Root anchorage and tree stability under wind load

Pauline Défossez
pauline.defossez@inra.fr

UMR ISPA INRA Bordeaux
Pauline Défossez, Ming Yang (phD, post-doc), Clément Saint Cast (phD), Sylvain Dupont

UMR Biogeco, INRA Bordeaux
Frédéric Danjon, Céline Meredieu

AMAP CIRAD Montpellier Thierry Fourcaud

UMR RECOVER IRSTEA Guillaume Veylon
Context
Wind causes damage in forests
Poland  August 2017 (Image: Reuters)

Wisconsin July 2011
Credit: Stacy Hopke / Burnett County Sheriff’s Office

NZ Cyclone Gita /Beech Forest  April 2018
https://ourtrees.nz
Toppling

3 years old

Photo : F. Danjon
Uprooting

Sitka spruce England. By B. Gardiner

Maritime Pine, France (photo: P. Défossez)

Larches Scotland (UK) © Richard Webb
Wind damage in forests

1950 - 2000: annual volume of damaged wood = 35 million m$^3$

**storm: 53%, fire: 16%, scolytes: 8%, other biotic: 8%**

Schelhaas, 2008
What happens with climate change?
Changes in soil properties

Soil warming in boreal forest

Soil saturation in temperate forest

©BONNAUD GUILLAUME
Potential change in near-surface wind

- Decrease in wind speed
- Increase in wind storm

McVicar et al., 2012 IPCC 2013
Climate change and wind risk in forests

Increase in wind risks

• Changes in soil properties
  ➢ decrease in soil mechanical strength

• Potential change in near-surface wind
  ➢ Decrease in chronics wind but increase in hurricane
Mechanisms of tree anchorage
Flexion tests

Force (kN)

Photos: D. Garrigou
FLEXION TEST

SOIL-ROOTS CHARACTERIZATION

Digitalization of root system

Soil mechanics

Root mechanics

Force vs Angle

Force (kN)

Angle (degrees)
SOIL-ROOTS CHARACTERIZATION

MODEL INPUTS

Architecture modelization

Digitalization of root system

Soil mechanics

Root mechanics

SOIL and ROOTS mechanics

FLEXION TESTS
SOIL-ROOTS CHARACTERIZATION

FLEXION TESTS

MODEL INPUTS

SOIL and ROOTS mechanics

Architecture modelization

Simulations curve: Anchorage model

Force/N

Displacement/m

Simulation curve: Anchorage model

ABAQUS
SOIL-ROOTS CHARACTERIZATION

Force vs Angle

Simulation curve: Anchorage model

Dupuy et al. 2005, Yang et al., 2014
The importance of root geometry
At root scale
At root scale

Flexion

Diameter D

Tension

Maximum stress \( \propto I \propto D^4 \)

Maximum stress \( \propto I \propto D^2 \)

\( I \) moment of inertia

Number of roots

Branching

Tapering
At root scale

Flexion $\propto I$
Tension $\propto I$

A=100  $l=0.5$  $l=208$  $l=840$

a, b, c: Maritime pine (from Danjon), d: black spruce (from Krause et al., 2014)
Root architecture
Root architecture

Heart

Tap-root

Herringbone

Plate

Dupuy et al 2005
Root architecture

Heart

Herringbone

Oak, from Zanetti et al, 2015
Root architecture

Sitka spruce, from B. Gardiner
Root architecture

\[ M_{\text{critique}} \]

\[ \text{angle} \]

\[ \text{Force} \]

Dupuy et al 2005
Root architecture

- Typology of roots
- Variability and plasticity of morphology

Danjon et al., 2005
Variability and plasticity of root systems

- Environmental stress
  - Prevailing wind
  - Soil structure (Danjon, 2005)

Danjon et al., 2013
Virtual root patterns
The importance of root geometry
The importance of root geometry
The importance of root geometry

Deflection angle at critical turning moment for each case

Result: Root strength = 60 % taproot, 25 % windward

Yang et al. 2016
How does the tree anchorage change with time?
The role of soil properties
Soil properties change with climate conditions.
How does the tree anchorage change with time?
Acclimation of roots under wind
Wind acclimation in roots

- Higher root diameter in leeward sector
- Oval cross-section of root
- Increase of root ramification in windward sector

Danjon et al, 2005; Nicoll and Ray, 1996; Stokes, 1995
Wind acclimation in roots

Adult trees

- Case 0
  maritime pines 19 Years (reference)

- Case 1
  case 0 without taproot

- Case 1-P
  Without taproot but with increase in root diameter of leeward sector

$M_{\text{critique}}$

Wind direction

Force

angle

h
Results

- Taproot major component
- Acclimation may balance taproot loss

Yang et al. 2016
Yang et al. 2018
Mechanisms of wind acclimation in roots?
Wind acclimation

Aerial part
Strain perception => growth response (h, D)

Root part ???

*Prunus avium (Coutand, 2010)*
Wind acclimation in roots

Numerical experiments to investigate stress/strain experimented by roots during the tree development.
Wind acclimation in roots

- Turbulent wind load
  - Time (s)
  - 500 to 600

- Root system embedded in the soil
  - Leeward roots
  - Windward roots
  - Taproot

- Aerial structure

- Possible ruptures

- Nodes where model outputs are analyzed

- Wind

- Root-soil system
Simulations

- 4 years
- 6 years
- 13 years

Monthly wind

Saint Cast (phD, 2019)
Wind acclimation in roots

Result: Change in stress distribution with tree development

Saint Cast (phD, 2019)
Conclusions

• The importance to consider dynamic solicitations inducing fatigue during the passage of wind storms
  ➢ Implication for modeling wind risk in forests

• The ability of trees to acclimate their root architecture during their development as function of their environment
  ➢ Implication for the tree survives in changing environnement
Perspectives

• To better understand the soil strength under cyclic loading
• To investigate the acclimation processes in root system
Acknowledgments

• UE Experimental Unit Pierroton

• Technical staff: J.M. Bonnefon, D. Garrigou, R. Ségura

• Computer staff: S. Griffon, M. Irvine

Grants

• Région Aquitaine (projet VENTPIN) ANR (projet TWIST: ANR-1C3-JS06-0006), LabexCOTE (ANR-10-LABX-45)