Reliability Analysis of Levee Performance Including Vegetation Effects

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Ringgold (1852)
Quantifying Levee Performance

Typical Analysis

How to quantify vegetation effects?
Primary Objective – Quantify Probability of Levee Failure due to Woody Vegetation

- Levee model
- Biomass model
- Effect of trees on stability (Factor of Safety, FS)
- Effect of trees on reliability (probabilistic approach)

Research made possible by:
California Levee Vegetation Research Program
Levee Model

- 17 ft embankment
- 18 ft blanket layer
- 25 ft wide crest
- Clay blanket
- Sandy embankment
- FS = 1.00
Biomass Model

• Vegetation data from CLVRP and others

Berry & Chung (2013)
Biomass Model

• Prior work allows quantification of root density and correlation to engineering parameters
• Based on Berry and Chung (2013) biomass model

\[ RAR \propto \frac{1}{\exp(l)} \]

• RAR = root area ratio
• \( l \) is distance from trunk center
Biomass Model – Tree Characteristics

1 m diameter cottonwood

Root ball:
2.4 m diameter

Max root extent:
3.5 m up-slope
5.1 m down-slope
Biomass Model – Spatial Distribution

RAR contours of a surveyed levee slope
(near Sacramento)
Effect of Tree on Stability

Root reinforcement:

\[ C_R \approx 50,000 \text{ psf} \]

- For \( RAR = 1.0\% \)
  \[ \Delta c_R \approx 500 \text{ psf} \]
  (near root ball)

- For \( RAR = 0.1\% \)
  \[ \Delta c_R \approx 50 \text{ psf} \]

\[ \Delta c_R = C_R RAR(x, y) \]
Effect of Tree on Stability

- Tree weight determined from published trends
- Weight proportioned by root volume (RV)
- Applied where root density is highest (root ball)

\[ W_{\text{slice } i} = W_{\text{tree}} \frac{RV_{\text{slice } i}}{RV_{\text{total}}} \]
Effect of Tree on Stability – Position on Slope

• $FS = 1.00$ (no tree)

• $FS$ analyzed for 1 m diameter tree at varying locations

• $\Delta FS = -0.01$ to $+0.10$
Effect of Tree on Stability – Position on Slope

- Edge of root zone begins to have small *positive* effect due to cohesion
Effect of Tree on Stability – Position on Slope

- As root ball overlaps sliding surface tree begins to have negative effect due to weight
Effect of Tree on Stability – Position on Slope

• Tree begins to have a *positive* effect as weight increases strength more than driving force
Effect of Tree on Stability – Position on Slope

- Peak *positive* effect once weight and root reinforcement are concentrated near toe of slope
Effect of Tree on Stability – Position on Slope

• *Positive effect decreases as root ball (weight) leaves the sliding surface*
Reliability Analysis

- Compute probability $FS < 1.0$
- Evaluate *importance* of input parameter uncertainty
Reliability Analysis – Parameters and $p_f$

- $P_f = 31.8\%$, no vegetation
- $P_f = 31.9\%$, tree near crest
- $P_f = 28.4\%$, tree near toe

Random Variables (11)

Water surface, $WSE$

Blanket layer: $\gamma$, $c$, $\phi$

Embankment: $\gamma$, $\phi$

Blanket thickness: $z_B$

Hydraulic conductivity ratio: $K_r$

Biomass:

- root ball diameter
- root depth
- root extent
### Reliability Analysis – Importance Measures

- **Effect of parameter uncertainty on levee performance**
- **Sign identifies capacity (−) or demand (+)**

![Importance Measures Diagram]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Importance of Random Variables, $\alpha$</th>
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<tbody>
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<td>$WSE$ (water surface elevation)</td>
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Reliability Analysis – Importance Measures

- Water surface elevation dominates performance
- Blanket unit weight most important for strength

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Reliability Analysis – Importance Measures

- Blanket properties more important than strength

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Reliability Analysis – Importance Measures

- Hydraulic conductivity less important than blanket unit weight
Reliability Analysis – Importance Measures

- Uncertainty in biomass factors has smallest influence on stability
Reliability Analysis – Importance Measures

- Embankment friction and hydraulic conditions switch
- Tree increases normal force and adds cohesion; pore pressure (H.C.) more important than phi

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Reliability Analysis – Importance Measures

- Root ball size switches from capacity to demand
- Larger root ball places reinforcement out of slide zone
Conclusions

• We believe we have been able to capture some of the subtleties of tree effects on slope stability

• We see that trees have a quantifiable influence on FS, and can cause computed FS<1.0

• Overall, stability of a levee is not sensitive to uncertainty in vegetation parameters, but they do have a secondary effect on levee performance – the most important are still water level, soil and geometry parameters

• The main strength of reliability based approach is in determining the importance of the different parameters, which then helps in guiding further analyses and investigations
Thank you
detailed reports and results in press …
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