New modelling tools for quantification of mechanical reinforcement of soil by plant roots

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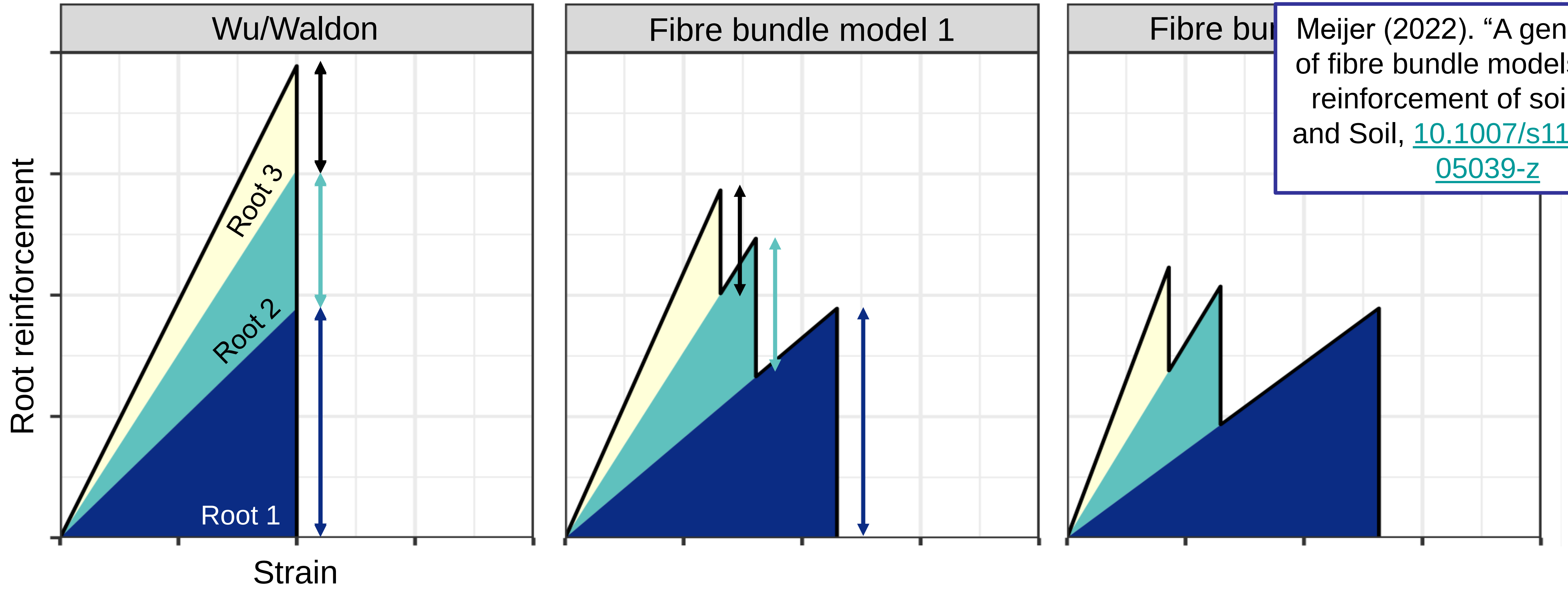
Sharing is encouraged

Fibre bundle models – load sharing



Meijer (2022). "A generic form of fibre bundle models for root reinforcement of soil", Plant and Soil, 10.1007/s11104-021-05039-z

Different load sharing mechanisms (β_F) result in widely varying reinforcement predictions

$$\frac{\text{Force in root } i}{\text{Force in root } j} = \left(\frac{\text{diameter } i}{\text{diameter } j}\right)^{\beta_F}$$

Fibre bundle models ♥ Waldron

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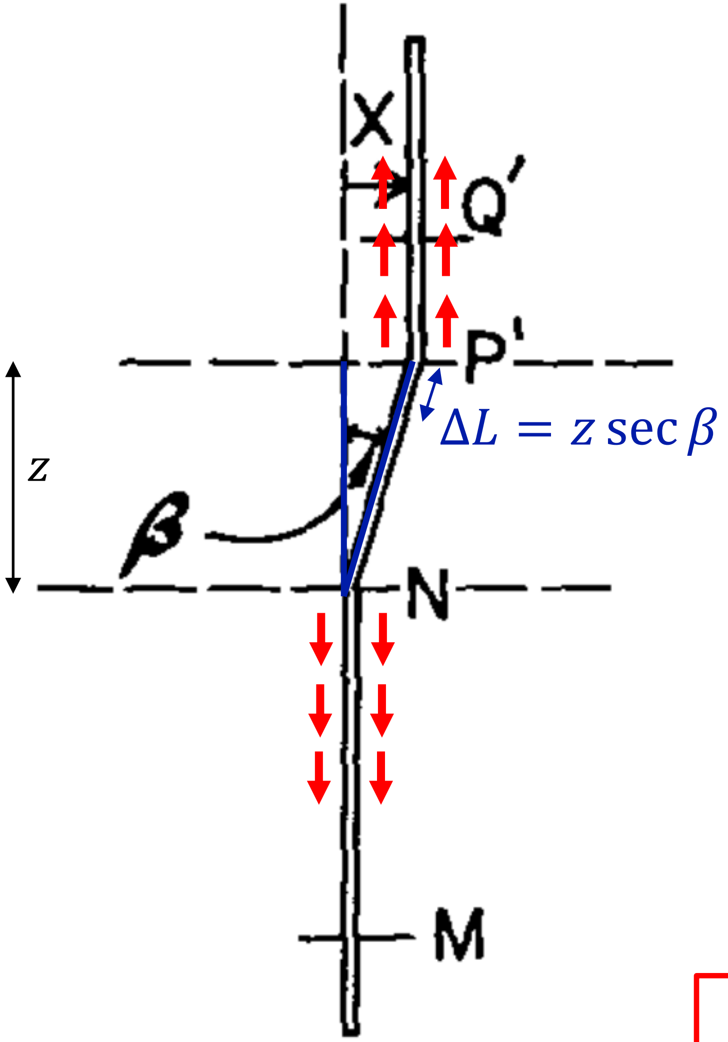


Waldron's original model from 1977:

1. Shear displacement generate root elongation and therefore tensile stress
2. Tensile stress reduces with distance to shear zone because of root-soil interface resistance

Equivalent FBM load sharing coefficient:

$$\beta_{F,Waldron} = 1.5 + 0.5\beta_E$$

Root diameter-stiffness power coefficient

$$E_r = E_{r,0}\left(\frac{d_r}{d_{r,0}}\right)^{\beta_E}$$

This gives us a FBM with a realistic strength mobilisation mechanism

DRAM ♥ Waldron

- We need to study the **mechanism** of root strength mobilisation in more detail
- Back to basics: based on Waldron (1977)'s original ideas, but with many improvements
- **DRAM**: Dundee Root Analytical Model
- DRAM is a **new**…
  …**fully analytical model…**
  …accounting for the **mobilisation…**
  …of **mechanical root reinforcement…**
  …in **direct shear conditions** such as landslides

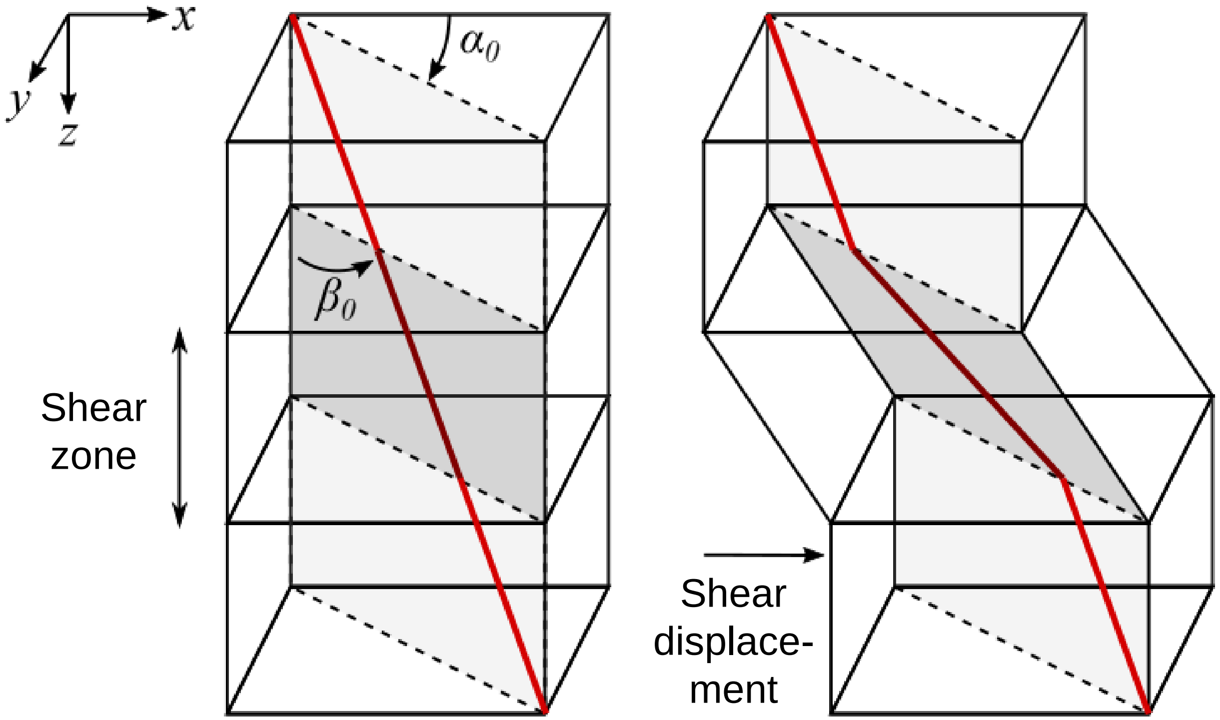
Meijer et al. (2022). "DRAM: a three-dimensional analytical model for the mobilisation of root reinforcement in direct shear conditions", Ecological Engineering, https://doi.org/10.1016/j.ecoleng.2022.106621

gjmeijer.shinyapps.io/DRAM

DRAM: let’s focus on what really happens in the soil

1. **3-dimensional root orientations**

Some roots mobilise faster than others, depending on their initial **orientation**



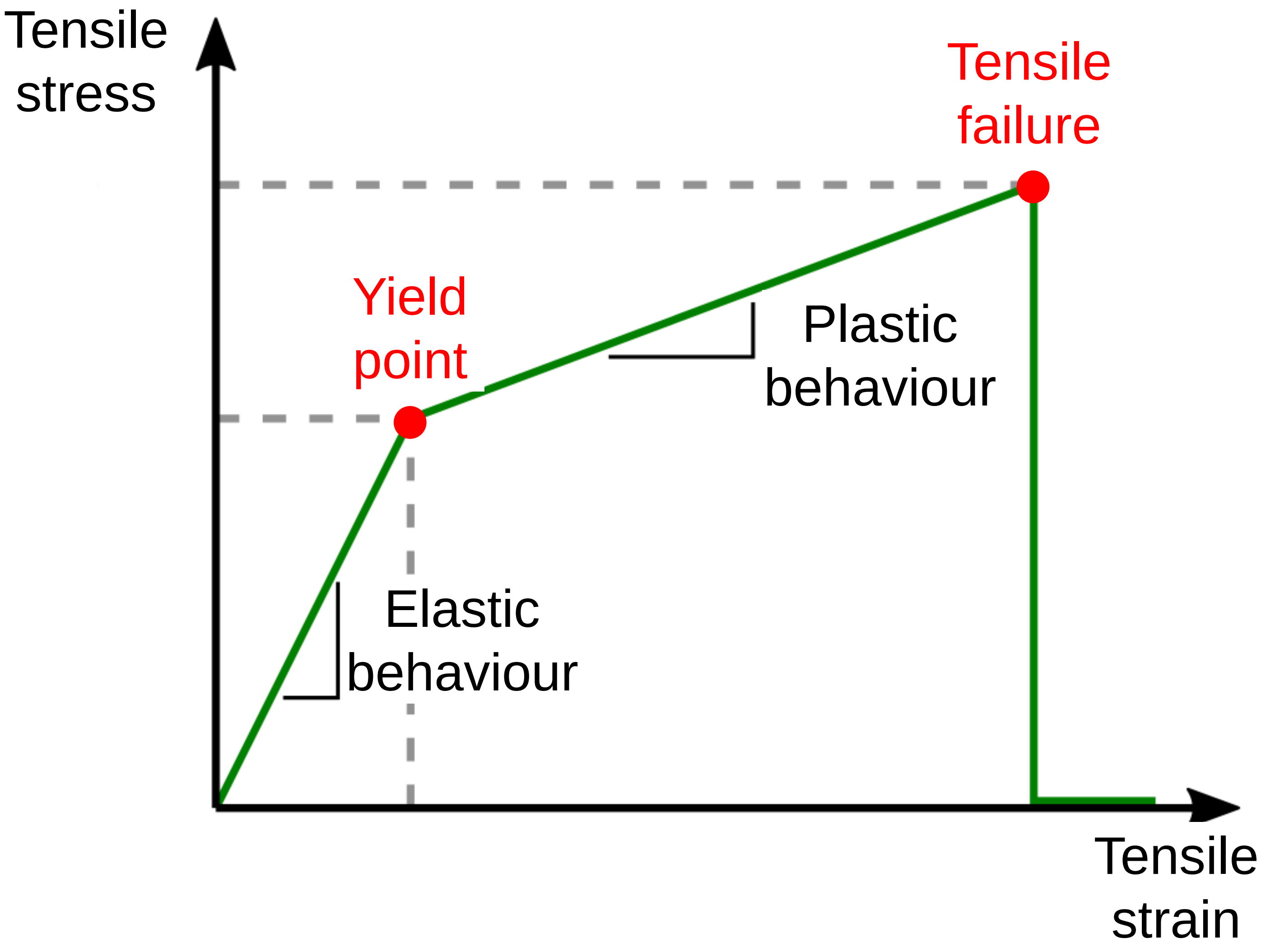
a) undisplaced position

b) displaced position

DRAM: let's focus on what really happens in the soil

1. 3-Dimensional root orientations

2. **Elasto-plastic root tensile behaviour**



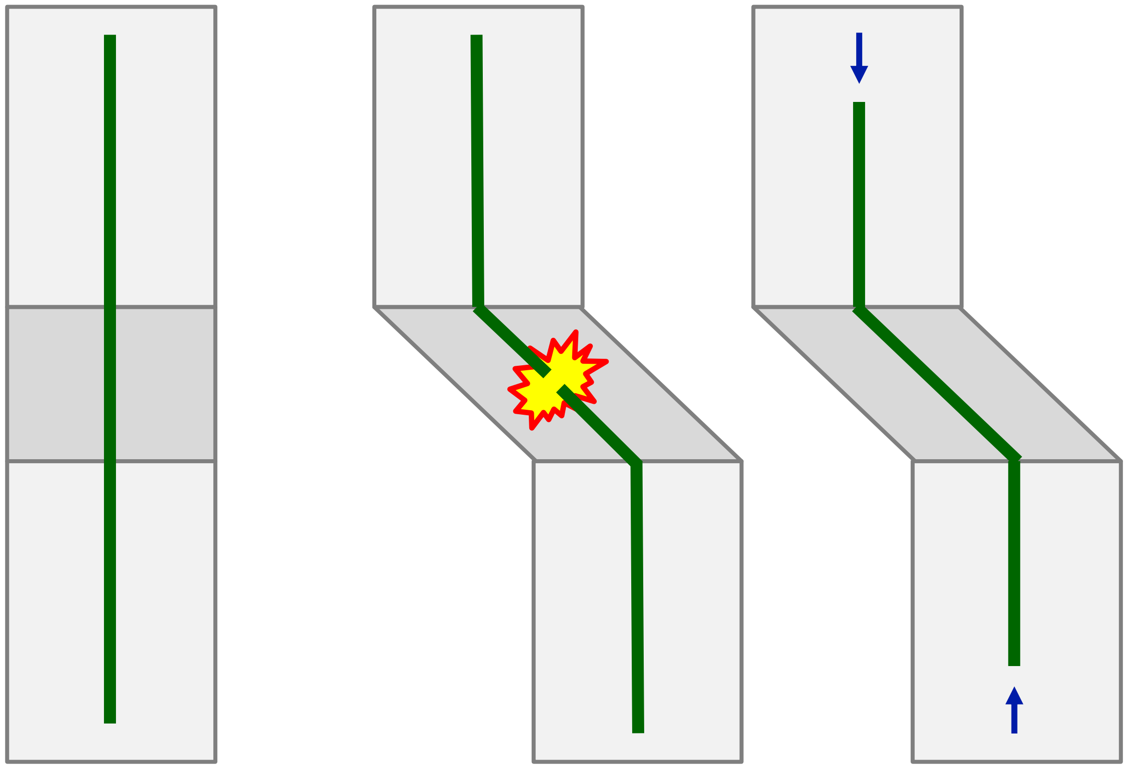
DRAM: let's focus on what really happens in the soil

1. 3-Dimensional root orientations
2. Elasto-plastic root tensile behaviour
3. **Root slippage and breakage**

Unde-formed position

Long or well-anchored roots **break**

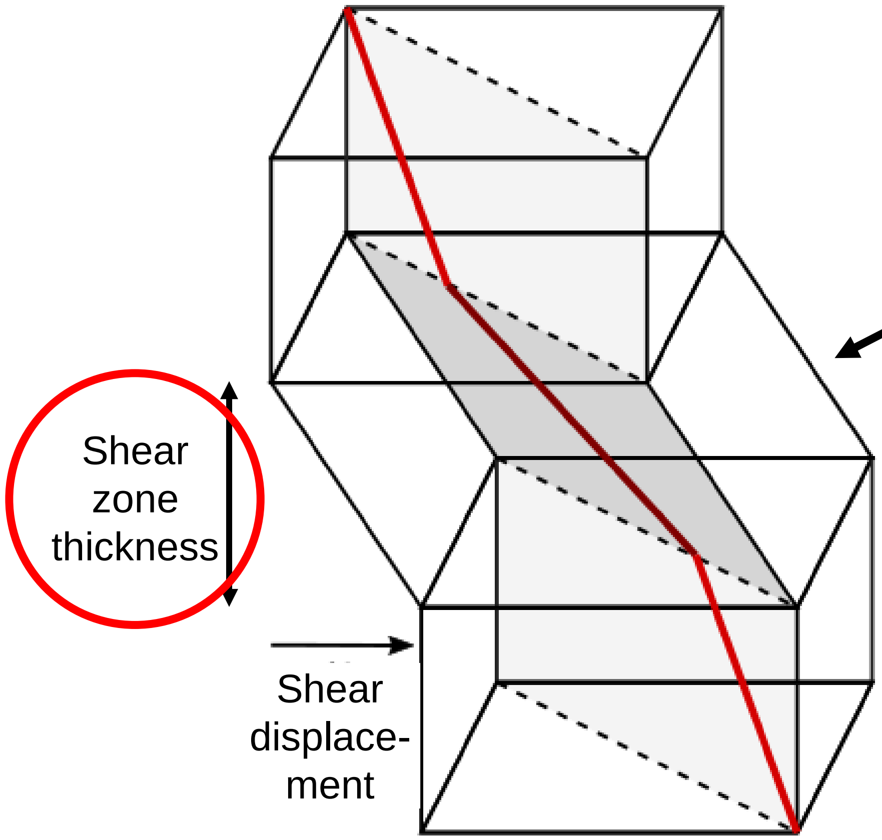
Short or poorly anchored roots **slip**



DRAM: let's focus on what really happens in the soil

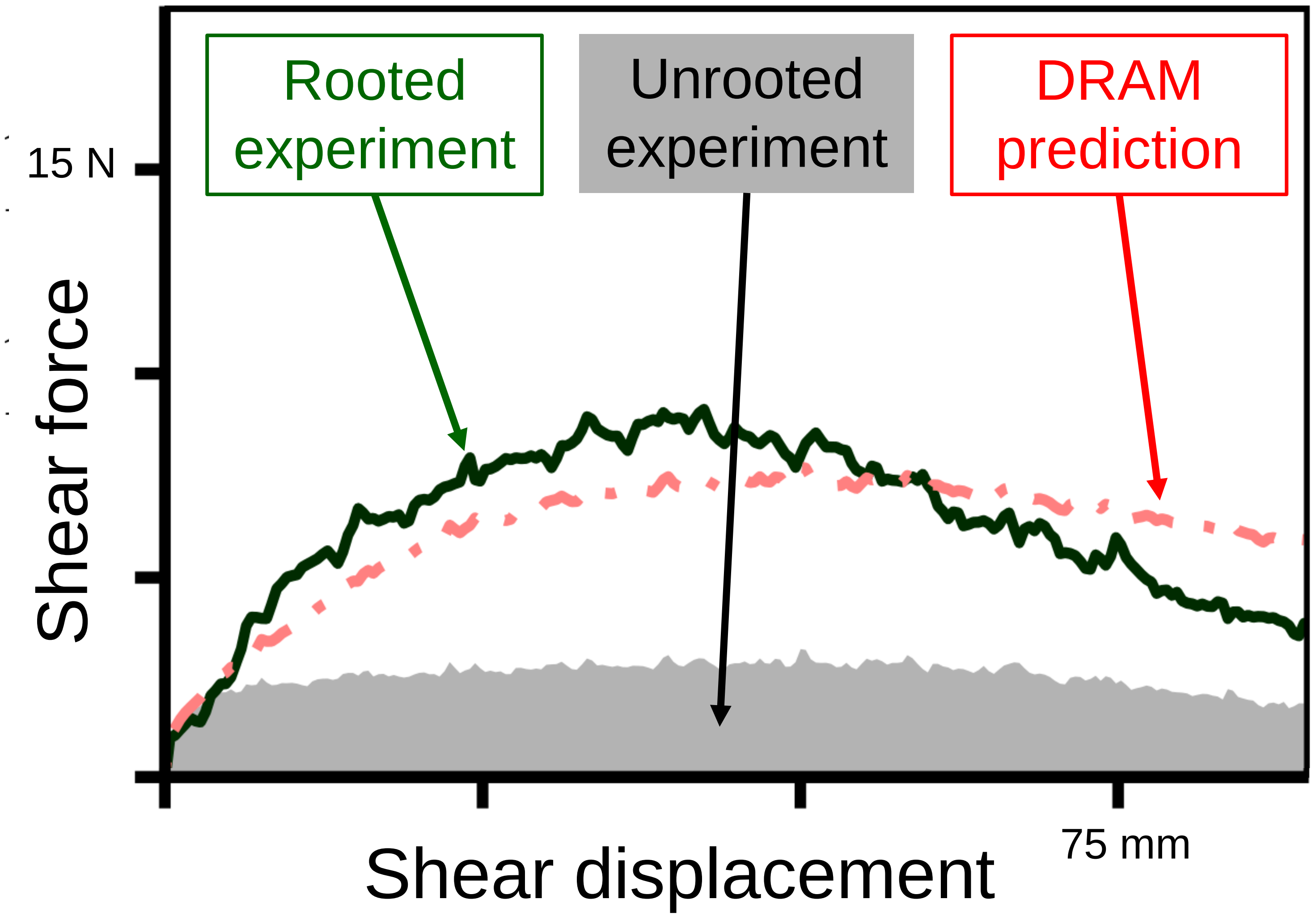
1. 3-Dimensional root orientations
2. Elasto-plastic root tensile behaviour
3. Root slippage and breakage
4. **Dynamic shear zone thickness**

Shear zone thickness in rooted soil often observed to be larger than in unrooted soil



Shear zone thickness allowed to **increase** during shear displacement to ensure **soil stress equilibrium**

DRAM: let's focus on what really happens in the soil



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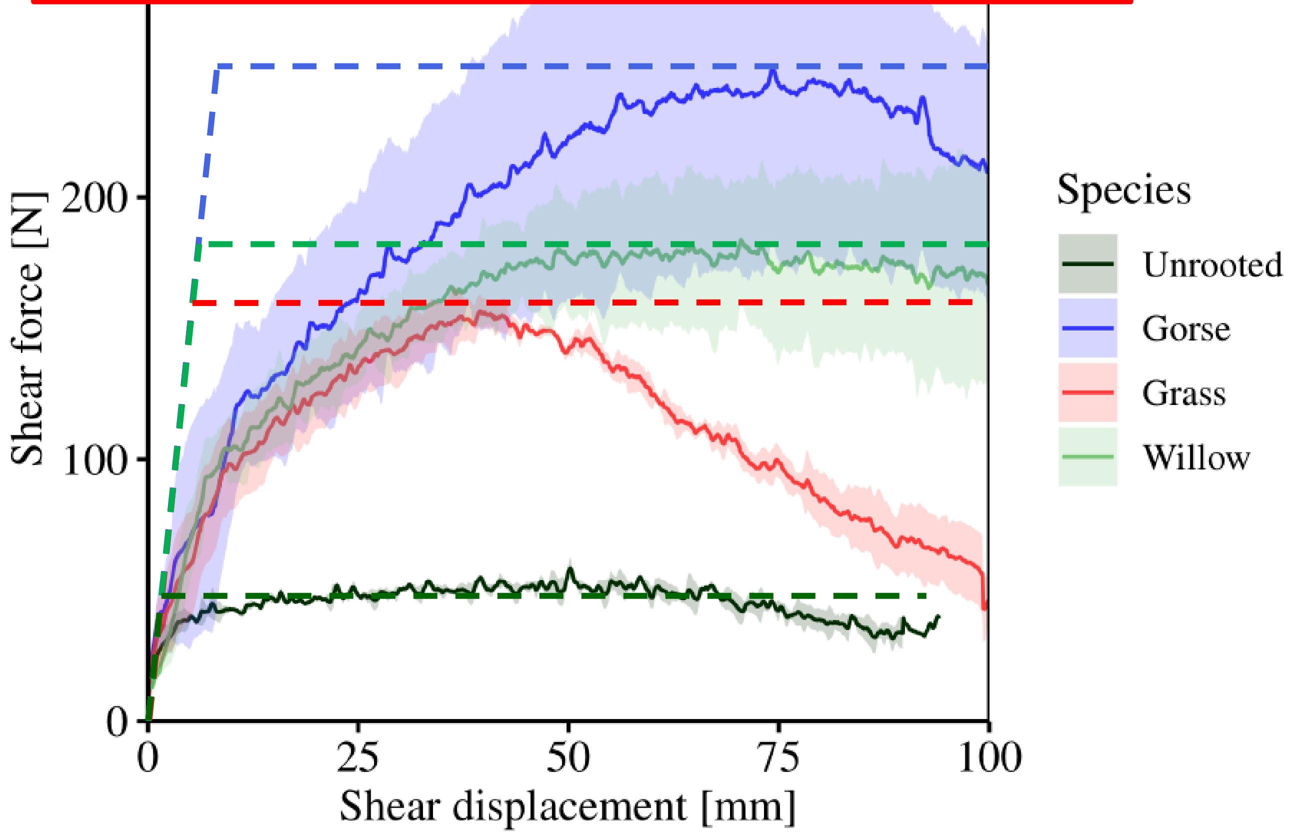
Finite Elements & the limits of "root cohesion"

Including root-reinforcement as an increase in soil cohesion may not be accurate

Grass

Willow



Liang et al. (2017). Ecological Engineering 107:207-227

Finite Elements - Composite modelling

Composite modelling – stress is distributed according to the volume fraction (ϕ) of each constituent:

$$\sigma = \phi_{soil}\sigma_{soil} + \phi_{root}\sigma_{root}$$

Assume equal strain in each constituent:

$$\epsilon = \epsilon_{soil} = \epsilon_{root}$$

We need two constitutive models: one for the soil, and one for the root

Meijer et al. (2022). "Root reinforcement: continuum framework for constitutive modelling", Geotechnique, https://doi.org/10.1680/jgeot.21.00132

Finite Elements - Composite modelling

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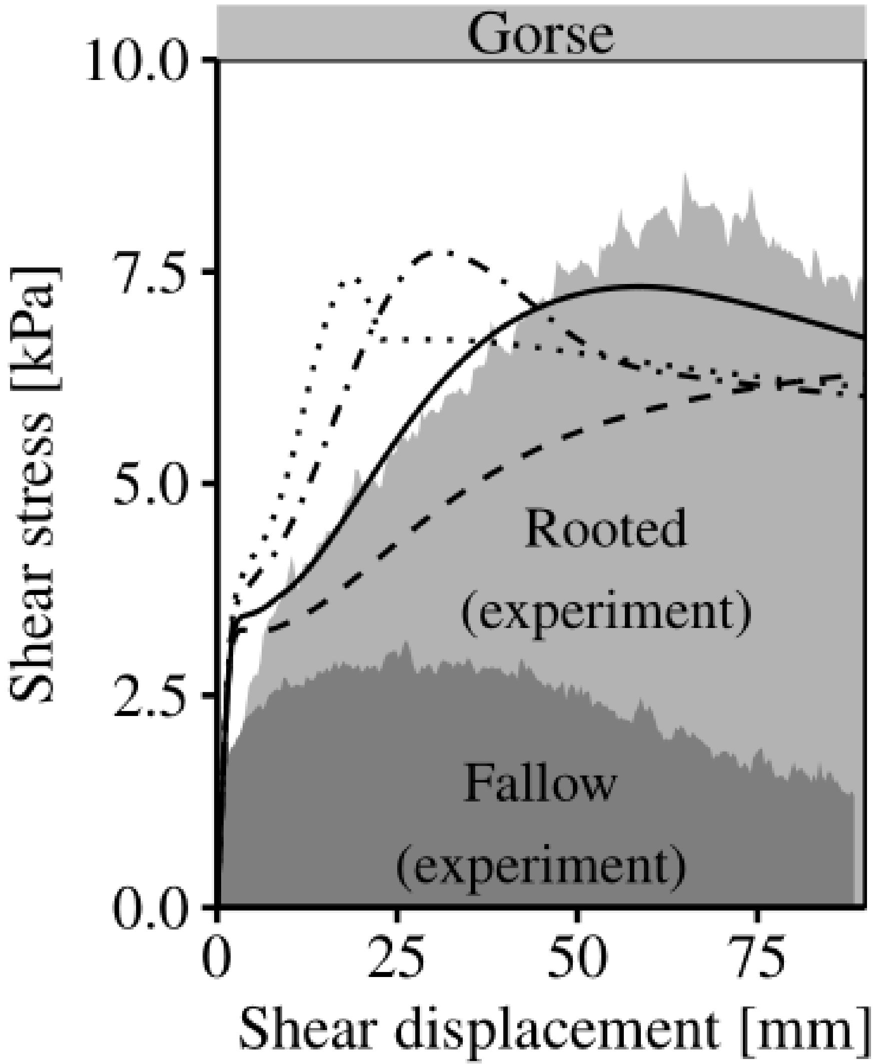

Treating 'soil' and 'root' as a **composite material** in finite element analyses provides better insight in:

- How the rooted soil mobilises (and loses!) strength with ongoing deformation
- Interaction between soil stresses, root stresses and volume change

Meijer et al. (2022). "Root reinforcement: continuum framework for constitutive modelling", Geotechnique, https://doi.org/10.1680/jgeot.21.00132

Conclusion

1. Improved load sharing rules for **Fibre Bundle Models**

Meijer (2022). "A generic form of fibre bundle models for root reinforcement of soil", Plant and Soil, DOI: 10.1007/s11104-021-05039-z

gjmeijer.shinyapps.io/FBMcw

2. New analytical model for root reinforcement in direct shear (**DRAM**)

Meijer et al. (2022). "DRAM: a three-dimensional analytical model for the mobilisation of root reinforcement in direct shear conditions", Ecological Engineering, DOI: 10.1016/j.ecoleng.2022.106621

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3. Constitutive framework for **FEM** based on composite theory

Meijer et al. (2022). "Root reinforcement: continuum framework for constitutive modelling", Geotechnique, DOI: 10.1680/jgeot.21.00132

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