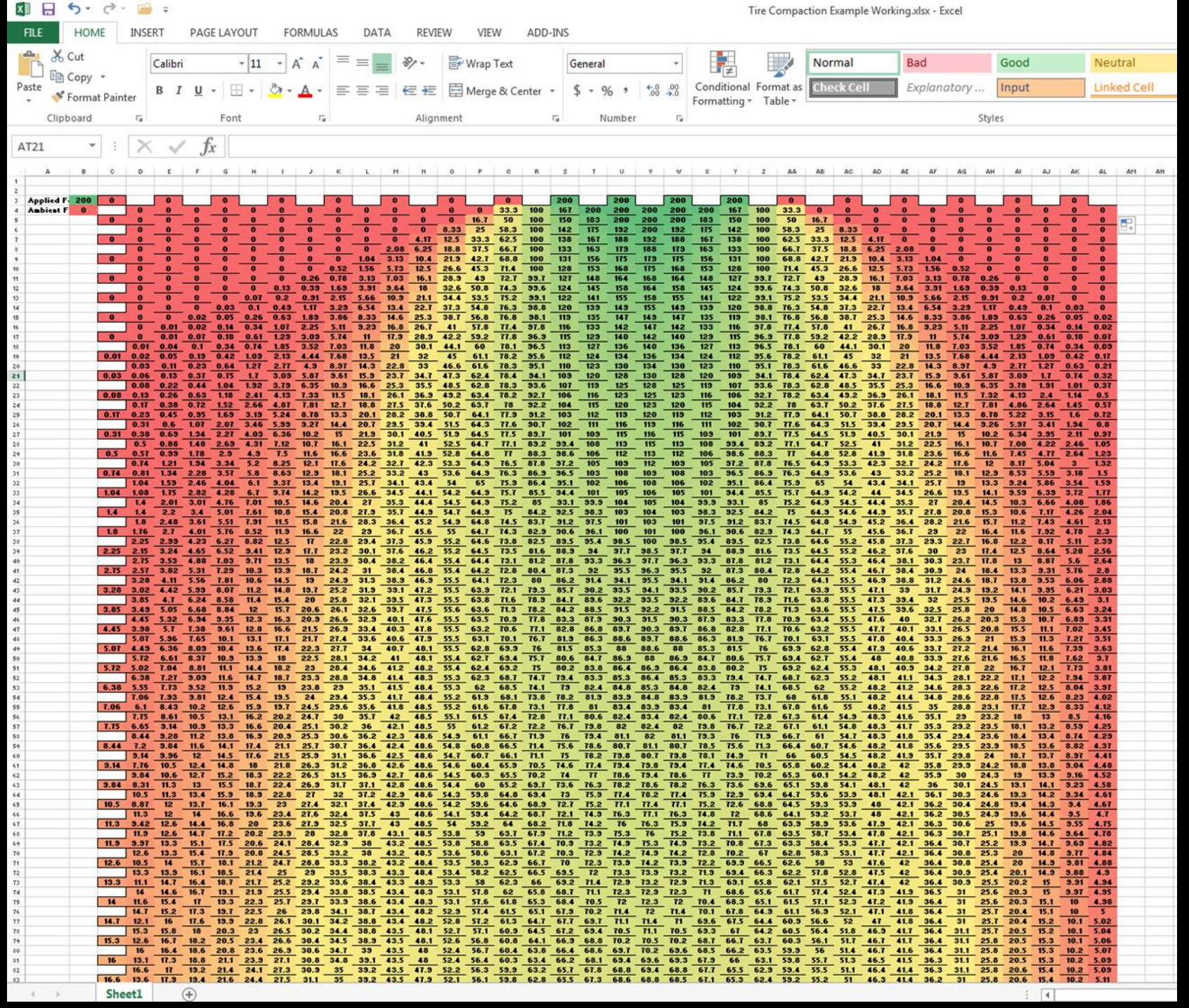


(f) Roots

0.1 – 10 m

Shallow roots in soil (Wiler, Switzerland)

Cohen et al. 2009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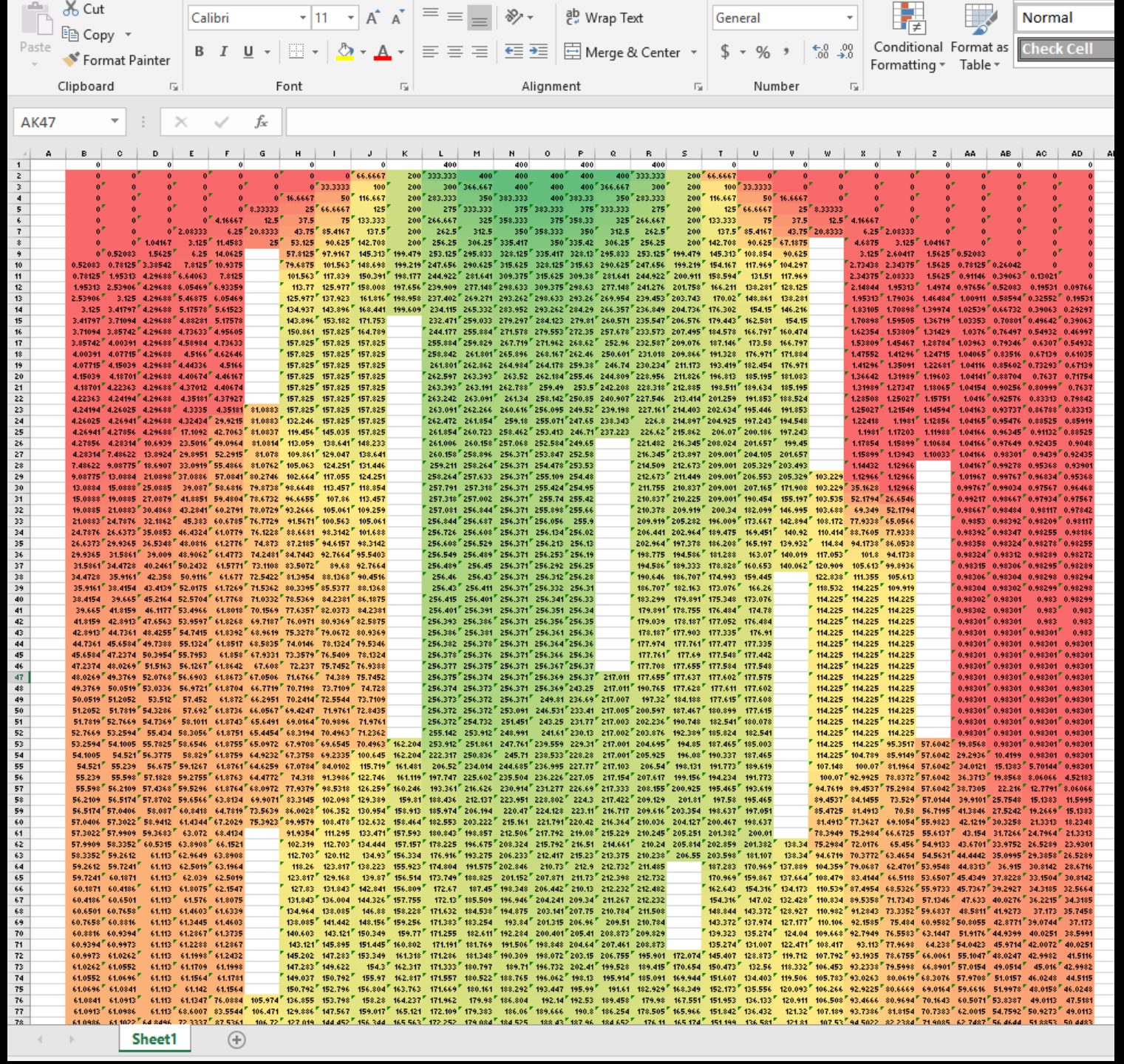


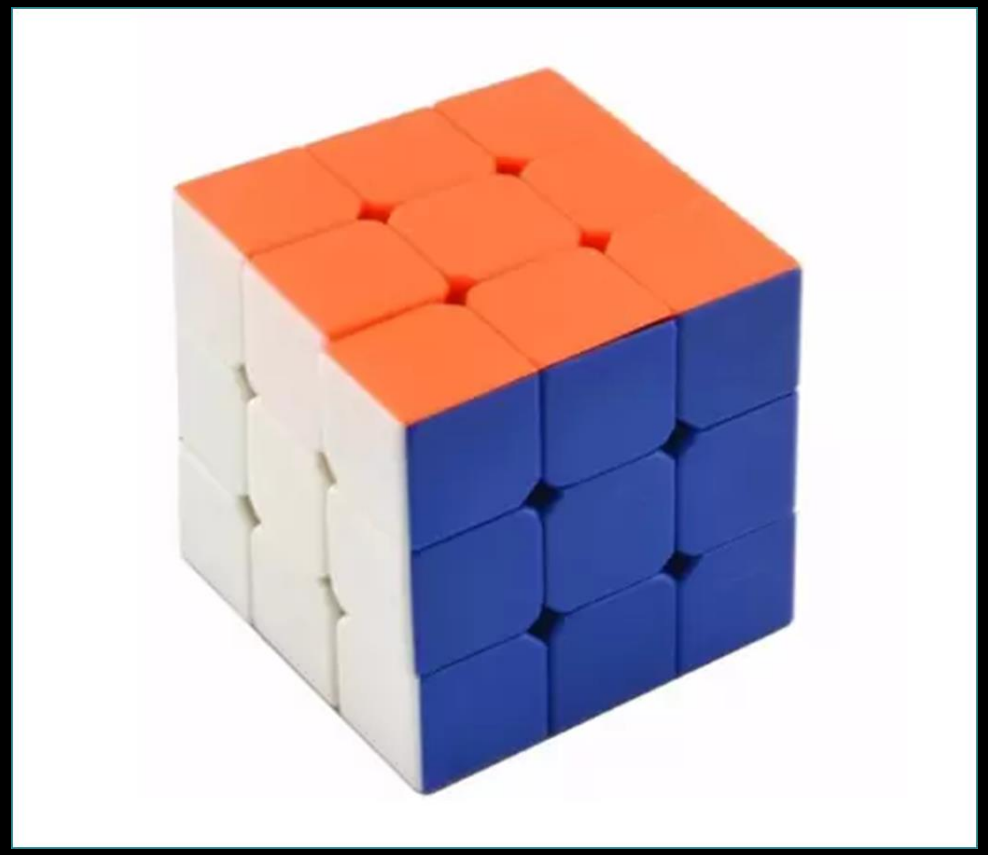
What Strategies Can We Use From This Knowledge of Stress, Strain, & Strength?

- Minimize Loads and Occurrences
  - Properly adjust tire pressures
  - Minimize number of field passes
  - Controlled traffic
  - Avoid wet soil conditions

What Strategies Can We Use From This Knowledge?

- Mechanical Works Homogenize
  - Either weakens soil or compacts soil
  - Reduces drainage… wetter conditions for longer
  - High input on your behalf
- Natural Works Aggregate
  - High cohesion and friction within aggregates
  - High friction between aggregates
  - Progressively better drainage in most soils

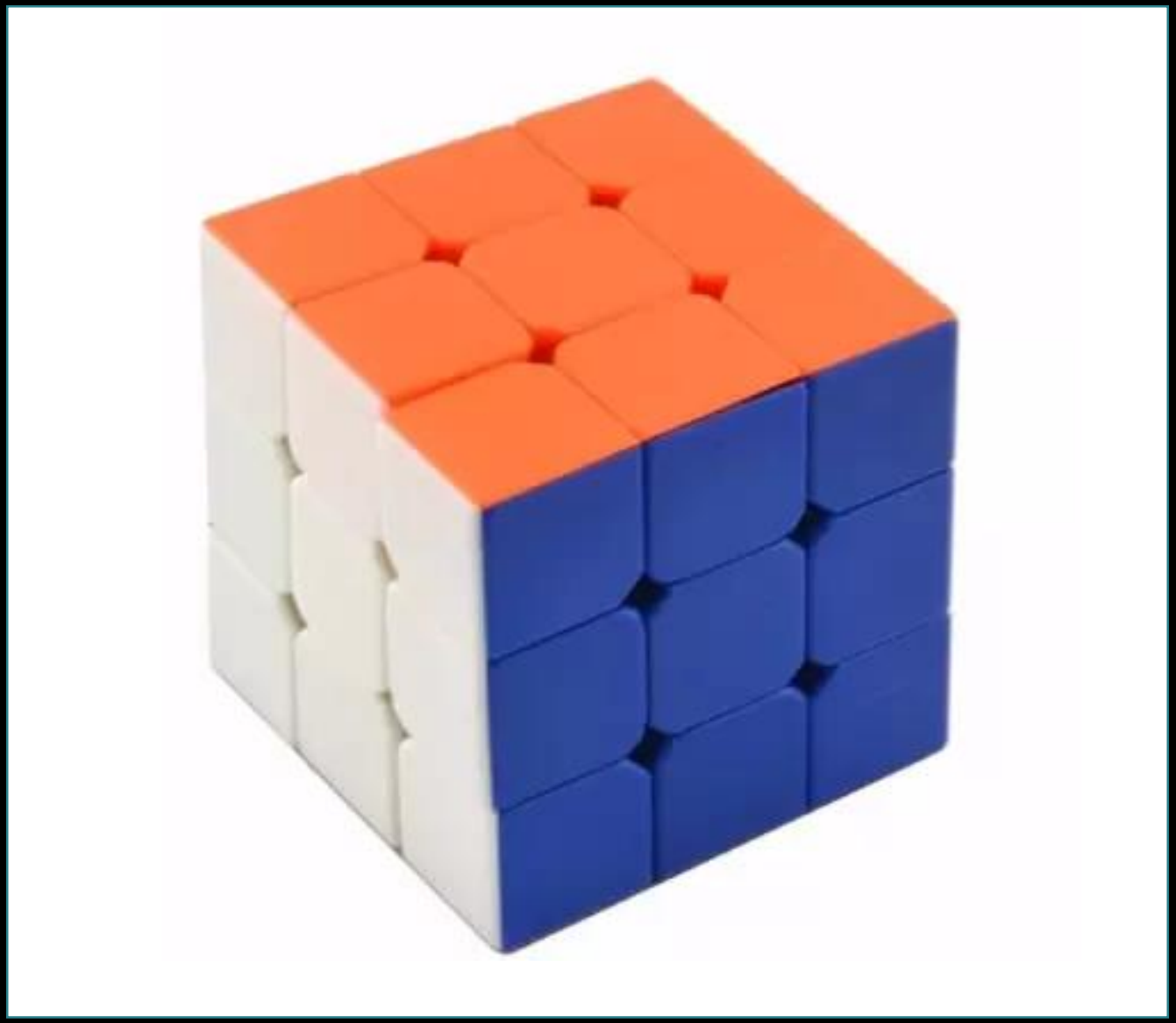
Everything nicely in order



Then everything falls into disarray

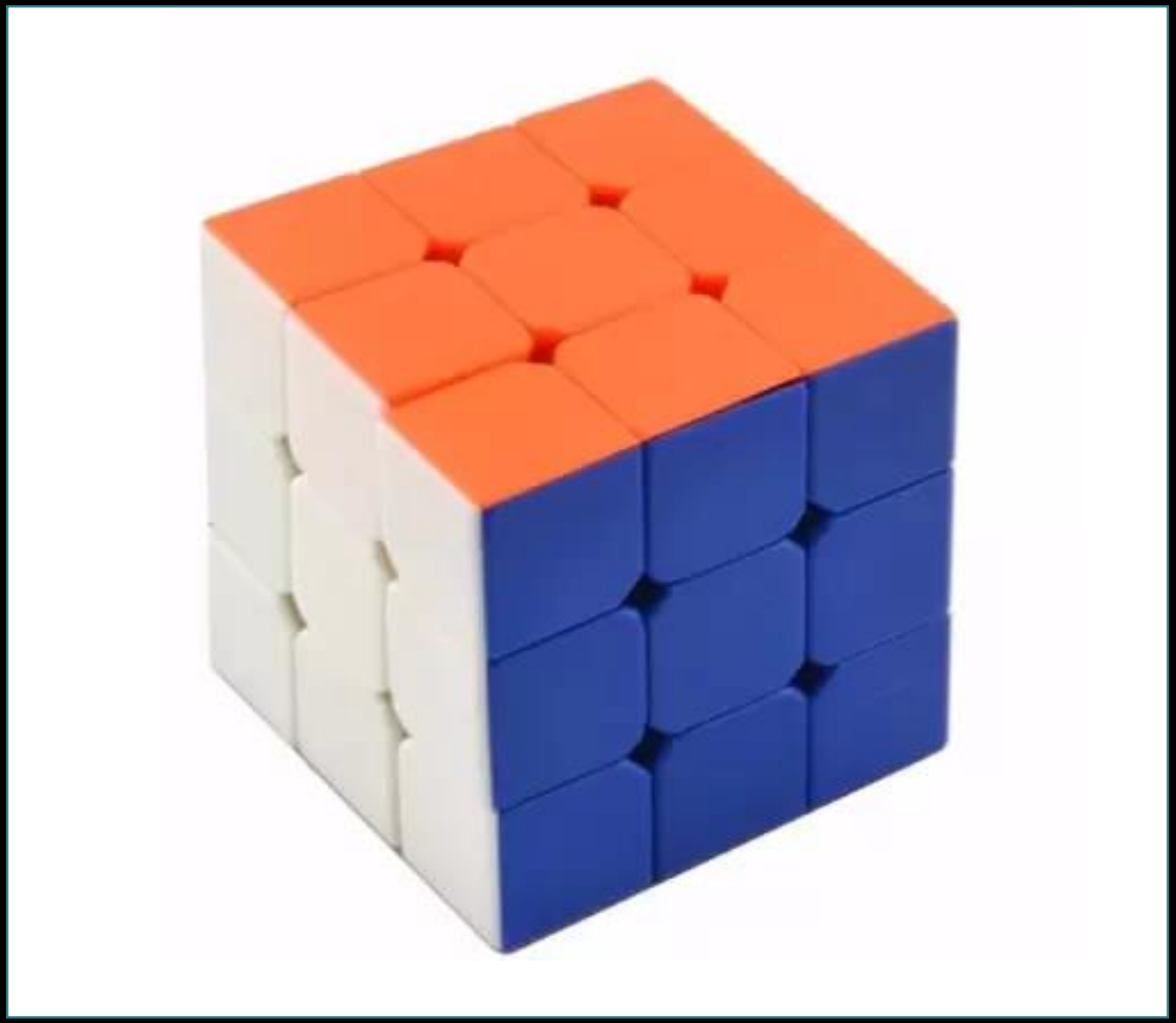
How do you get it back in order?

What's the Point?



There is nothing special or magical about getting a cube back in order

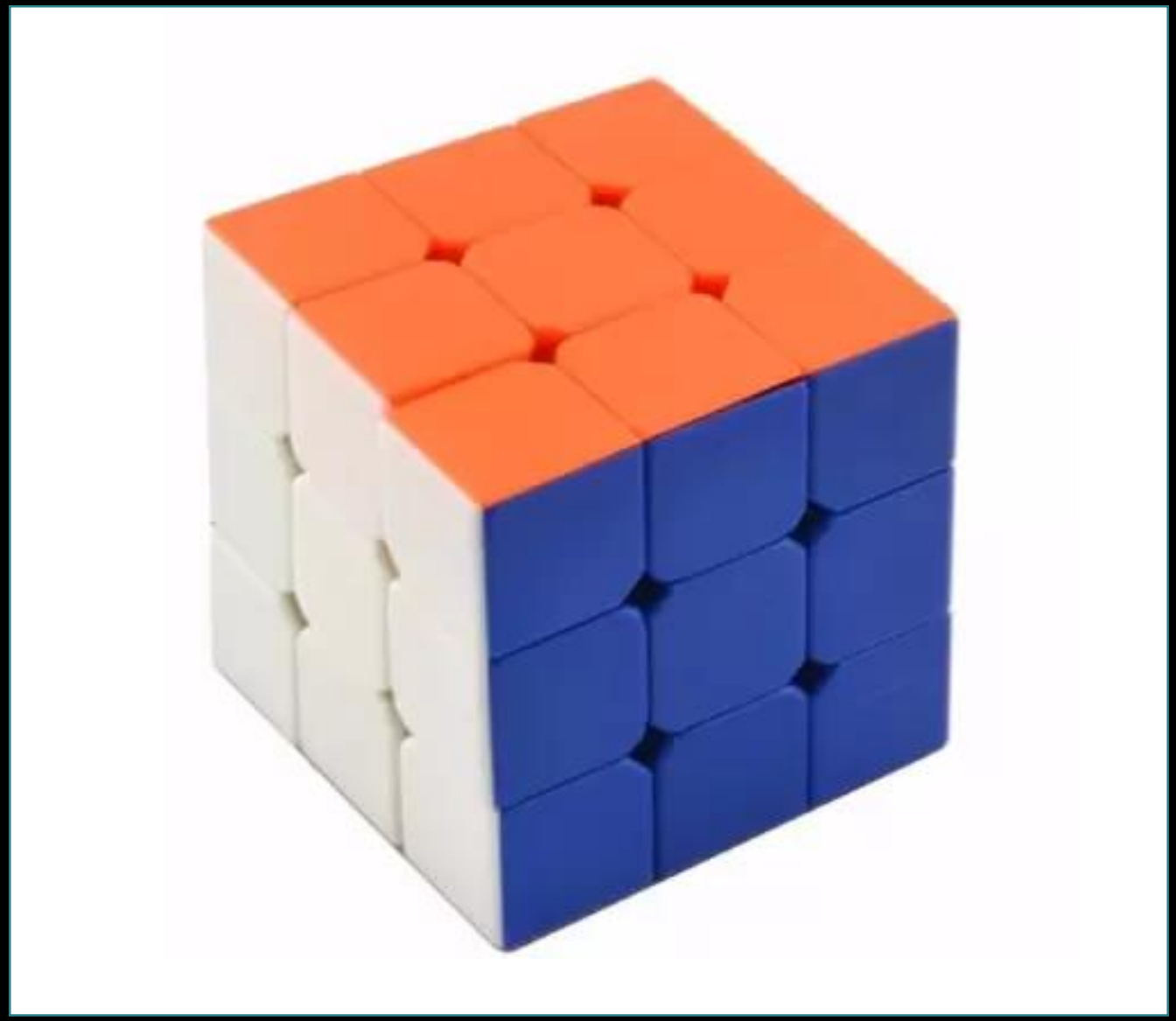
What's the Point?



It takes some knowledge…

That's what you already have and why your at this workshop

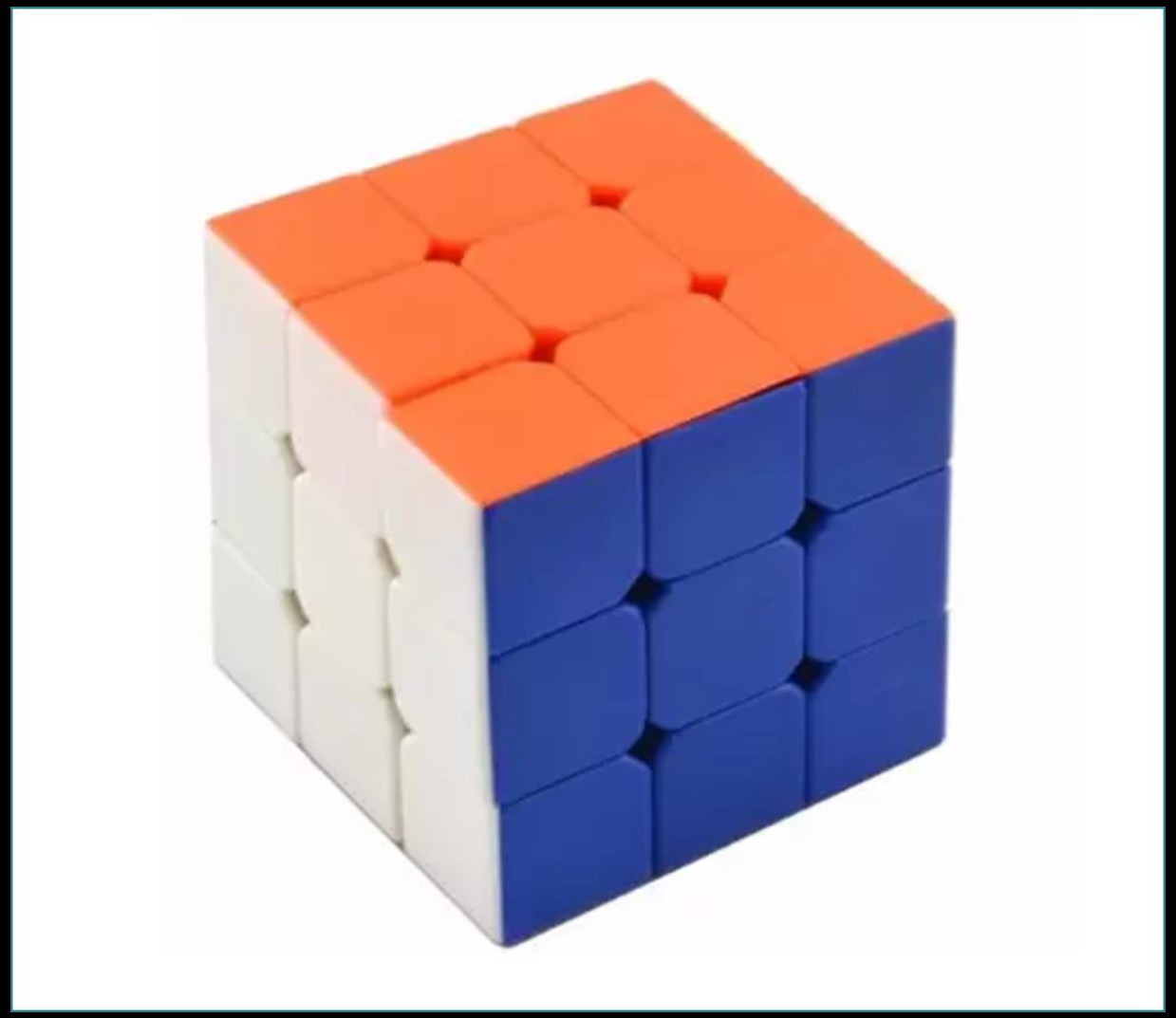
What's the Point?



It takes some trust in the process…

Trust leads to Confidence

What's the Point?



It takes patience

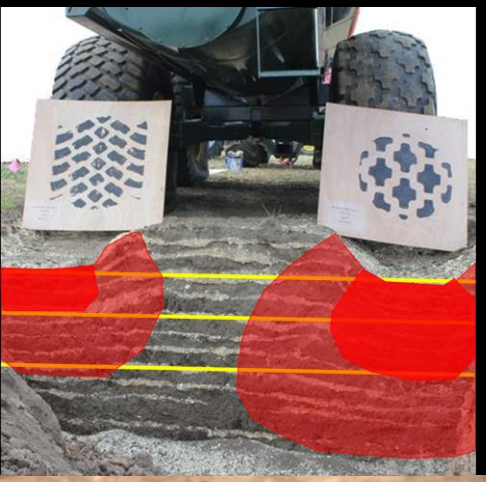
Solving a cube takes a minute

Solving compaction often takes years

How do you get it back in order

1. Some Knowledge
2. Strategy
3. Trust & Confidence
4. Patience

Physics of Soil Compaction and its Remediation



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