Risk-Based Levee System Analysis with Multiple Failure Modes

PEER Internship Program – Summer 2012

Undergraduate Intern: Paul Shipman, CSU Sacramento – pshipman7@gmail.com
Intern Mentors: Nathan Burley & Dr. Jay Lund, UC Davis
University of California Davis

Introduction

Risk analysis of levee systems requires estimating the probability of flood events and the consequences of levee failure. This is done by identifying failure modes, creating models for these modes to generate failure frequency curves, and finding the geometry of levees to minimize total annual damages and construction costs.

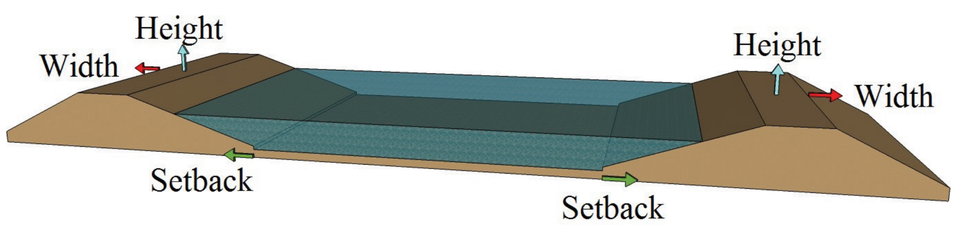
Intermediate failure modes (non-overtopping failures) are often omitted from levee systems models to simplify the problem. This fails to reflect the actual mechanics of the problem and may not return optimized solutions.

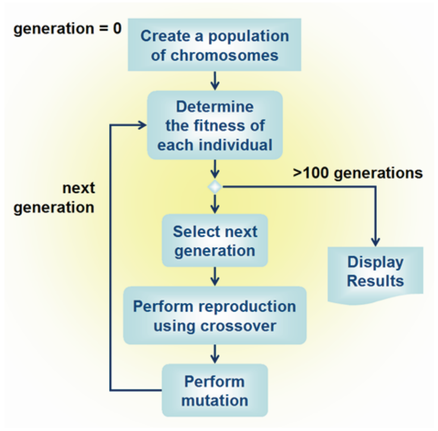
Analyzing system interaction allows models to designate a levee to act as a "fail-safe". The fail-safe levee is designed to fail in a significantly large flood event in order to protect the rest of the system from failure. This model incorporates intermediate failure modes and the concept of a fail-safe levee in order to generate realistic optimal levee geometries based on set flow distributions, land use, and soil properties.

Model Setup

The model examines two levees (across the river) in one reach and finds the optimal geometry in terms of the following decision variables:

- Levee Height
- Levee Width
- Setback from the River

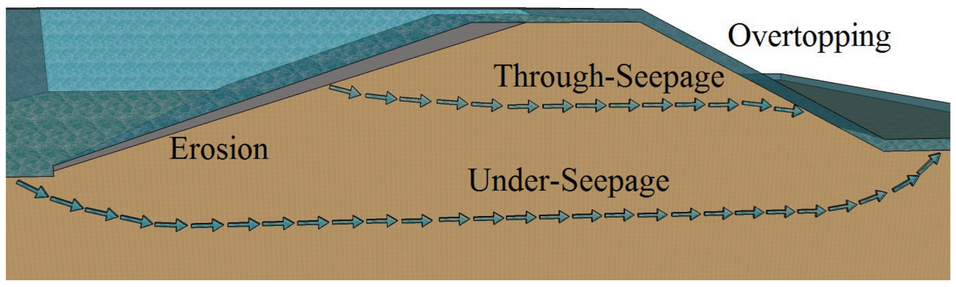




These decision variables are allowed to vary for both levees creating a best case solution for minimizing total cost. Solving for six decision variables with complex interactions creates a large solution space that requires an efficient optimization program. To quickly analyze the solution space this model uses the Excel evolutionary solver. The Excel evolutionary solver utilizes a generic algorithm, outlined in the flow chart.

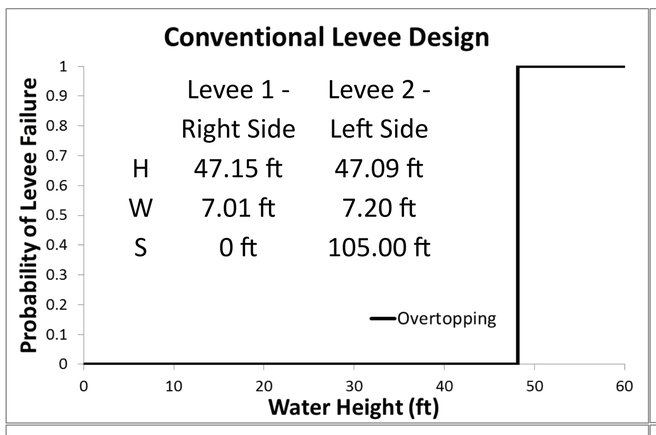
The model uses performance functions created by USACE to estimate the probability of failure for:

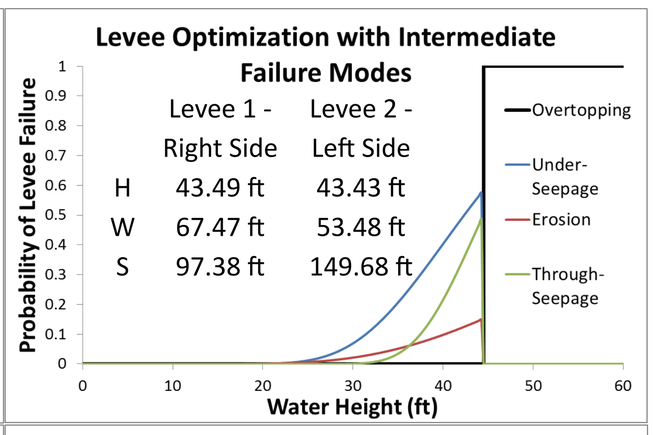
- Overtopping
- Through-Seepage
- Erosion
- Under-Seepage

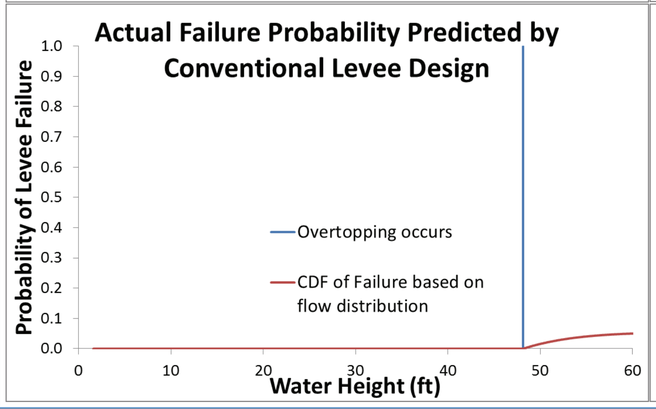


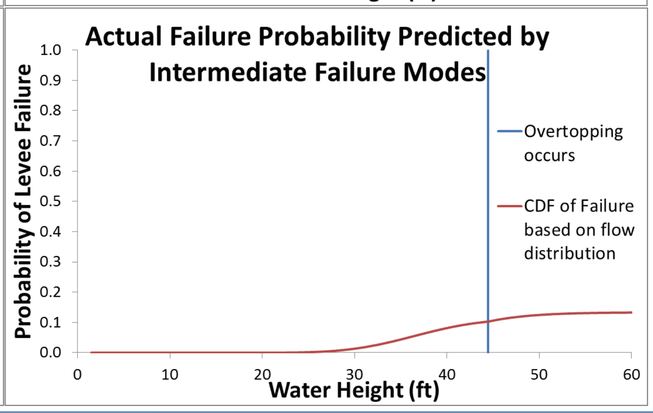
Results

Set-up	Levee 1 Height (ft)	Levee 1 Width (ft)	Levee 1 Setback (ft)	Levee 2 Height (ft)	Levee 2 Width (ft)	Levee 2 Setback (ft)	Total Cost ($M/year)	Overtopping Probability of Failure
City/Field	13.07	27.99	3.38	11.27	7.00	100.24	132.657	99%
City/Town	42.00	72.85	98.83	41.74	83.66	148.27	273.787	4%
City/City	47.18	32.42	148.84	47.41	33.27	149.50	352.443	1%
Town/Field	40.50	97.79	60.43	39.63	100.34	150.00	123.817	8%
Town/Town	44.80	44.95	149.95	44.95	24.55	149.95	200.586	1%
Field/Field	42.00	72.30	149.66	41.92	108.96	149.07	55.782	3%









Conclusions

- When relative flood damages become significantly different on opposing sides of the river, it is more economical to not build a levee on the side with the least value.
- Designing the system with a fail-safe levee reduces construction costs overall and improves life safety.
- The addition of intermediate failure-modes on levee system analysis drastically changes the results of the optimization.
- There is a significant need for further research into levee failure modes to validate and improve current models.

Future Research

This modeling approach could be expanded to include multiple reaches by including river hydraulics. Calculating downstream flow after a breach and backwater effects are examples of hydraulic impacts to be modeled. Application to a large watershed like the Sacramento River basin may produce interesting results and help guide future policy actions.

Acknowledgements

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