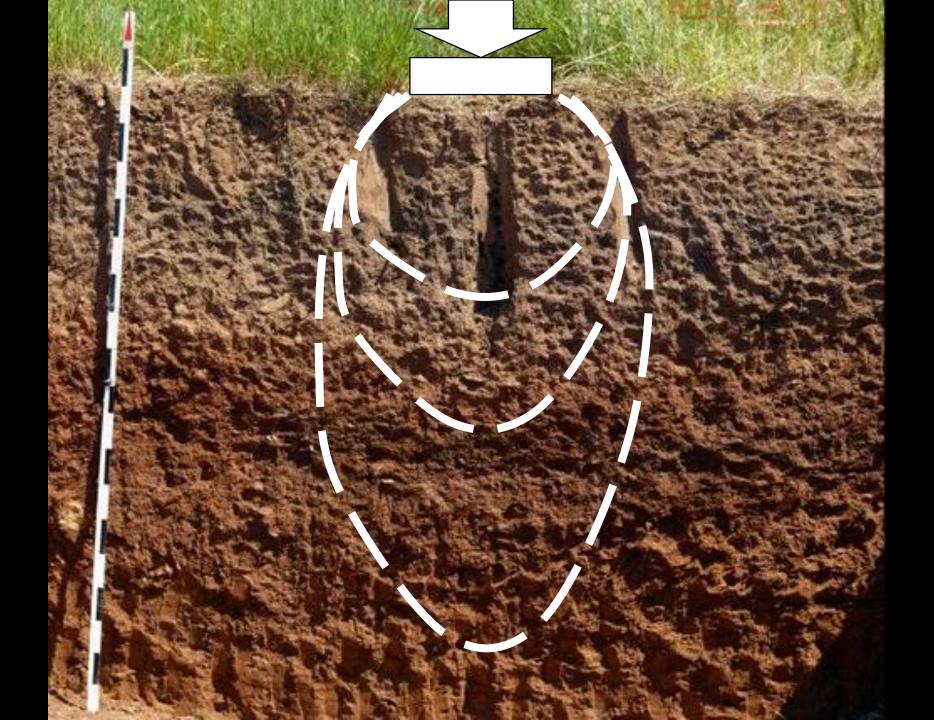
# Physics of Soil Compaction and its Remediation

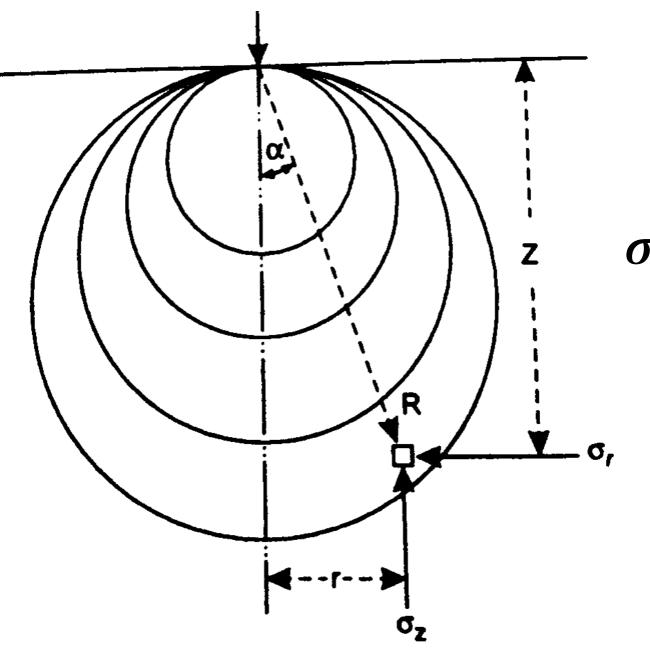


### Compaction... How does it work? Stress, Stain, and Strength





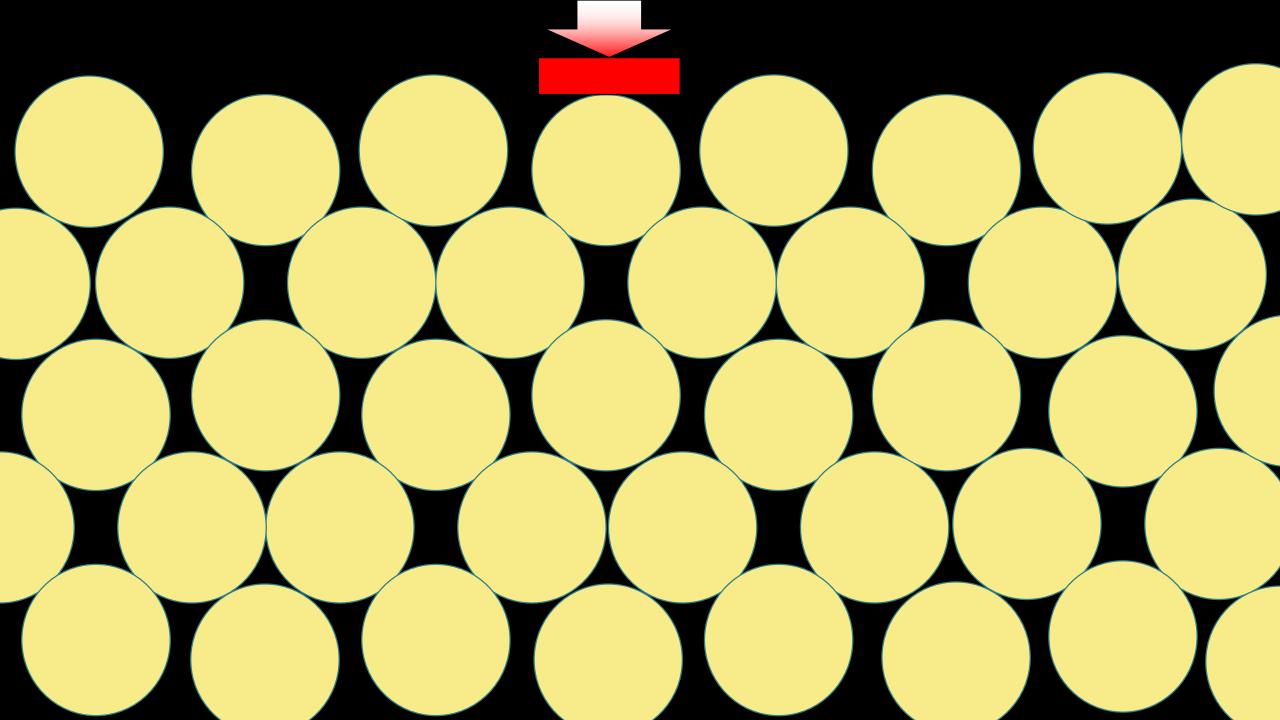
#### Distribution of vertical shear stress under a concentrated vertical load

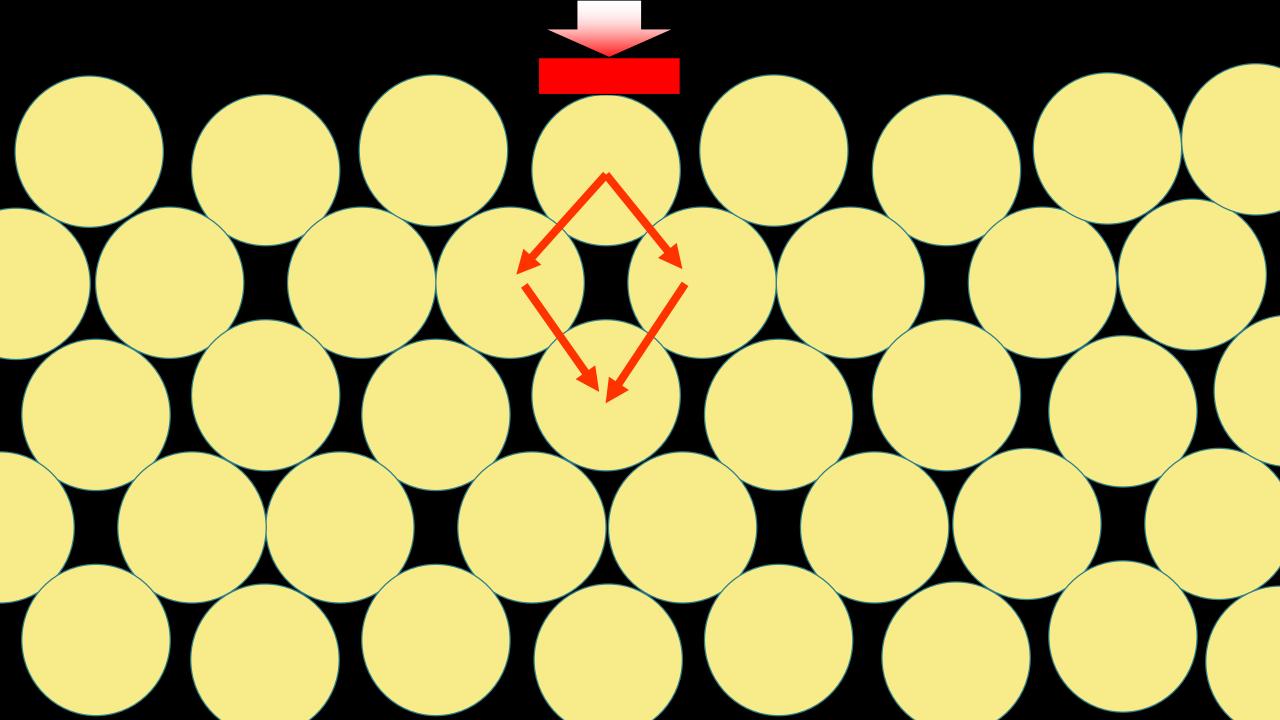


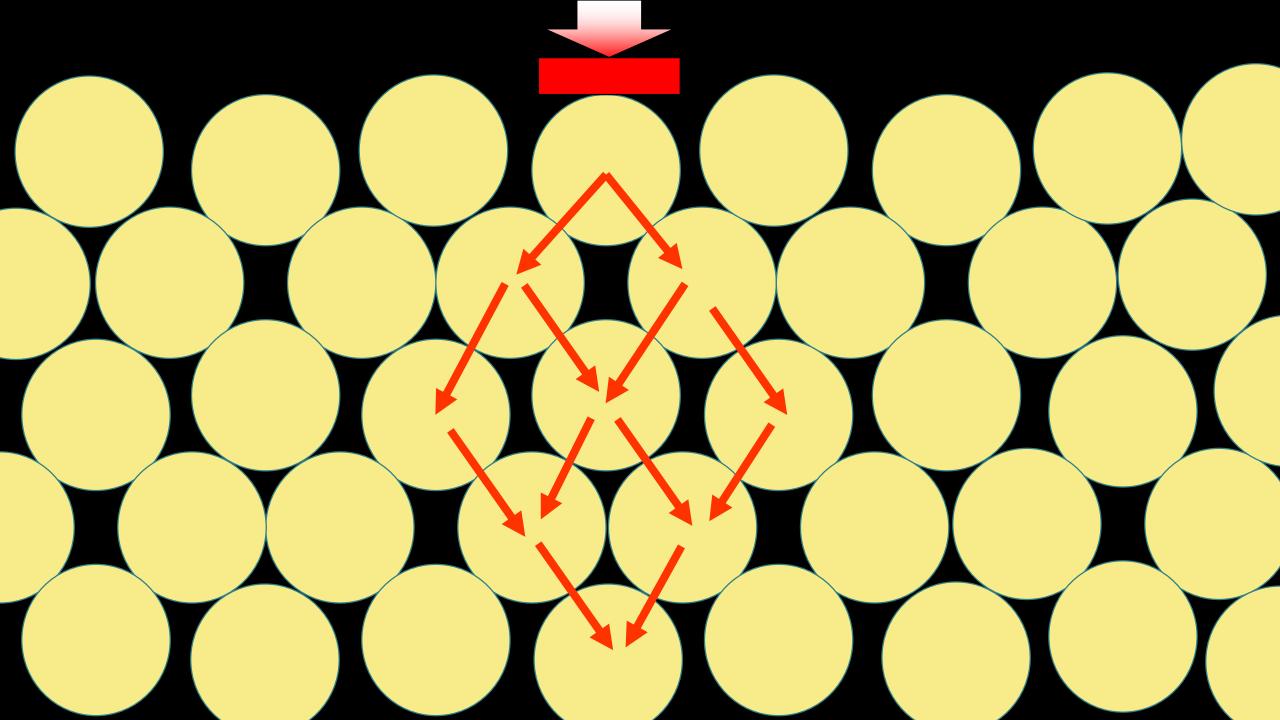
#### **Boussinesq theory**

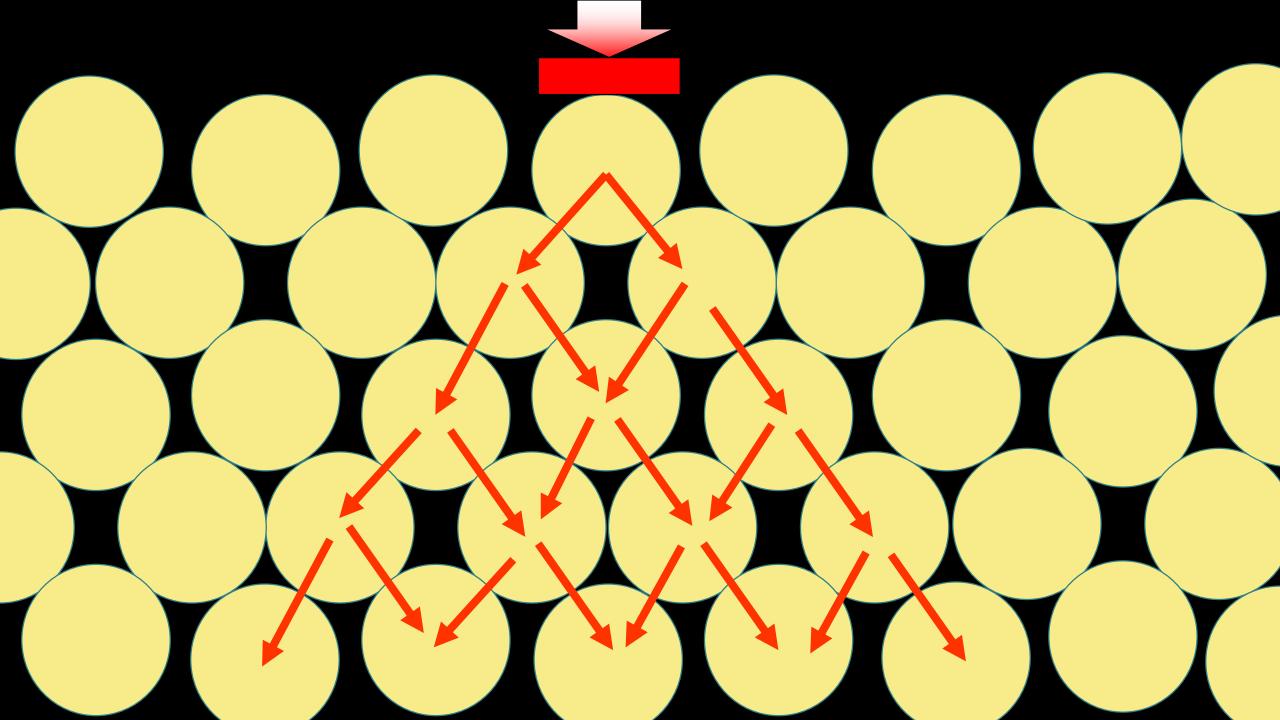
$$\sigma_z = L * \frac{3}{2\pi} * \frac{z^3}{(r^2 - z^2)^{5/2}}$$

## Nesting of Tangent Circles

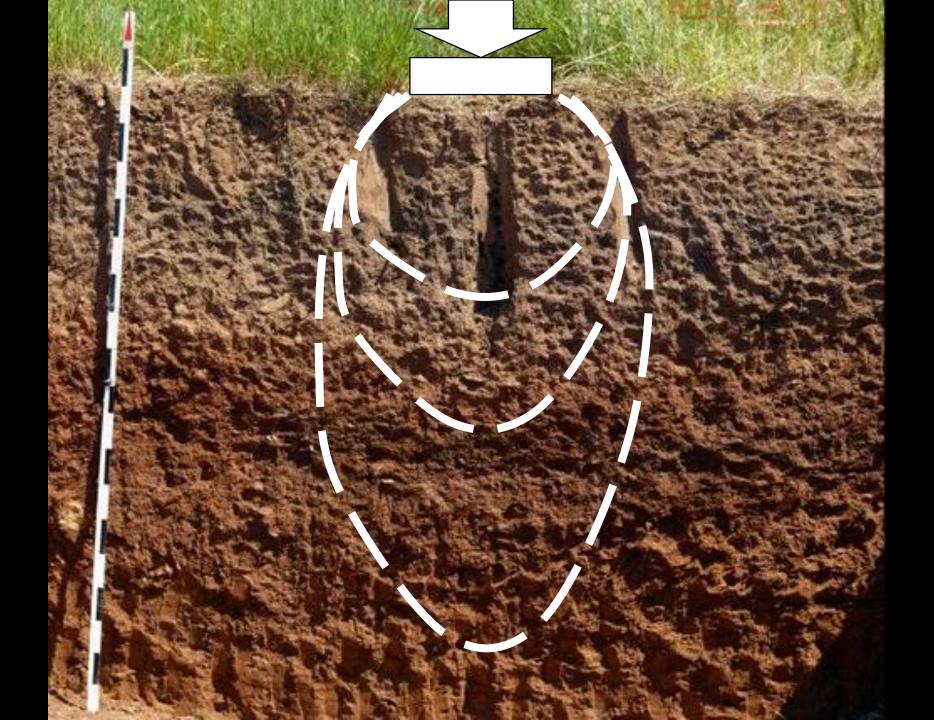




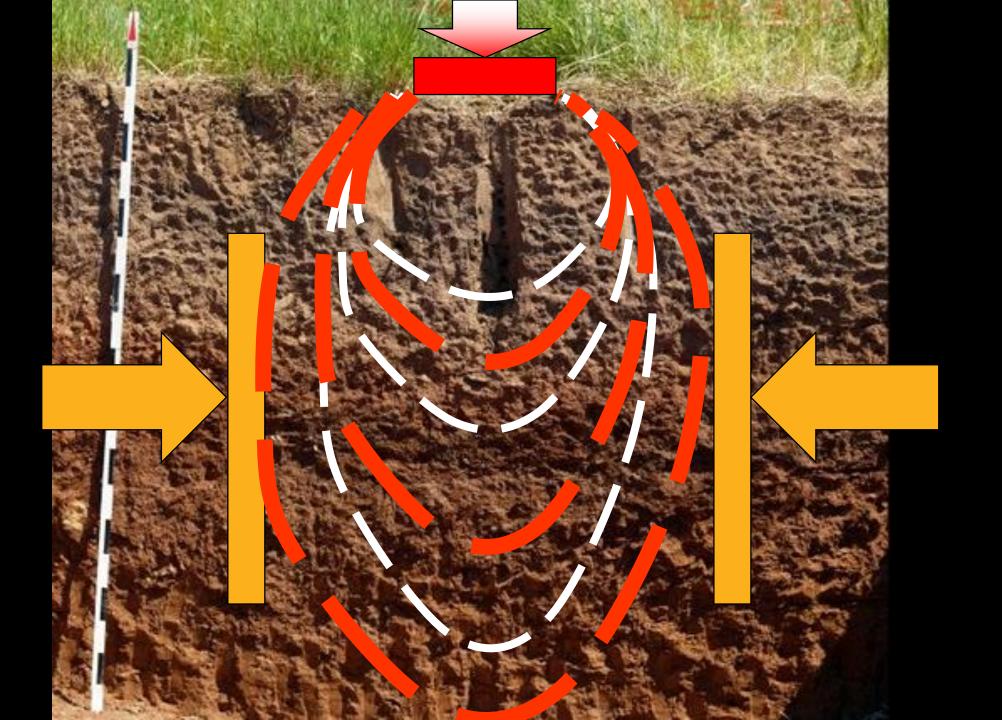


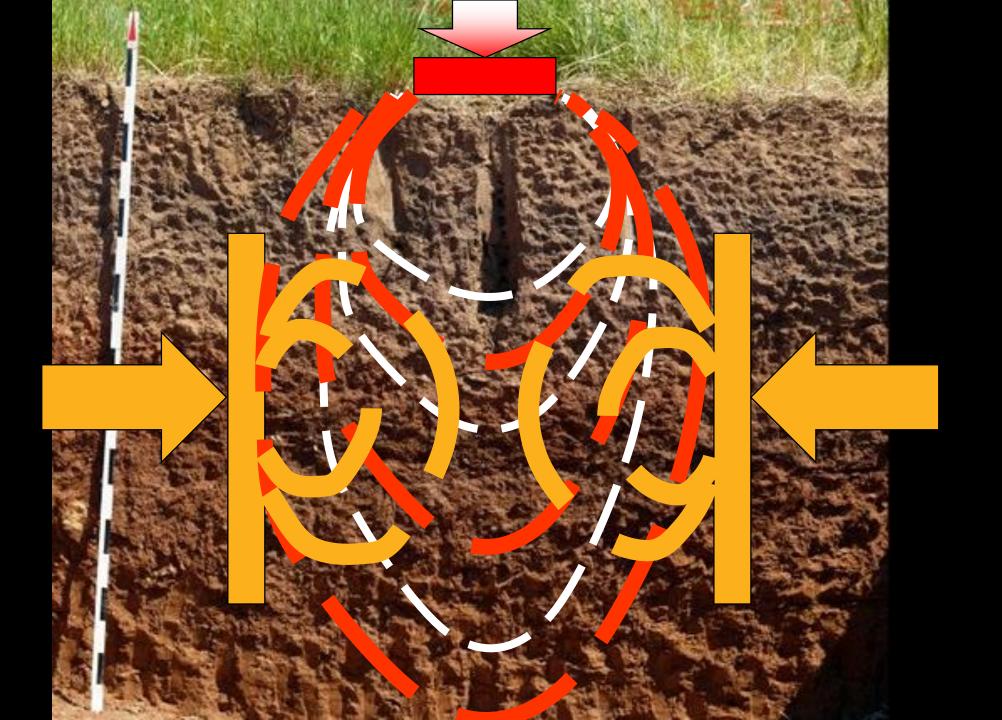


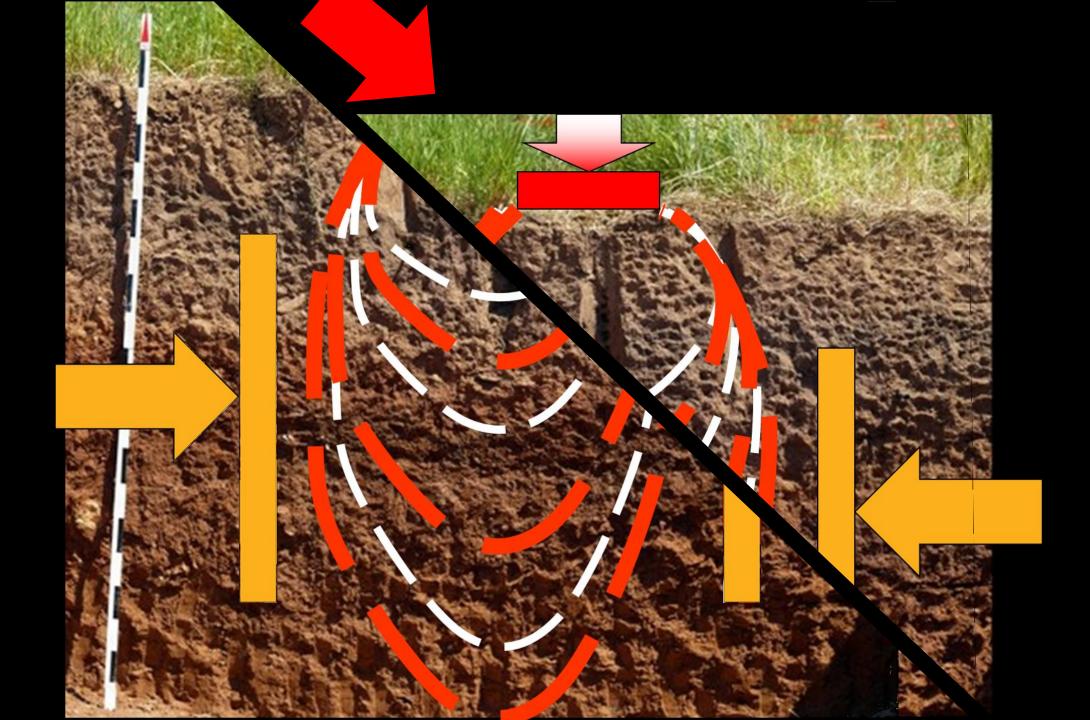
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38 39 40	2.25 2.1		65 6.52	3.41 1	12.3 17.	7 23.2	30.4 38	.6 46.2 3.2 46.4	55.2 6	64.5 73 64.4 73	82.5 8.5 81.6 8.1 81.2	88.9	94 97. 93.3 96.	.7 98.5 .3 97.7	36.3	94 88.9 93.3 87.8	81.6 73.5 81.2 73.1	64.5 5	5.2 46.2	37.6 3	0.3 23.7	17.4 12. 17.8 13	8.64	5.28 2	.56	
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65 66 67	10.5 8.8 11.3 3.4	3 12	14 16.6	13.6 2	23.4 27.	6 32.4	37.5 4	3 48.6	54.1 5	59.4 64	1.2 68.7	72.1	74.9 76.	3 77.1	76.3	75.2 72.6 74.8 72 74.2 71.7	68.6 64.1	59.2 5	3.7 48	42.1 30	.2 30.5	24.9 19.	6 14.4	3.5	4.7	
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77 78 79	14.7 12. 15.3 12	1 16 1 3 15.8 6 16.7	18 20.3 18 20.5	23 2	6.5 30.	2 34.4	38.8 43 38.8 43	.4 48.2 .5 48.1	52.8 52.7 52.6	57.1 60 56.8 60	.3 64.7 1.8 64.5	67.2	69.4 70. 68.8 70	71.4 5 71.1 2 70.5	70.5	69.6 67.5 69.3 67 68.7 66.7 68.5 66.2	64.4 60.9 64.2 60.5 63.7 60.3	56.4 51 56.1 5	1.8 46.9	41.7 30 41.7 30	31 31.1 4 31.1	25.7 20. 25.7 20. 25.8 20	4 15.2 5 15.2 5 15.3	10.1 5	.04	
80 81	16 13.	16.4 1 1 17.3 1	8.6 <u>20.8</u> 8.8 <u>21.1</u>	23.6 2	6.9 30. 27.1 30.	6 34.7 8 34.8	39 43 39.1 43	.5 48 .5 48	52.4 52.4	56.7 60 56.4 60	63.8	66.4	68.6 69. 68.1 69	7 70.2	69.6	68.5 66.2 67.9 66	63.5 59.9 63.1 59.8	56 51 55.7 51	1.4 46.7	41.6 30	5.4 31.1 5.3 31.1	25.8 20. 25.8 20.	5 15.3 5 15.3	10.2	70.i	
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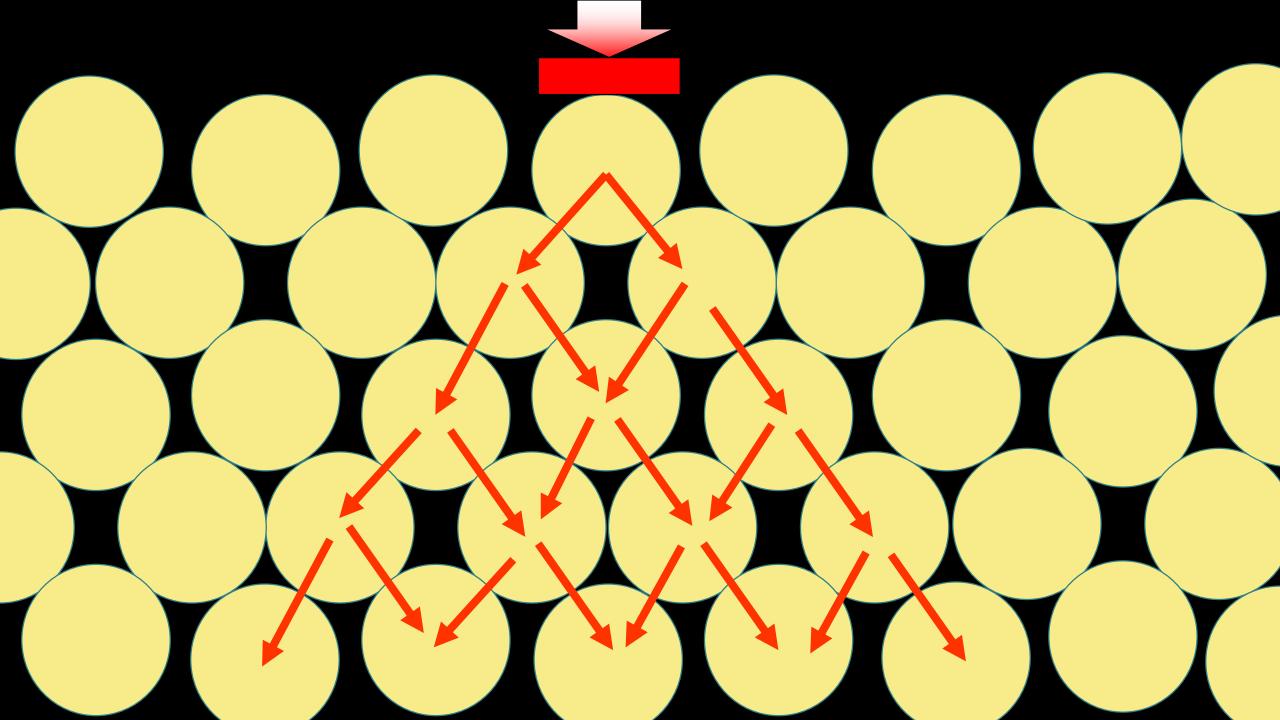


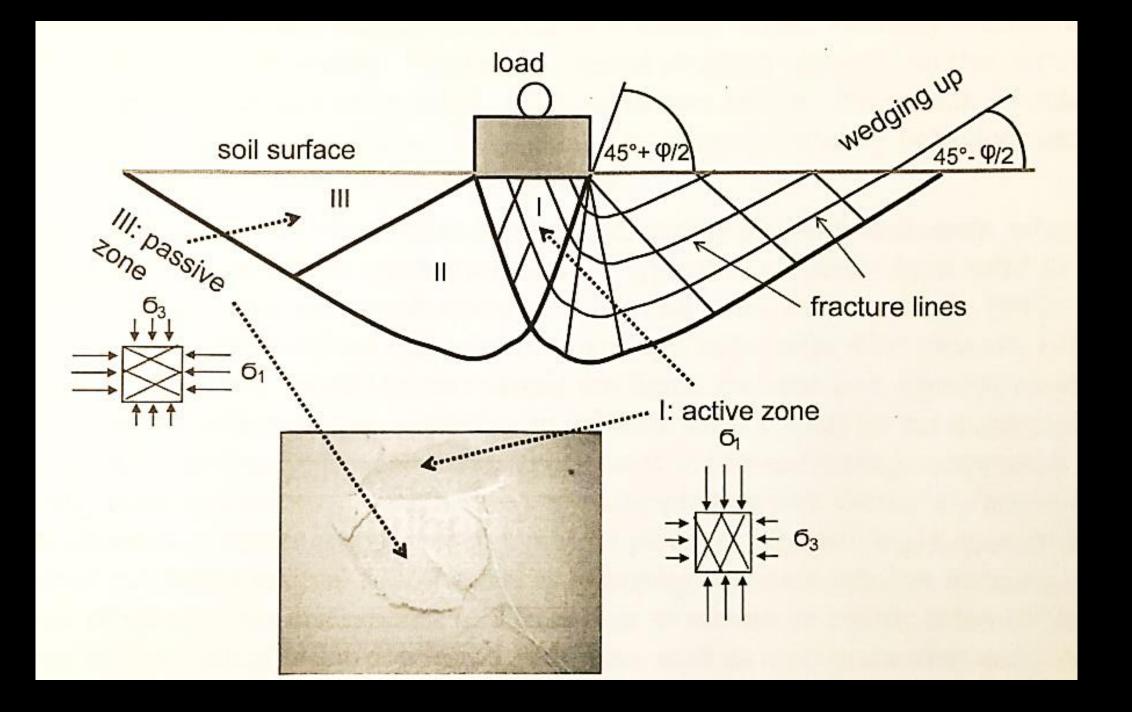










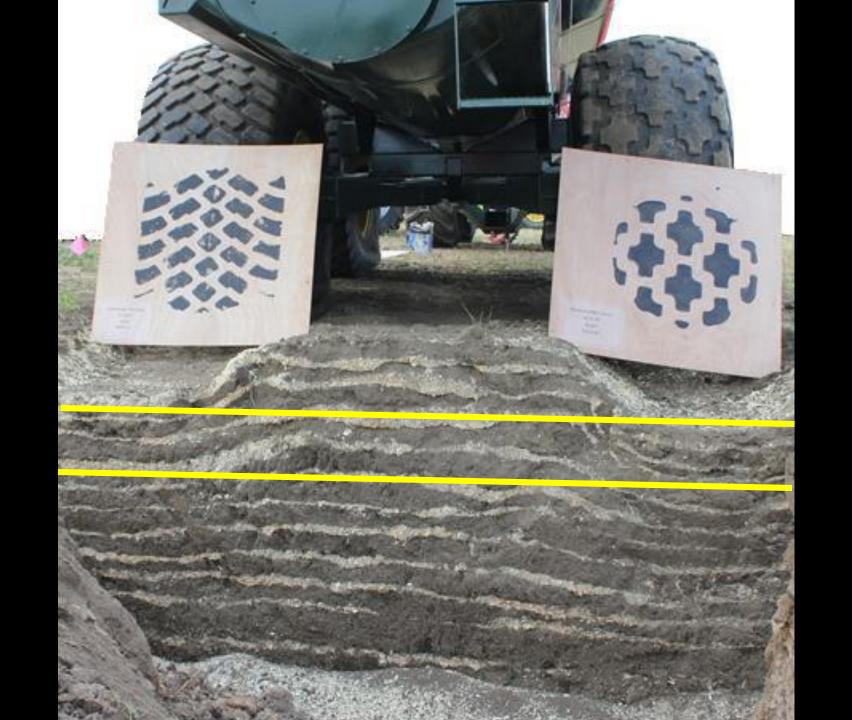


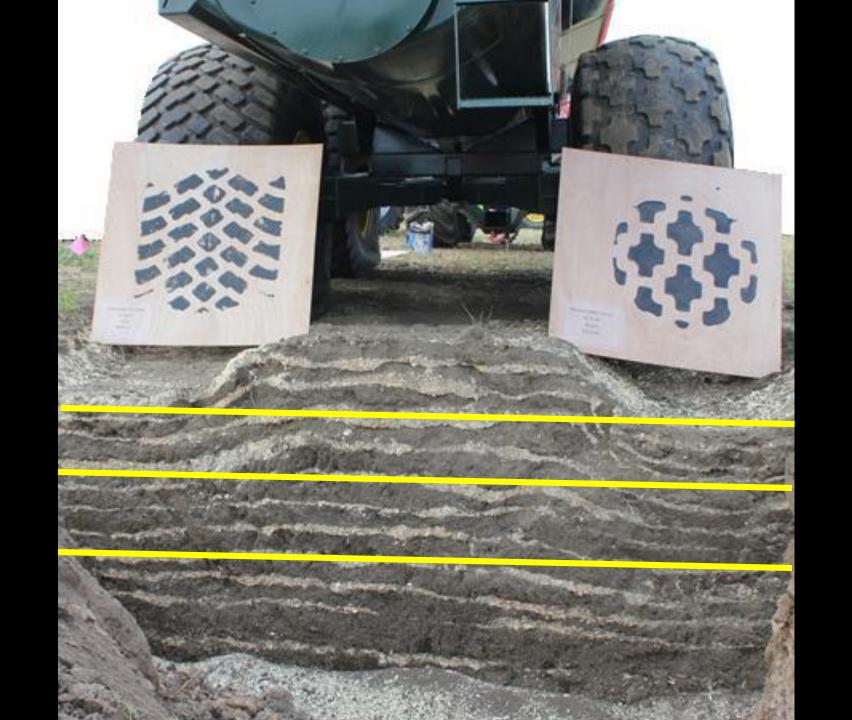


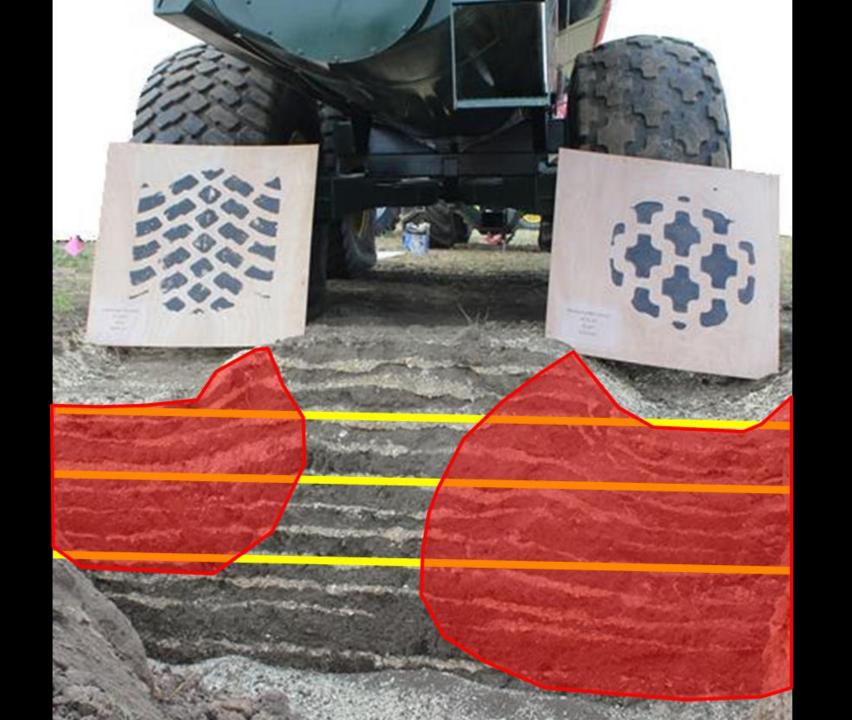








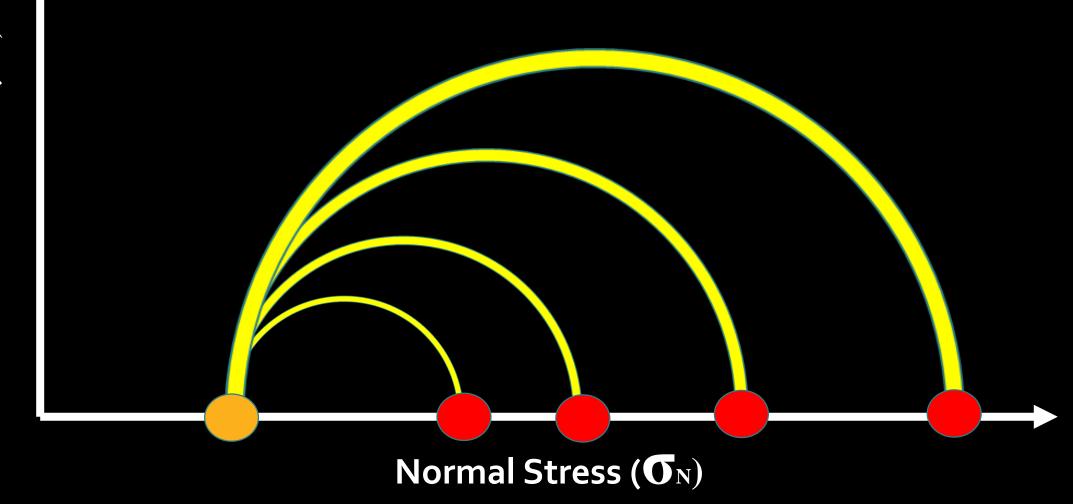


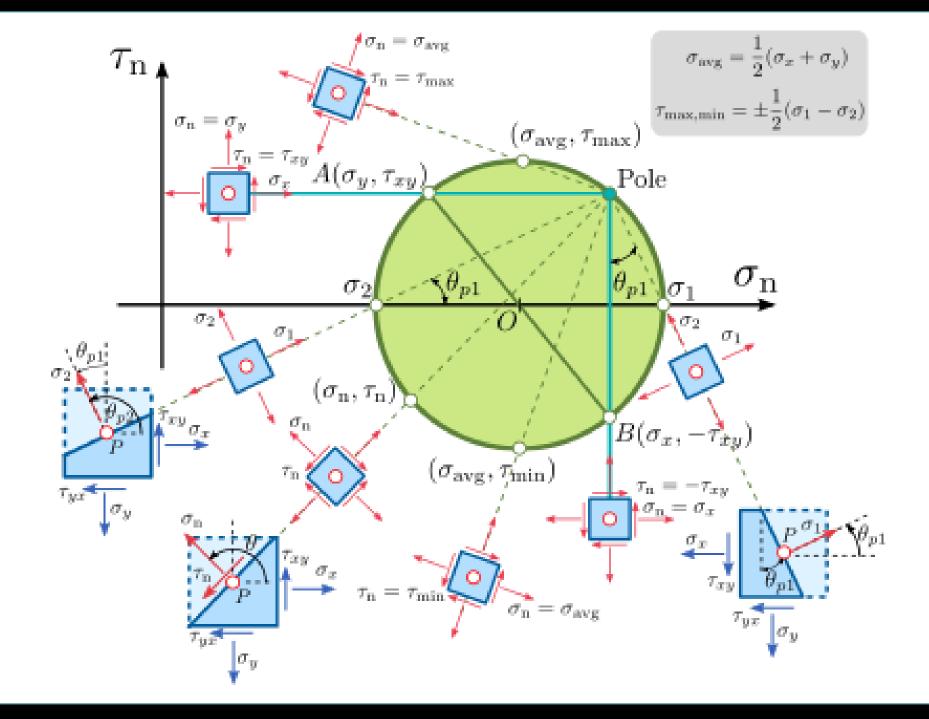


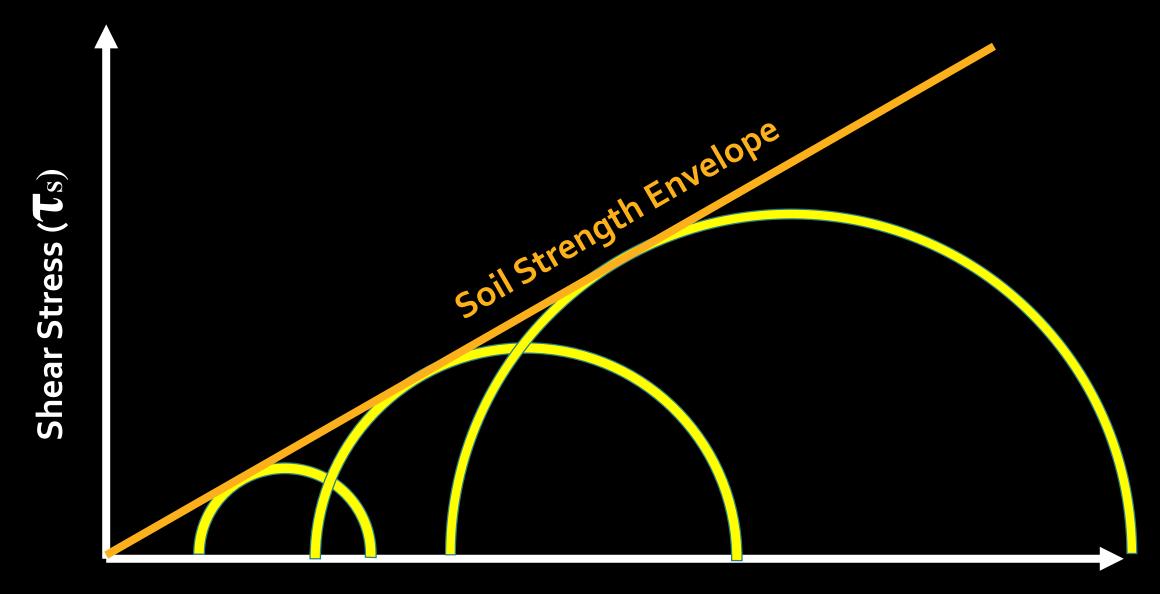
σ2

**51** 

### Shear Stresses Increase as Differences between $\sigma 1$ and $\sigma 2$ Normal Stresses Increase

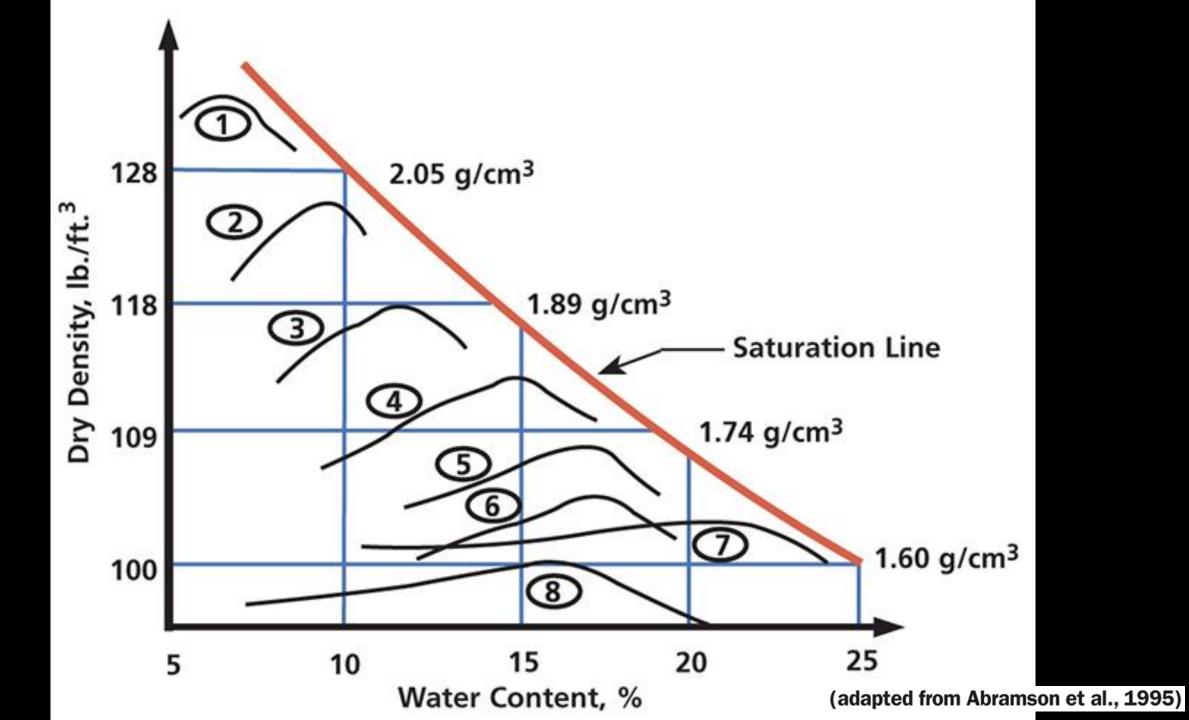


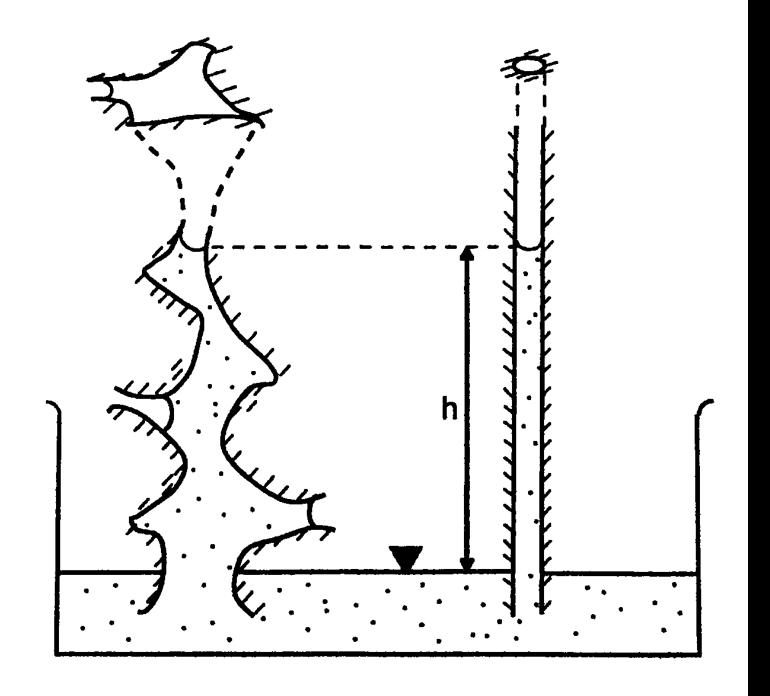




Normal Stress ( $\sigma_N$ )







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



Left: Control (non-compacted) soil.

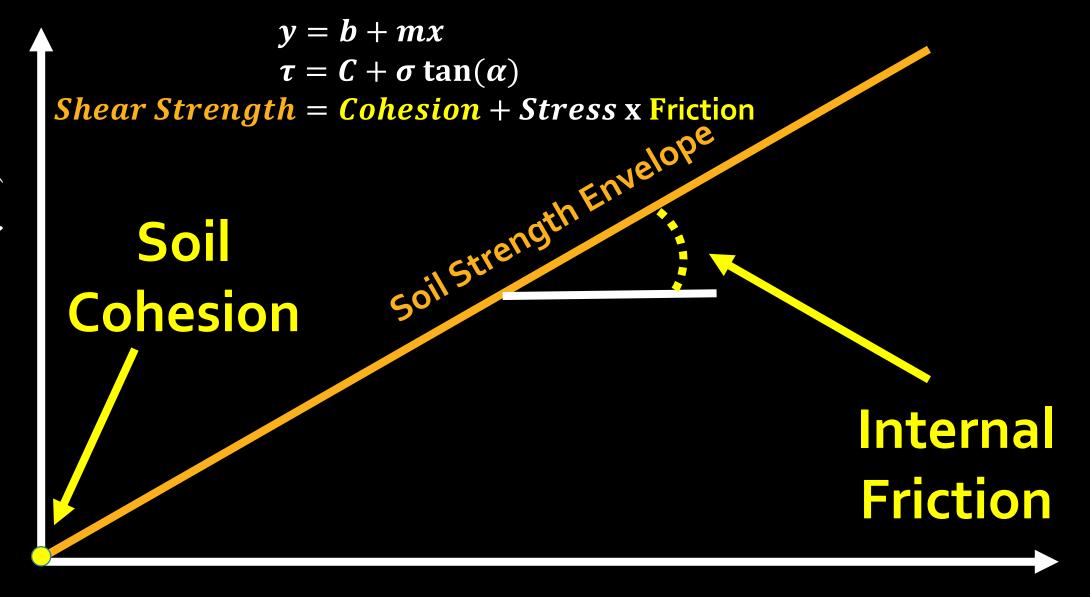


Right: Soil from plots where heavy machinery drove over the ground in an experimental treatment 29 years earlier.

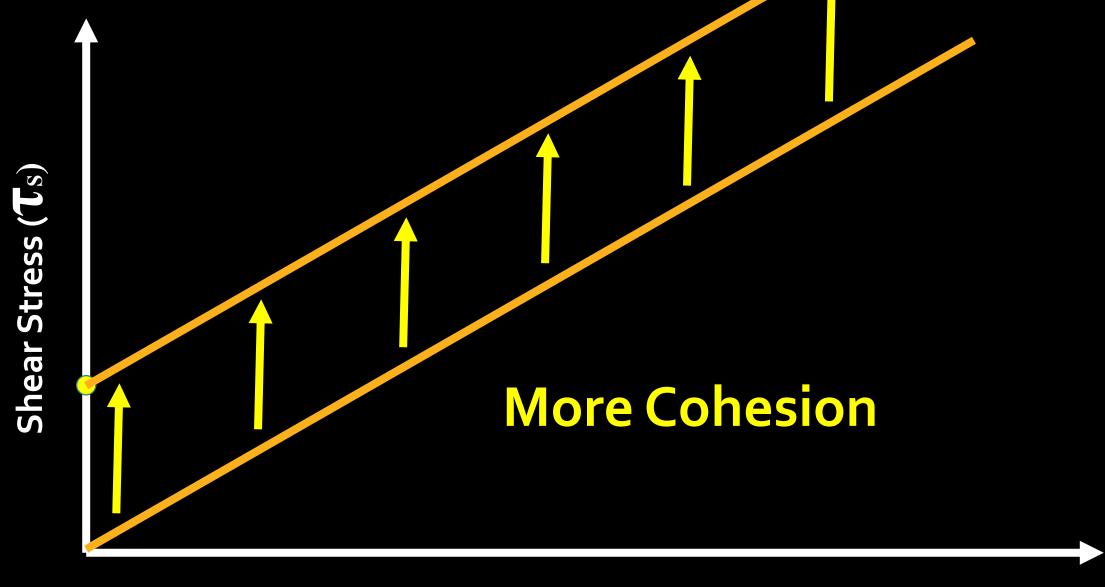
X-ray, computed tomography (CT) scans by Mathieu Lamandé.

https://www.soils.org/discover-soils/story/medical-imaging-helps-reveal-lasting-impacts-soil-compaction

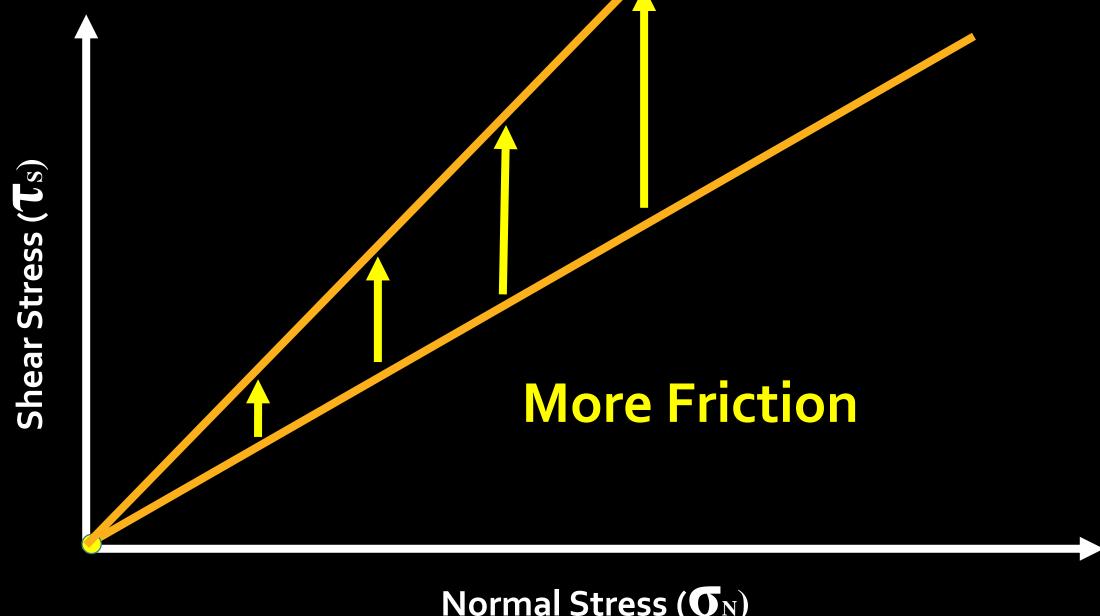
Normal Stress (**G**<sub>N</sub>)



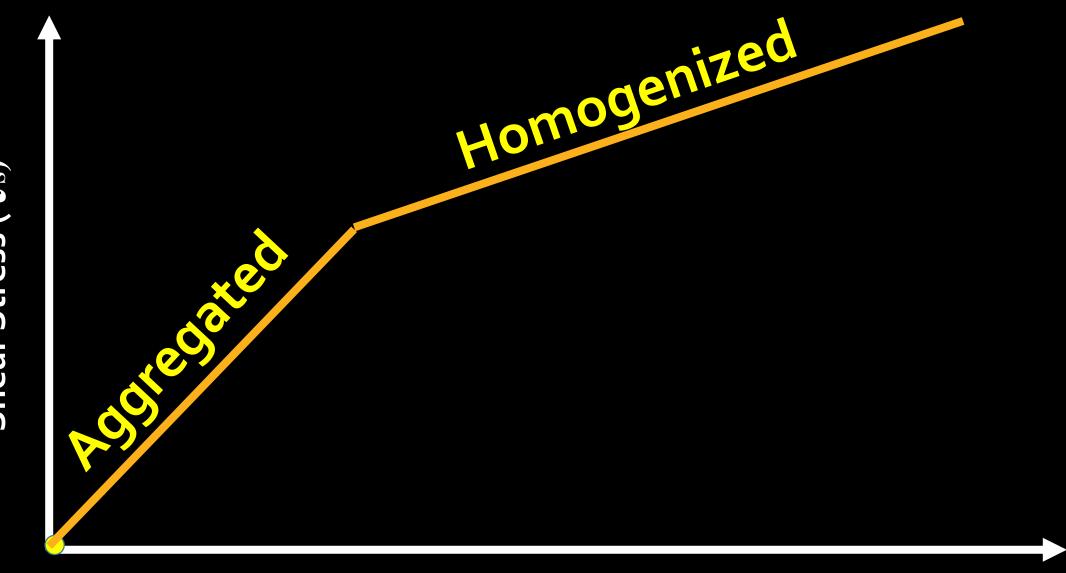
Normal Stress (**G**<sub>N</sub>)



Normal Stress (**G**<sub>N</sub>)



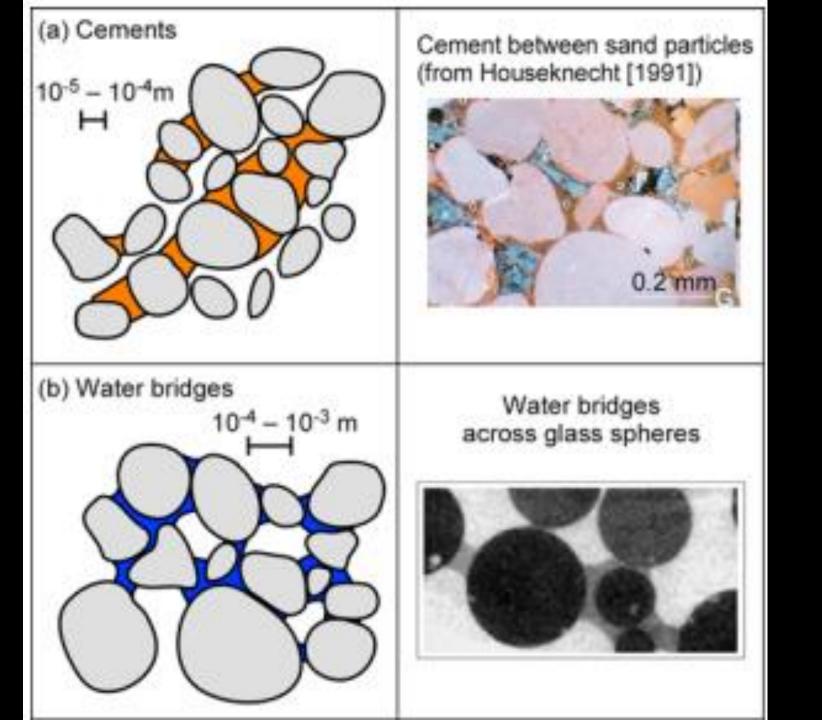
Normal Stress (**G**<sub>N</sub>)



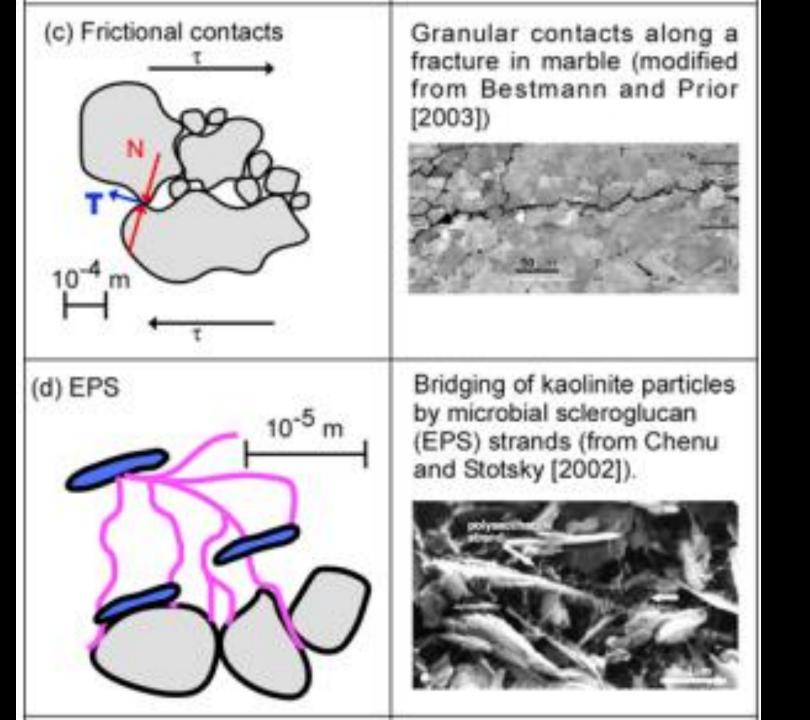
Normal Stress (**G**<sub>N</sub>)

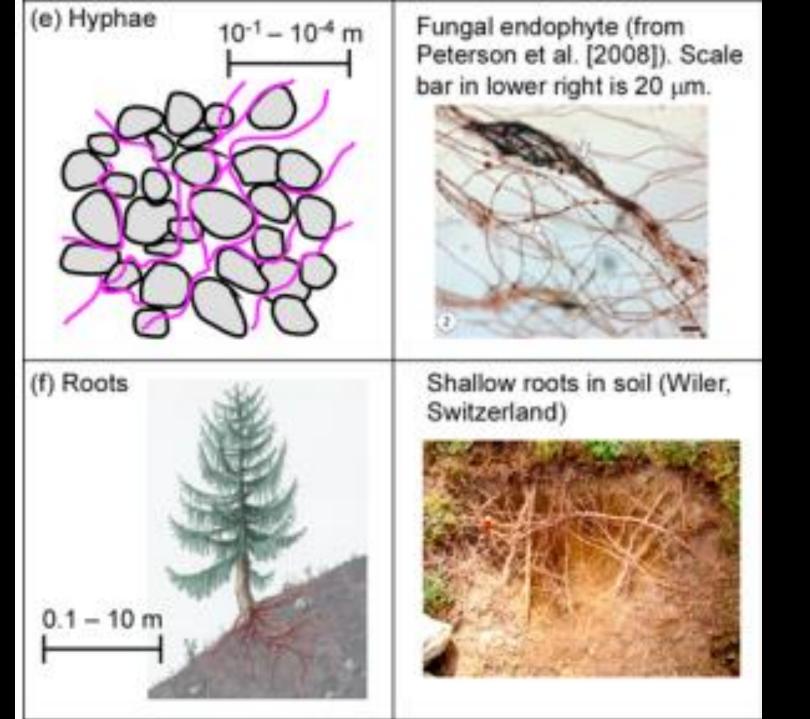
#### What Influences Cohesion and Friction?

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

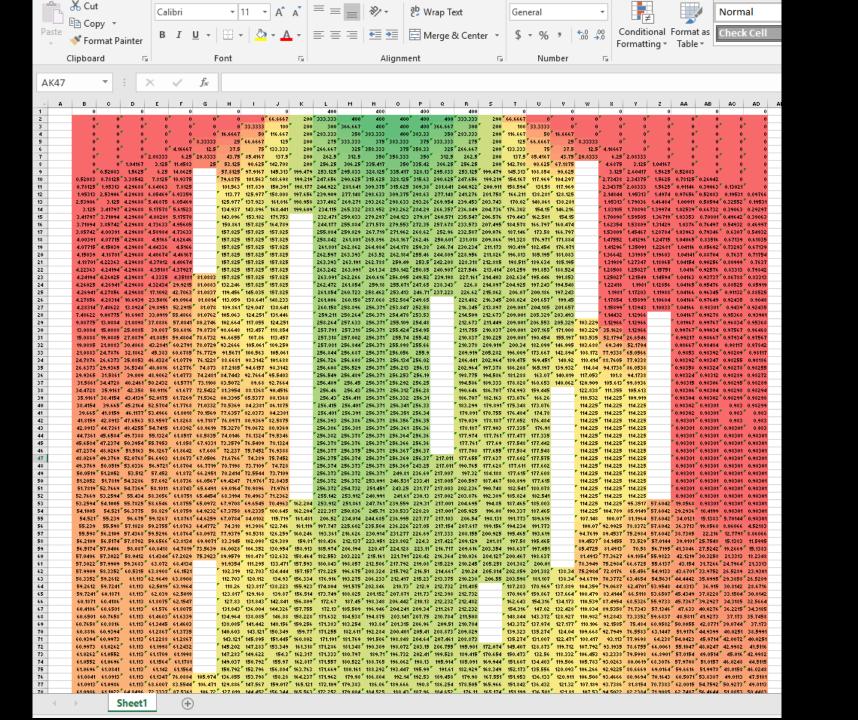


Cohen et al. 2009





XI 📙	5 · ♂ · 🚔 ÷												6	Tire Compaction Example Working.xlsx - Excel												
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Paste	Copy Format Painter	B <i>I</i>	<u>u</u> - 🖽	H - 2	- A	- ≡	==	任担	₽N	/lerge &	Center •	\$	- %	, 6.0	.00	Conditional		Check	Cell	Explo	anatory	Inpu	it		inked C	ell
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AT21	- : D	< 1	fx																							
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14 15	0 0	0 0	.02 0.05	0.1 0 0.26 0	0.49 1.17 0.63 1.8	7 3.29 9 3.86	6.54 13 8.33 14	.4 22.7 .6 25.3	37.3	54.8 76 56.8 76	.3 98.8 .8 98.1	120	139 143 135 14	9 155 7 149	143	139 120 135 119	98.8 76.3 98.1 76.8	54.8 31 56.8 31	7.3 22.7 8.7 25.3	13.4 6. 14.6 8.	54 3.29 33 3.86	1.17 0.4 1.89 0.6	3 0.26	0.05	0	
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( )																							4			



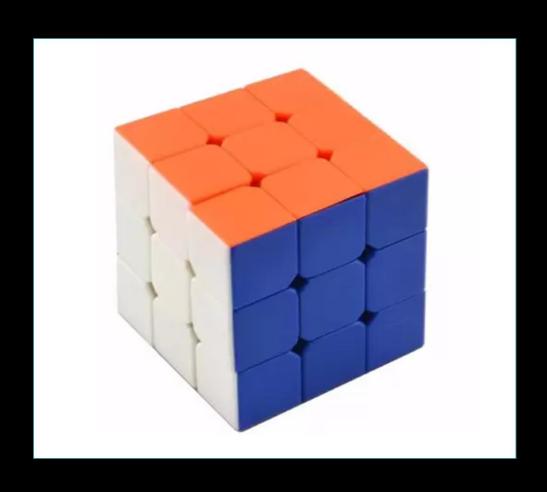
# What Strategies Can We Use From This Knowledge of Stress, Strain, & Strength?

- 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

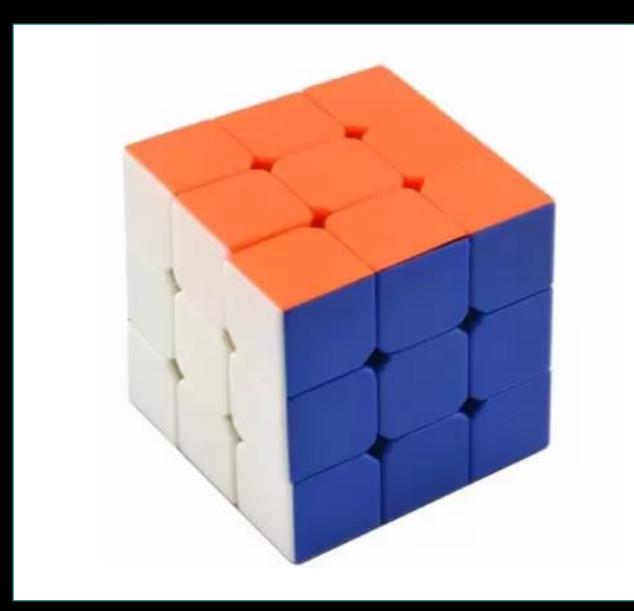




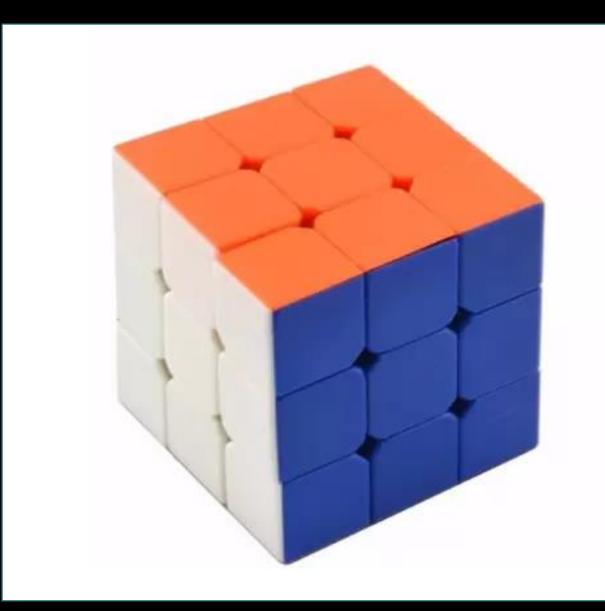
## How do you get it back in order?



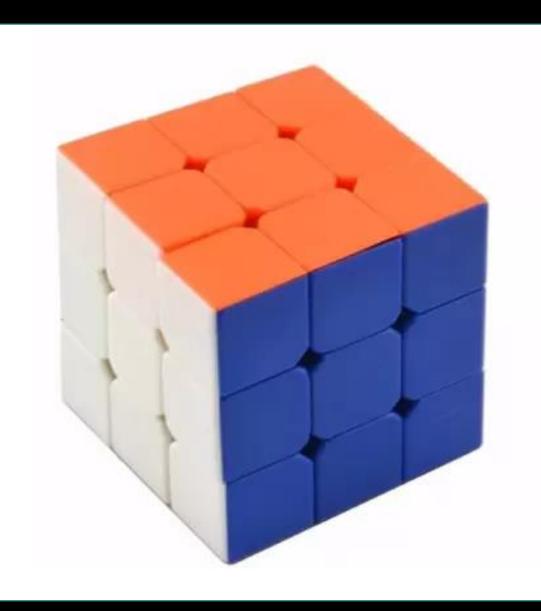




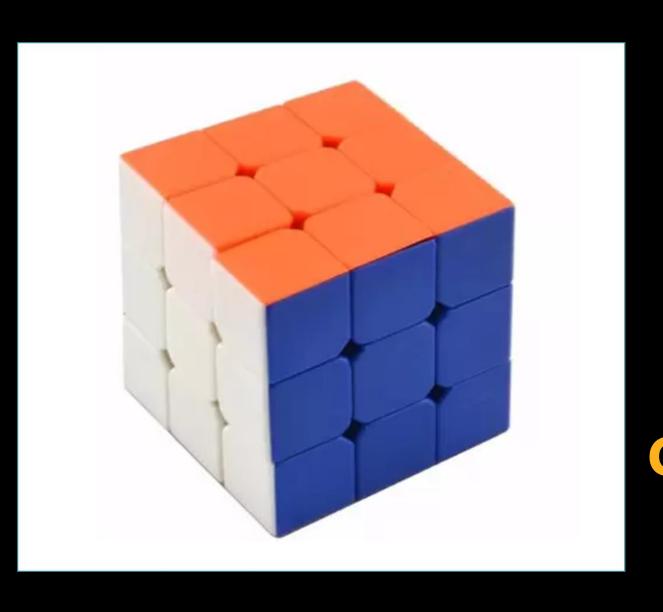
There is nothing special or magical about getting a cube back in order



It takes some knowledge... That's what you already have and why your at this workshop



It takes some trust in the process... Trust leads to Confidence



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

