Tree root growth patterns and geotechnical roles on levee

Part II

Methods and Applications

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1. New field method for acquiring root system data

2. Data processing and model building

3. Analyzing root system patterns along levees

4. Data/models applications
Systematic approach to acquire and categorize \textit{in situ} root system data

- Consider root system complexity and spatial attributes

- Use critical \textit{variables of tree root architecture} to determine the \textit{range} (root system extent) and \textit{resolution} (minimum unit)

- Include above-ground, slope, below-ground compartments

- Classify the data as spatial points (1D), linear connections (2D), surface patterns (3D), and resulting thematic spatial composition
1 Pneumatic excavation

2 T-LiDAR scanning

Pneumatic Excavation And LiDAR Scanning (PEALS) system

3D and in-situ

- 15 Valley Oaks
- 5 Cottonwoods

20 trees in total

- Most trees (18/20) on the water-side levee slope.
- Two control trees (flat)
Pneumatic excavation (compressed air) *in situ* root systems
Ground-Based Tripod LiDAR scanning
Process field data and acquire the resulting models

- Stage I: T-LiDAR point cloud data (3D)
- Stage II: conversion of point-cloud data
  - Tomographic slicing, hierarchical nested dataset, biomass model
  - Vectorization of polylines, topological dataset, vector model
Stage I

1. Prescan: aboveground architecture and soil surface

2. LiDAR scan after root excavation

3. Assembly of aboveground, soil surface, and root system

4. 3D LiDAR image assembly of Pocket Levee Oaks (The Pocket site, Sacramento, CA)
Stage II

- Tomographic slicing (hierarchical nested dataset) -- Root Biomass Model
- Vectorization of polylines (topological dataset) -- Root Vector Model
3D Point-cloud data, XYZ format

Set up the coordinate system
Origin of the coordinate system tree trunk center at the slope surface

x axis: parallel to the levee

z axis: vertical axis

y axis: perpendicular to the levee

Upslope

Downslope

The Pocket Levee

Sacramento River
Root biomass model

• Design the model based on spatial patterns: size, linkage, distribution
• Use root cross-sectional area or diameter as the critical variable
• Sample the variables in virtual trench profile (2D sampling)
• Tomographically reconstruct the 3D hierarchical nested dataset
Virtual trench profile as the tomographic slices

Virtual trench profile

Root CSA
Tomographic reconstruction can use linear or radial slices.

- **Longitudinal** (Upslope, Downslope, Vertical)
- **Radial**
2D plot
R statistical program

Spatial analysis format
ArcGIS

Spatial metrics
Fragstat

Data sheet for root biomass model

<table>
<thead>
<tr>
<th>Slice ID</th>
<th>Root #</th>
<th>Root CSA /Slice (m²)</th>
<th>Root Cumulative CSA %</th>
<th>DTC (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>n</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Root vector model
branching pattern and directionality

- Vectorize the point-cloud data as “polylines”
- Using azimuth angle (to the north pole), zenith angle (to sky), root length, root order as the critical variables
- Reconstructing Topological relationship
Vectorizing the point-cloud data

Point-cloud data

Making Polylines
## Data sheet for root vector model

<table>
<thead>
<tr>
<th>Root ID</th>
<th>Root order</th>
<th>Azimuth angle</th>
<th>Vertical angle</th>
<th>Branching angle</th>
<th>Root length</th>
<th>Branching point</th>
<th>Root Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root 1</td>
<td>Root 1</td>
<td>Root 1.1</td>
<td>Root 1.2</td>
<td>Root 1.3</td>
<td>Root 1.5</td>
<td>Root 1.6</td>
<td>Root 1.7</td>
</tr>
</tbody>
</table>
Data analysis

• Root system info
• Root system morphological plasticity in relation to levee geometry
Root system info

• Aboveground Info
  - species, location, age, DBH, height, canopy
• Root system center (TCS point)
• Horizontal spread (Root system extent)
• Maximum rooting depth
Horizontal spread
Maximum rooting depth

Tree numbers on levee: 17

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>X left limit</th>
<th>X right limit</th>
<th>Upslope limit</th>
<th>Downslope limit</th>
<th>Max Rooting Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg.</td>
<td>12.7</td>
<td>2.10</td>
<td>2.35</td>
<td>1.70</td>
<td>2.35</td>
</tr>
<tr>
<td>SD</td>
<td>6.3</td>
<td>1.44</td>
<td>1.53</td>
<td>1.05</td>
<td>1.65</td>
</tr>
<tr>
<td>Max</td>
<td>34</td>
<td>5.89</td>
<td>5.85</td>
<td>4.34</td>
<td>7.18</td>
</tr>
<tr>
<td>Min</td>
<td>6</td>
<td>0.15</td>
<td>0.46</td>
<td>0.72</td>
<td>0.08</td>
</tr>
</tbody>
</table>

- Maximum root system extent was usually on the downslope side.
- Average maximum rooting depth equals 1.58m (±0.47 SD), always the taproot, every tree on levee has a taproot.

Unit: m
Root system morphological plasticity in relation to levee geometry

- **Asymmetry**: Slope profile
- **Symmetry**: Parallel to the levee

 alternating growth directions

- **Shallow surface growth pattern**

- **2nd order**
- **3rd order**
- **4th order**
- **5th order**

- **Horizontal growth pattern**

- **Tap root**
- **Alternating growth directions**

- **0°** to **360°**
Root system Upslope VS. Downslope asymmetry

- Downslope side: more trees have further root extent, greater biomass, and higher root number

- Why are more roots on downslope side of the levee than upslope side?
Root biomass distribution

Upslope VS. Downslope

- Based on the Root Biomass Model by using the Tomographic approach
- Biomass = \( a + b \times \text{Root Extent} \)
- \( Y_i = \beta_0 + \beta_1 X_i + \beta_2 X_i \, 1(X_i) + \varepsilon_i, \quad i = 1, 2, \ldots, 48 \)
  - \( Y_i \) is the natural logarithm of the RCSA/profile of the \( i \)th VTP map
  - \( X_i \) is the \( i \)th VTP map’s distance to the TCS point
  - \( 1(X_i) \) is an indicator function defined as:
  - \( 1(X_i) = 1, \) if \( X_i \) is downslope; \( 1(X_i) = 0, \) if \( X_i \) is upslope.
# Root biomass rate of decrease

| Tree ID   | Upslope | Downslope | Pr(>|t|) |
|-----------|---------|-----------|---------|
| v6        | ✓       |           | <0.05   |
| v7        | ✓       |           | <0.05   |
| v8        | ✓       |           | <0.05   |
| v9        | ✓       |           | <0.05   |
| v12       | ✓       |           | <0.05   |
| v13 - disturbed slope |       | ✓         | <0.05   |
| v14       | ✓       |           | <0.05   |
| v15       | ✓       |           | <0.05   |
| v16 - tiny root system |       | ✓         | NS      |
| v17       | ✓       |           | <0.05   |
| v19       | ✓       |           | <0.05   |
| v20       | ✓       |           | <0.05   |
| v21       | ✓       |           | <0.05   |
| v22       | ✓       |           | <0.05   |
| v23       | ✓       |           | NS      |
| p2009     | ✓       |           | <0.05   |
Root system symmetry

Parallel VS. Perpendicular

- The second order roots as the major structural roots (the 1st order root is the taproot)
- Two groups
  - Parallel to levee (1, 4, 5, 8 sectors)
  - Perpendicular to levee (2, 3, 6, 7 sectors)
- More second order roots parallel to levee for every tree
Shallow/horizontal growth pattern

- Average rooting depth from 0.35m to 0.8m.
- 90% root biomass from the depth of 0.38m to 1.55m
- More horizontal roots than other type of roots in every root system
Root branching pattern

General patterns of root systems

Use root topological index (RT)

- Oppelt et al. 2001
- Quantitatively illustrating the branching pattern of root systems
- Dichotomous (RT=0) to herringbone (RT=1) branching

RT = 0.109

RT = 1
Root branching pattern vs. DBH

RT Index

- Bigger tree has lower RT index
- Small trees are tend to be more herringbone branching
- Higher RT index may represent mechanically stable

Aboveground parameter: DBH
Trees growing in flat ground

- General patterns of root systems on a flat plain may be more symmetrical (Stokes and Mettheck, 1996)

- Our results (One cottonwood and one valley oak in Vernalis) correspond with the previous study

- Symmetrical and absence of taproot

- Root biomass radially distributes with an exponential decreasing trend
Data/Model applications

1. Below-ground biomass estimation
2. Levee slope stability modeling
3. Levee slope surface erosion mapping
4. Levee vulnerability assessment
1. Below-ground biomass estimation

Root Biomass

Aboveground parameter: DBH

\[
y = 303.47x - 40.151
\]

\[
R^2 = 0.83
\]
2. Levee slope stability modeling

- Virtual trench profiles can be used to locate the root system within the potential failure plane of levee slope for modeling.
- RAR and CSA can then be used to determine Factor Of Safety (FOS) in levee slope stability model.
3. Levee slope surface erosion mapping

1. Land use/cover
2. General geomorphology
3. Soil - Root source/sink dynamics
4. Erosion Processes
4. Levee vulnerability assessment

Potential root system

Surface processes

Subsurface connectivity and Slope FOS

Vulnerability evaluation
Thanks, Q & A