

Tree anchorage : the mechanical properties of structural roots

Pauline Défossez

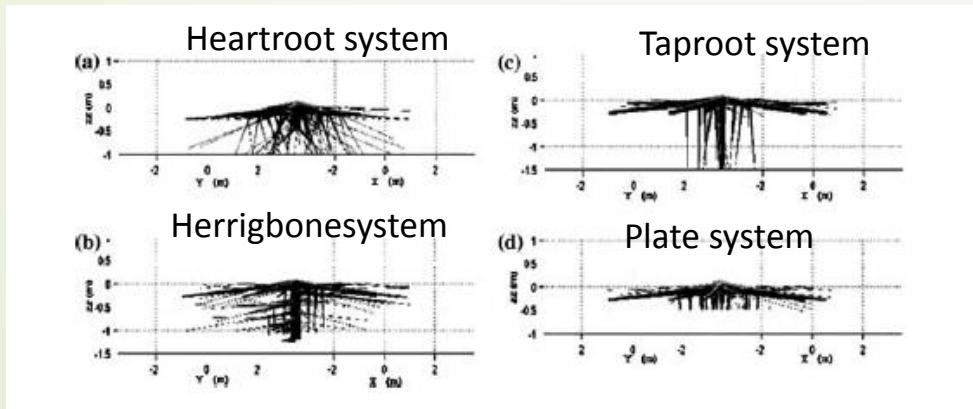
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UMR Biogeco, INRA
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The mechanical strength of structural roots

- Architecture of root system

Coutts, 1983; Coutts, 1986; Ennos et al., 1993; Crook & Ennos, 1996; Ray & Nicoll, 1998; Coutts et al., 1999; Moore, 2000; Danjon et al., 2005; Dupuy et al, 2005...



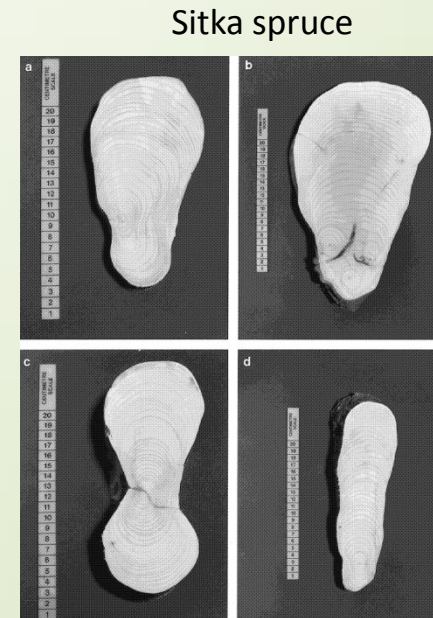
Dupuy et al 2005

- Geometry of roots

Shape of root section *Nicoll & Ray, 1996; Coutts et al., 1999*

Dimensions

- Resistance of root wood

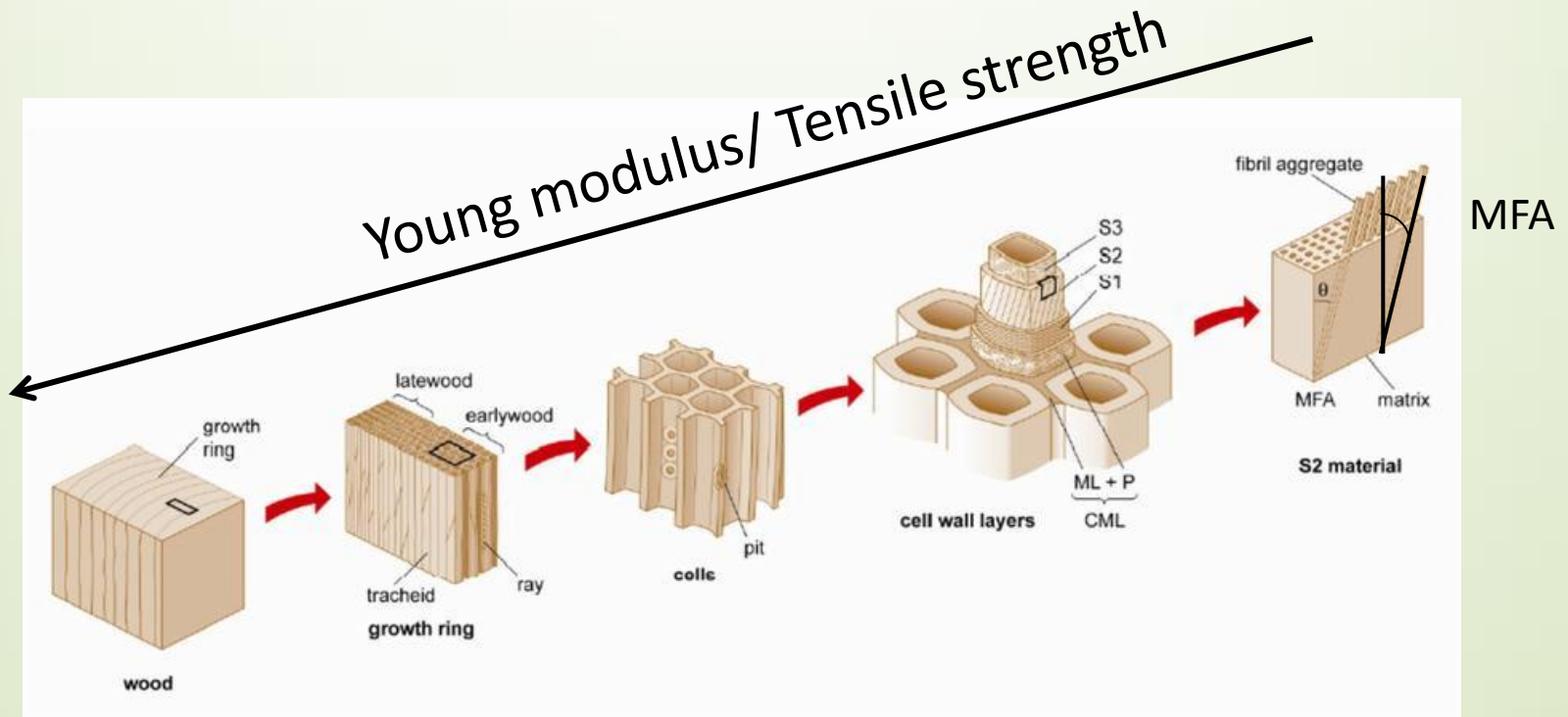


Nicoll & Ray, 1996

Questions

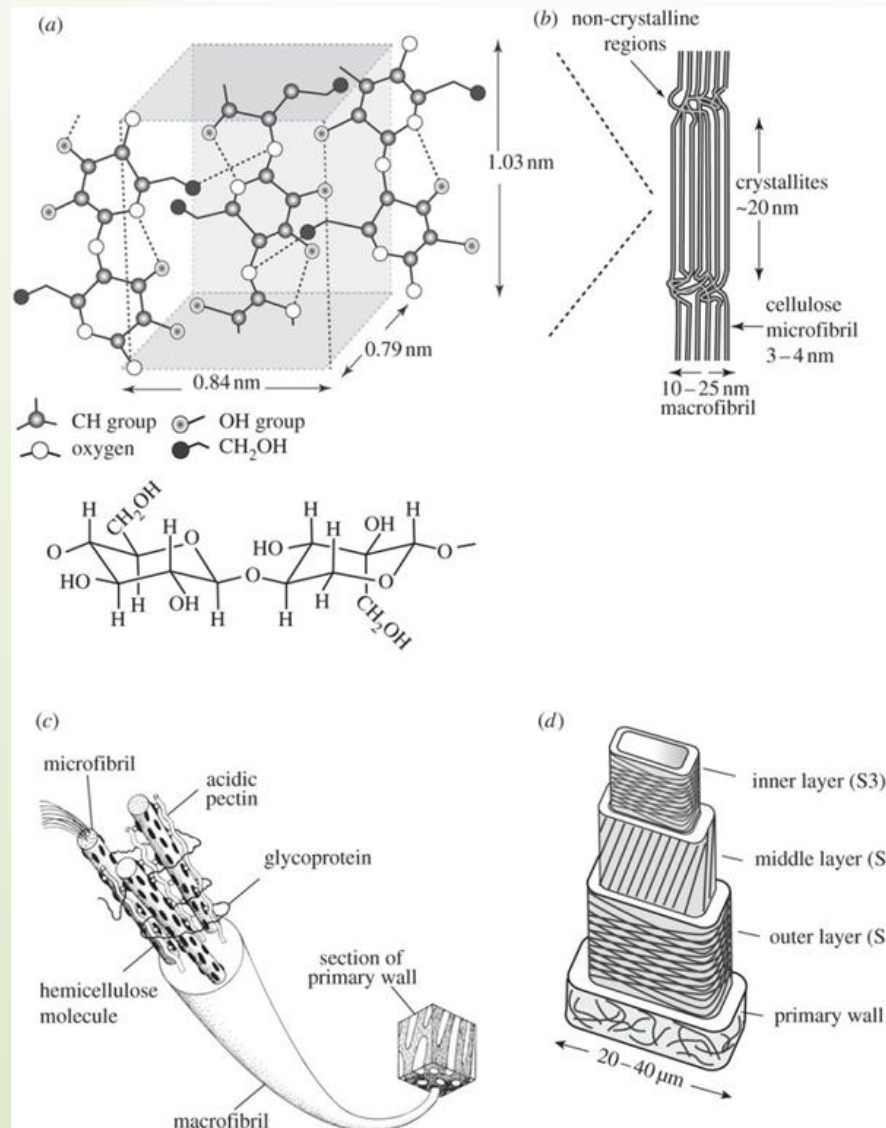
- Quantify the properties of structural roots and their variations
- Analyse the link between root mechanical properties, the biochemistry, the wind direction, and the root physical characteristics
- Clarify the role of root mechanical properties in root anchorage

Advances on wood



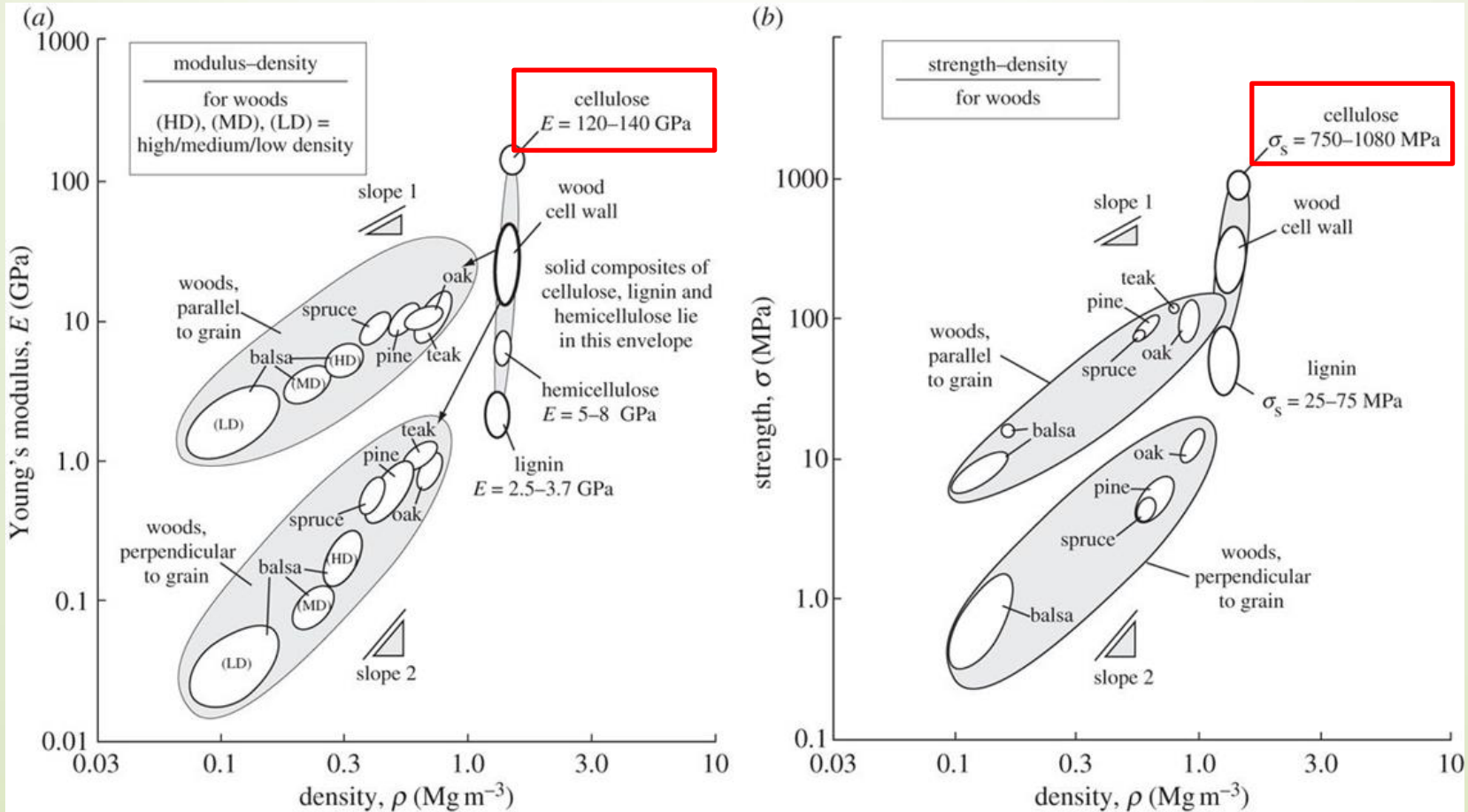
Source ETH Zurich

Advances on wood



Gibson (2012)

Advances on wood



Gibson (2012)

Advances on wood

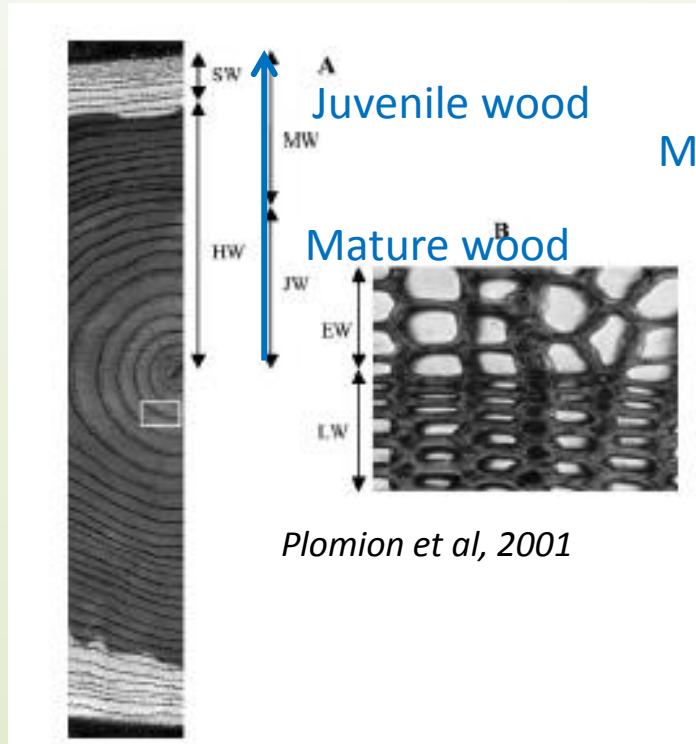
MFA ↗ Axial Young modulus
Tensile strength ↘

review Donalson, 2008

MFA ↗
Moore et al, 2014

bark

pith



MFA ↘

Early wood

Late wood

MFA ↘

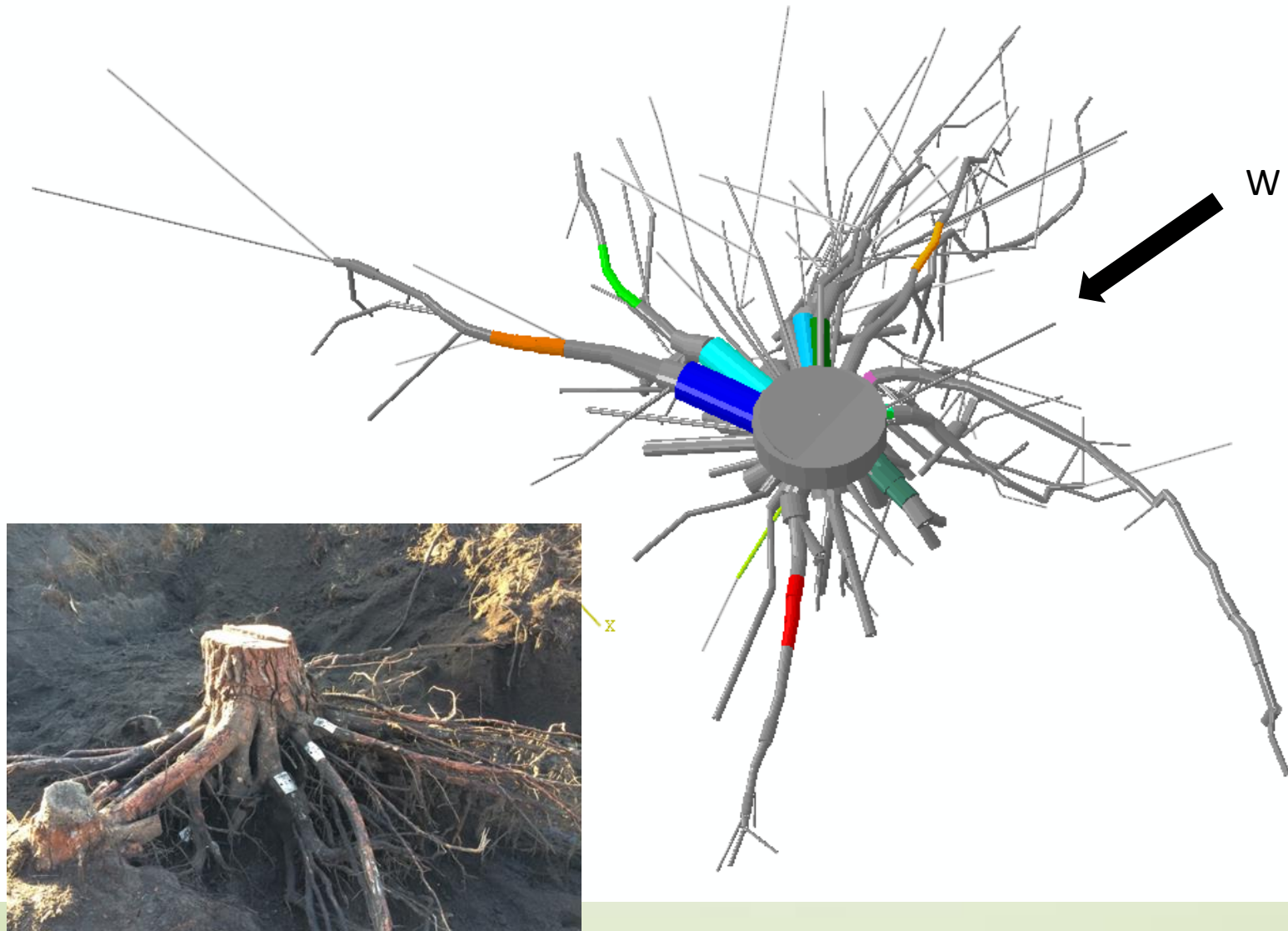
Wood properties of roots

- Measurements on fine roots < 10 mm
 - Tensile strength decreases with
 - ✓ diameter of roots (Stokes; Bischetti...)
 - ✓ cellulose (Genet, 2005)
- Few measurements on structural roots
 - Rupture limit
 - ✓ has an optimum as function of distance from root base (Niklas, 1999; Stokes and Mattheck, 1996)
 - ✓ increases with wind exposure (Niklas, 1999)
 - Young modulus
 - ✓ decreases with wood density (Khuder et al, 2007)
 - ✓ increases with wind exposure (Stokes et al, 1997; Niklas, 1999)

Material and Methods

- Maritime Pine (h=24m, DBH=115 cm)
- Excavation of one root system
- Root architecture
- Mechanical properties on decimeter beams of green root wood
- Cellulose and lignin contents
- Root Cross section area

Root architecture/sampling



Cross root sections

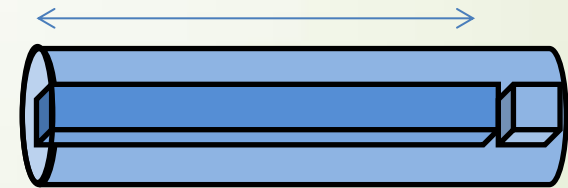


Materials and methods



27 Root elements

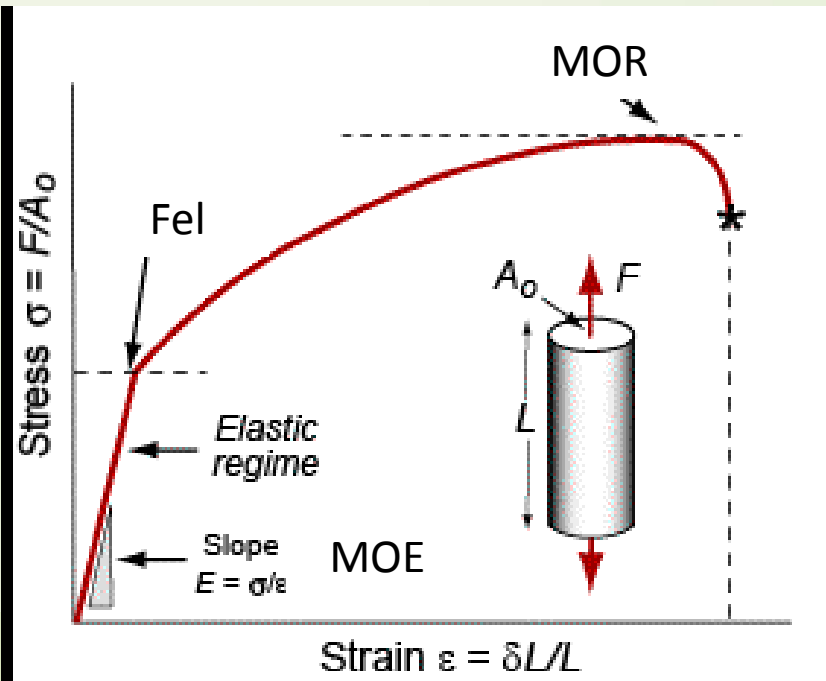
20 cm



section

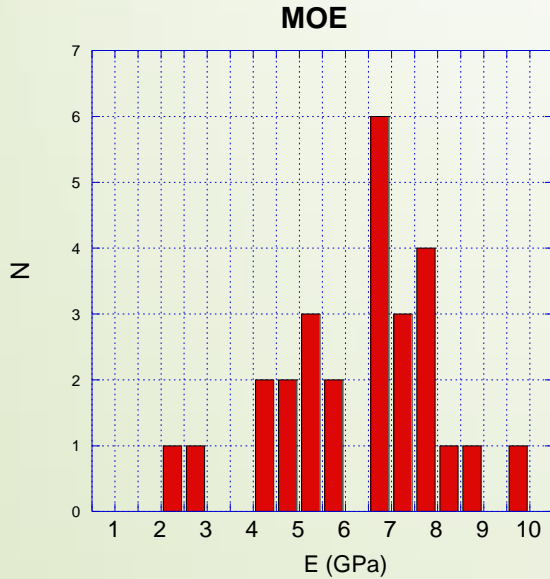
Flexion tests
Cellulose content

density
humidity

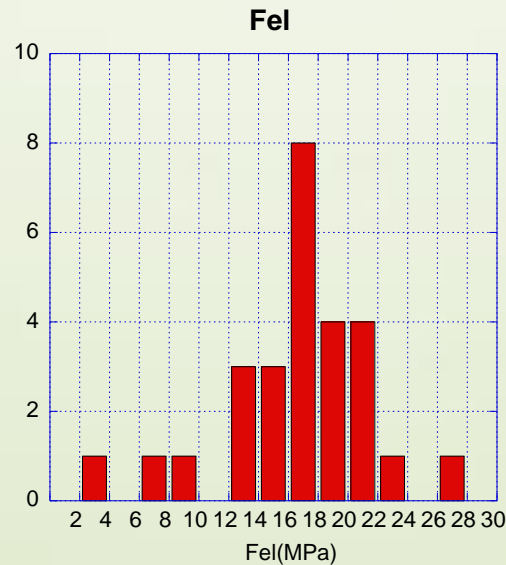


Results

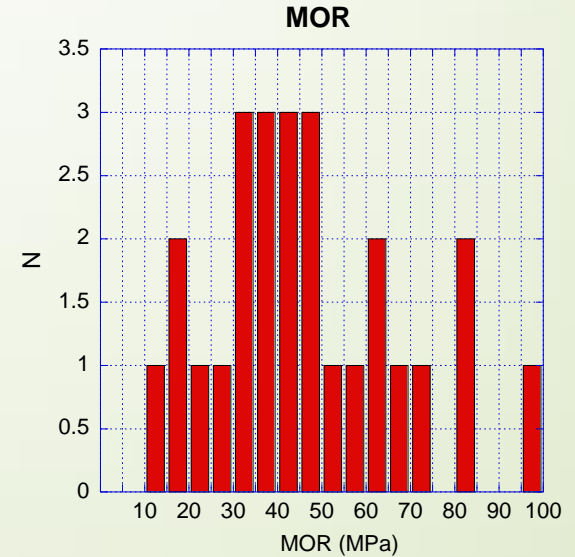
- High dispersion



MOE=6.334 GPa
 σ =1.773 GPa
28 %



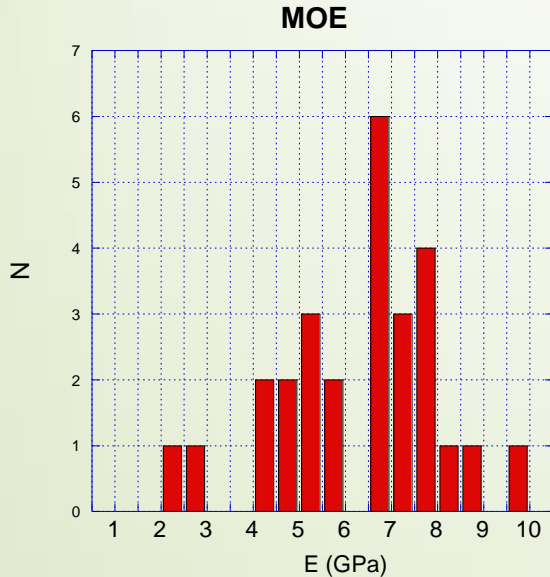
MOR=46.47 MPa
 σ = 21.11 MPa
45 %



Fel=16.50 MPa
 σ = 4.82 MPa
29 %

Results

- Young modulus MOE



Beam 10 cm X 1 cm²
Maritime pine

MOE= 8.122 GPa

Khuder et al (2007)

MOE=6.334 GPa

σ =1.773 GPa

28 %

Results

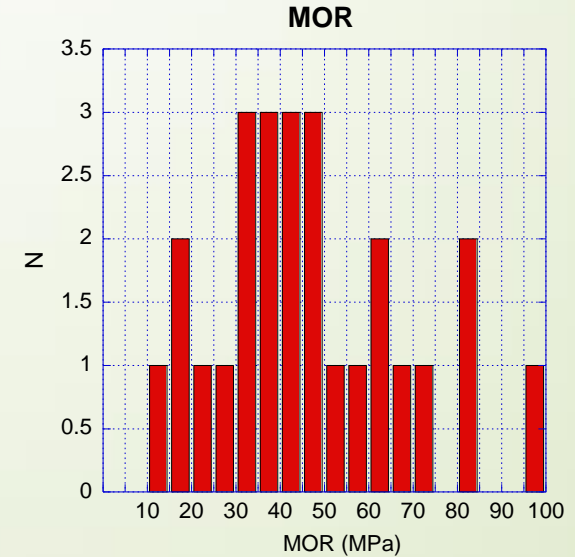
- Tensile strength: MOR

Fine roots < 3 mm
Maritime pine

MOR ≈ 20 MPa

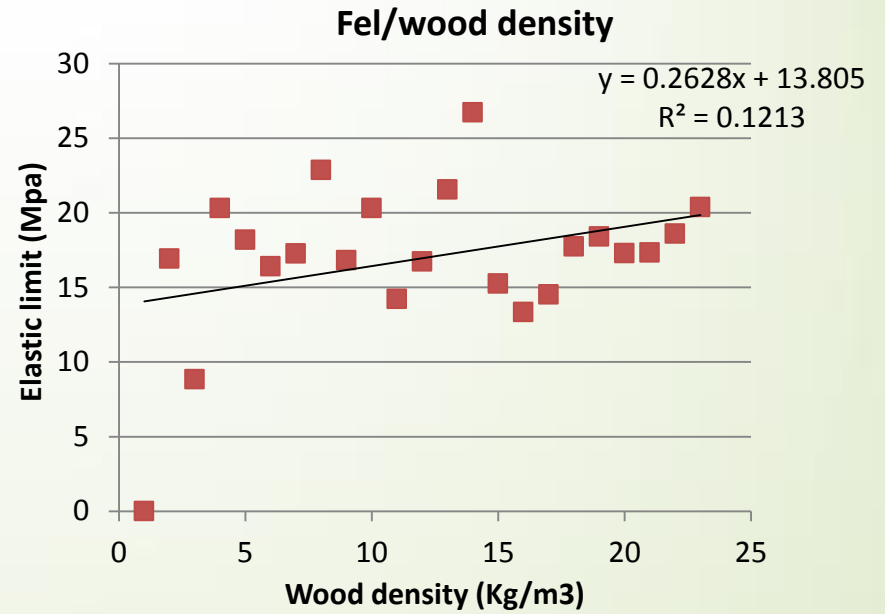
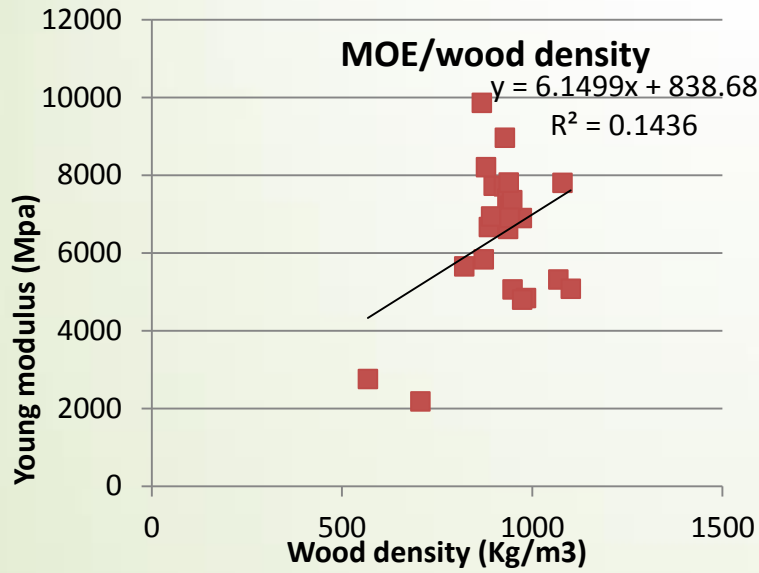
Genet et al (2005)

MOR = 46.47 MPa
 $\sigma = 21.11$ MPa
45 %



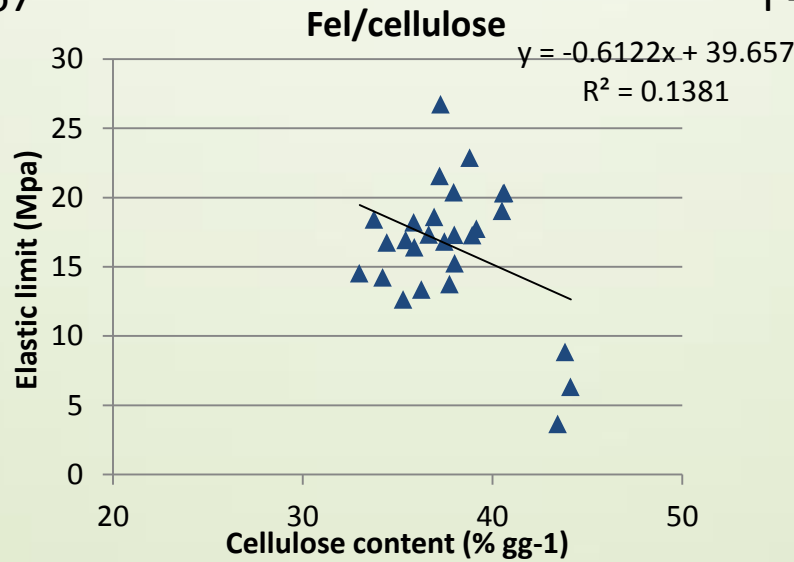
Variations

- Wind direction
- Cross section area
- Cellulose and lignin content
- Wood humidity, wood density



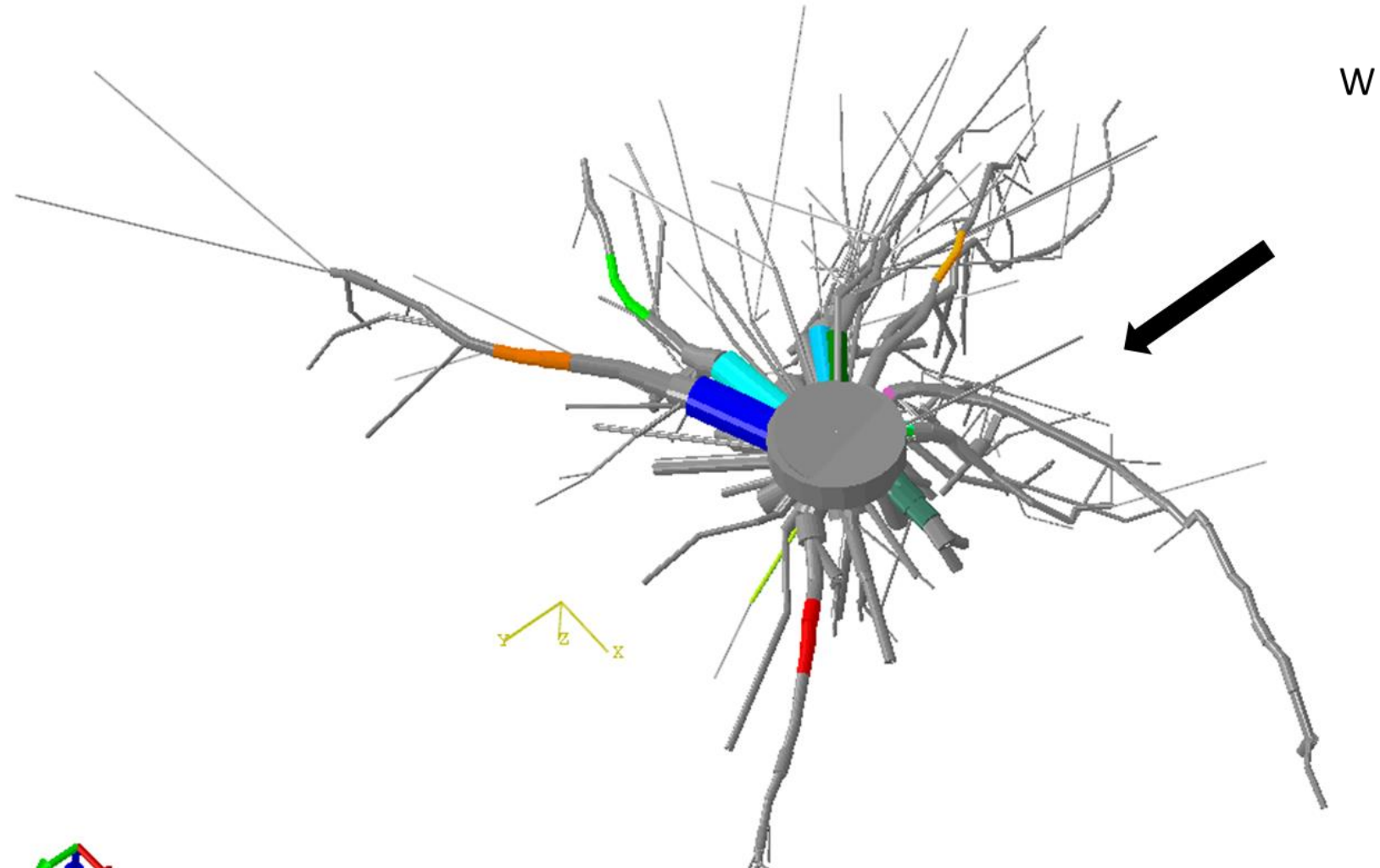
P-value=0.067

P-value=0.009



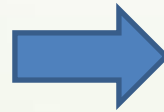
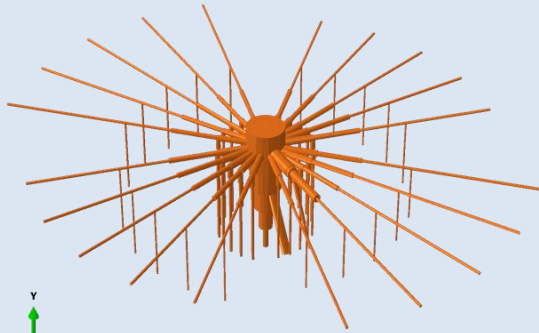
P-value=0.056

High dispersion Root architecture



Tree anchorage simulations

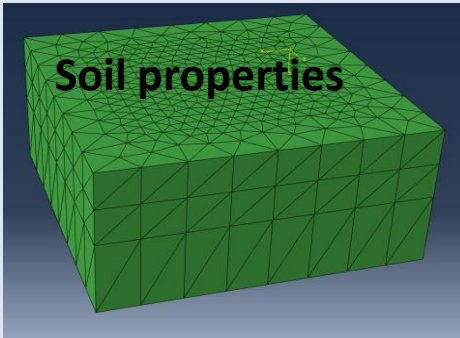
Root architecture



 **ABAQUS**
Superior

RootAnchor MODEL

Soil properties



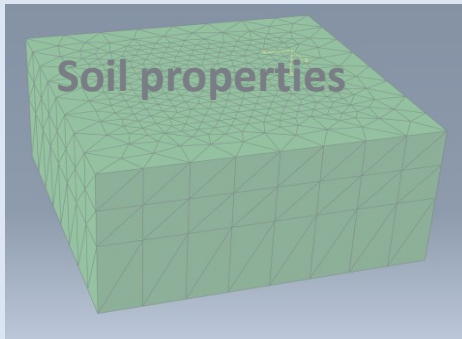
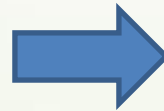
Root mechanical properties



MOE MOR

Tree anchorage simulations

Root architecture



Root mechanical properties



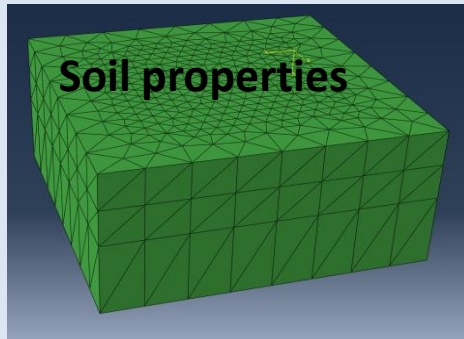
Rootmax
Rootmean
Rootmin

Δ MOE= 12.5%, Δ MOR= 20.5%

Dispersion << experimental values

Tree anchorage simulations

Root architecture



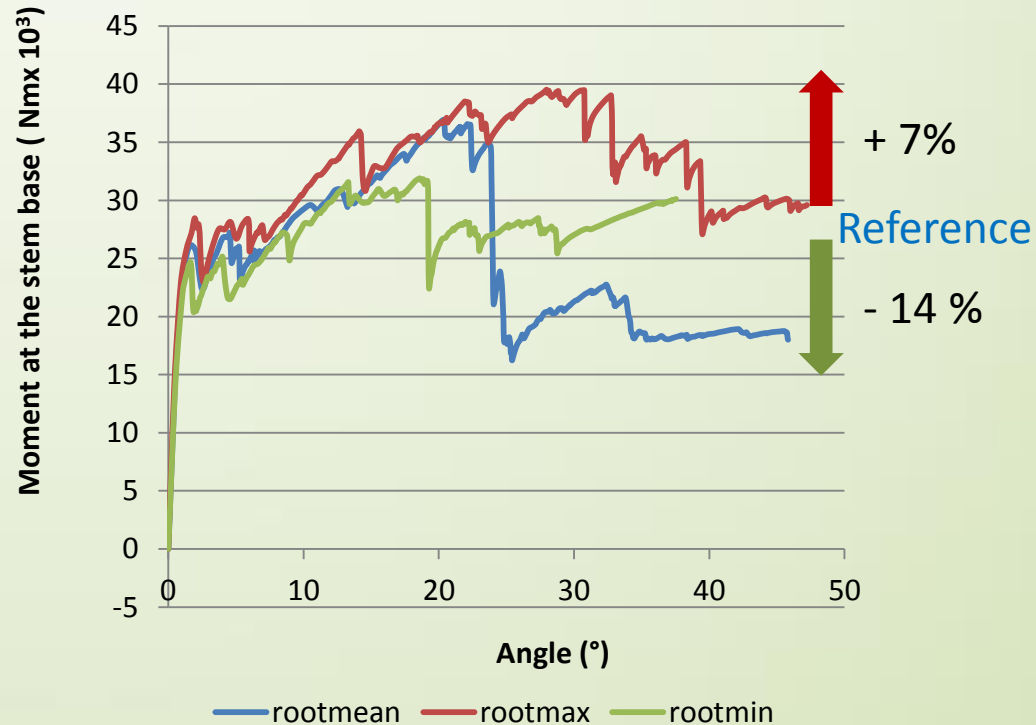
Root mechanical properties



Rootmax
Rootmean
Rootmin



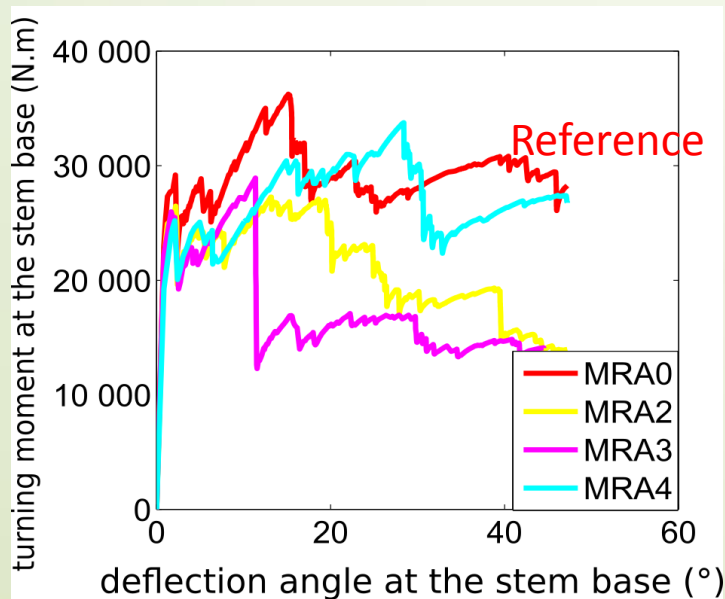
$\Delta\text{MOE} = \pm 12.5\%$, $\Delta\text{MOR} = \pm 20.5\%$



Tree anchorage simulations

Root system architecture

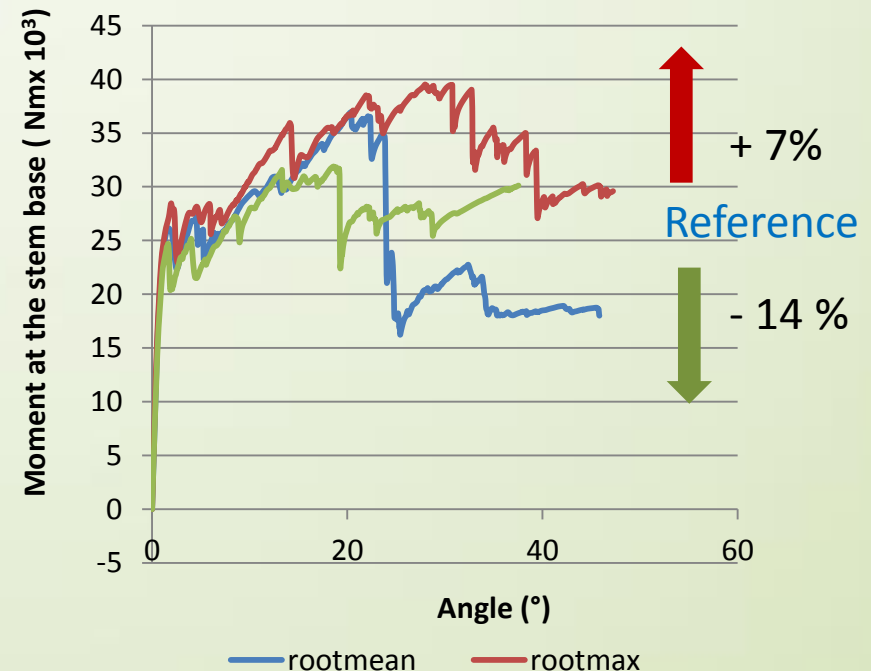
- 24.8% Loss of windward shallow roots (MRA2)
- 20.2 % Loss of perpendicular shallow roots (MRA3)



Yang et al. 2015, submitted

Wood root properties

Δ MOE= +/-12.5%, Δ MOR= +/-20.5%



Conclusion

- The importance of the root mechanical strength on anchorage comparable to root geometrical effects
- More data are needed to analyse properly the variations of the mechanical properties of root wood

Thank you for your attention

Funding

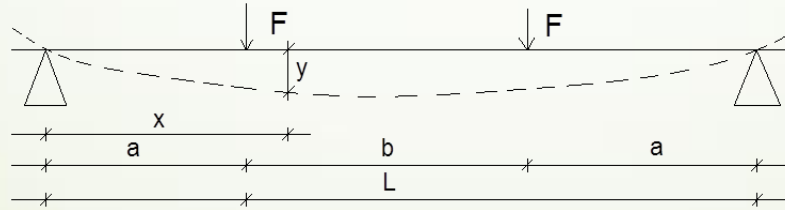
Cluster of Excellence COTE

ANR

Idex/CNRS

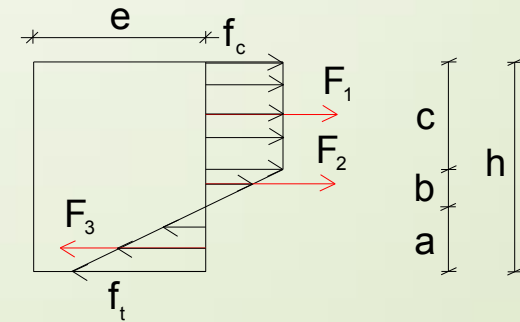
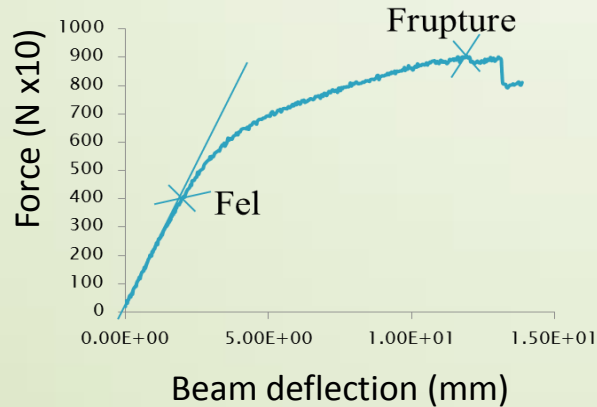


Mechanical properties



MOE, Young modulus
 Fel, Yield strength

MOR Tensile strength



Elastoplastic material