Modelling tree anchorage - Applications to Pinus pinaster
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To cite this version:
Ming Yang, Pauline Defossez, Frédéric Danjon, Sylvain Dupont. Modelling tree anchorage - Applications to Pinus pinaster. Mathematical Modelling of Wind Damage Risk to Forests, Oct 2015, Arcachon, France. hal-02740109

HAL Id: hal-02740109
https://hal.inrae.fr/hal-02740109
Submitted on 2 Jun 2020

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Modelling tree anchorage

Applications to *Pinus pinaster*

Ming Yang, Pauline Défossez, Frédéric Danjon, Sylvain Dupont, Thierry Fourcaud

UMR ISPA INRA
UMR BIOGECO INRA
UMR AMAP CIRAD
Background

• Tree anchorage mechanism is less known, and it needs to be well estimated in risk models
• Little is known about the direct impact of adaptive plastic growth of structural roots on tree anchorage
Plan

• Modelling tree anchorage: first application to a young *Pinus pinaster* tree
• Toward a more general representation of root system architecture in tree anchorage
  – Case study: windward & leeward reinforcement compensating for taproot loss
• Perspectives
Modelling root anchorage

SOIL DOMAIN
Geometry
- L, D, H
- Discretized into Hex elements:

Mechanical properties
Elastoplastic (Mohr-Coulomb)

Boundary conditions

ROOT SYSTEM
Geometry
- Digitized root system
- Discretized into Timoshenko beam elements:

Mechanical properties
- Elastic-Damage

Tied to the rigid stem

Assumptions:
- Static process
- Homogeneous properties for the soil domain
- Root-soil interface simplified (embedded element)

Based on Dupuy et al., 2005

Tree-pulling test using Pinus pinaster
Developing damage law applied to roots

- **Model derivation**: continuum damage mechanics
- **Assumption**: structural root material is brittle
- **Mechanical behaviour**:  
  - Elastic–failure behaviour
  1. Damage initiation criterion
    \[ f = \frac{\varepsilon_{t1} \cdot \varepsilon_{11}^2 + [\varepsilon_{11}^t - (\varepsilon_{11}^t)^2] \cdot \varepsilon_{11}}{\varepsilon_{c11}} > \varepsilon_{11} \]
  2. Damage evolution law
    \[ d = 1 - \frac{\varepsilon_{11}^t}{f} \cdot e^{-\frac{E_r \cdot \varepsilon_{11}^t \cdot (f - \varepsilon_{11}^t) \cdot L_c}{G_f}} \]
  3. Workarounds to convergence difficulties
     ➔ numerical viscous effect:
     \[ \dot{d}^v = \frac{1}{\eta} \cdot (d - d^v) \]

*Model derived from Linde et al., 2004*
## Input material parameters

<table>
<thead>
<tr>
<th>Roots</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Value</td>
</tr>
<tr>
<td>Density (kg m(^{-3}))</td>
<td>421.4</td>
</tr>
<tr>
<td>Young’s modulus (GPa)</td>
<td>8</td>
</tr>
<tr>
<td>Shear modulus/Young’s modulus (-)</td>
<td>0.0755</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>43.2</td>
</tr>
<tr>
<td>Compressive strength (MPa)</td>
<td>20.6</td>
</tr>
<tr>
<td>Energy of fracture (J m(^{-2}))</td>
<td>209.4</td>
</tr>
<tr>
<td>Viscous parameter</td>
<td>0.000075</td>
</tr>
</tbody>
</table>
Estimating tree anchorage strength

- Properly defined tree anchorage strength induced by individual root damage
- Simulated anchorage strength in good agreement with the corresponding tree-pulling experiment

Yang et al., 2014
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Toward a more general representation of root system architecture in tree anchorage

Fraser and Gardiner, 1967

Danjon et al., 2013
Theoretical patterns

Coutts et al., 1999

Danjon et al., 2012
Illustrations of root adaptive growth

- Species-dependent
- Confounding effects cannot be resolved experimentally
- No direct links between tree anchorage strength and root adaptive plasticity using experimental approaches

Nicoll and Ray, 1996

Danjon et al., 2005
Case study: windward & leeward reinforcement compensating for taproot loss

- **Case 0**
  typical root system of 19-year-old *Pinus pinaster* (reference)

- **Case 1**
  Taproot removed from case 0

- **Case 1-P**
  Windward and leeward (cage) sectors reinforced with the biomass of the removed taproot
Case study: windward & leeward reinforcement compensating for taproot loss

Deflection angle at the stem base $\theta \approx 5^\circ$
Case study: windward & leeward reinforcement compensating for taproot loss

Deflection angle at critical turning moment for each case

Case 0

Case 1

Case 1-P
Case study: windward & leeward reinforcement compensating for taproot loss

- The taproot plays a major role in tree anchorage, especially for young trees
- Anchorage loss is partially recovered
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THANK YOU FOR YOUR ATTENTION