Risk Based Approaches for Levees in the U.S. and Abroad: Lessons for the NFIP

Mike Seering (AECOM)
David Powers (HR Wallingford)
“NFIP should move to a modern risk analysis that makes use of modern methods and computational mapping capacity to produce state-of-the-art risk estimates for all areas that are vulnerable to flooding”

-National Research Council 2013
What is Risk Based Analysis?

– Probability x Consequence = Risk

– *The portion of the process in which potential failure modes, structural performance, and adverse consequences are identified. It is also the process during which a quantitative and qualitative estimate of the likelihood of occurrence and magnitude of consequence of these potential events is made.* (FEMA, 2015)

– Considers a full range of events (not simply the 1%-annual-chance)

– Considers failure probabilities for structural features, including levees and floodwalls

– Factors in consequence modeling
Risk Based Analysis for Levees

- Risk Based Analysis currently being performed for levees by USACE and by other agencies internationally
- TMAC recommends that the NFIP
  - Move away from the “base flood” to ratings by multiple flood events
  - Structure-specific consequences
- Would be consistent with Biggert Waters 2012 and Homeowner Flood Insurance Affordability Act
- Natural floodplains may achieve TMAC objectives without fundamental changes to modelling approaches.
- Levee risk based analysis would need to consider failure mechanisms and scenarios for multiple flood events.
Source
River or sea

Pathway
e.g. beach, defence, floodplain

Receptor
e.g. property, agriculture, infrastructure, people in the floodplain

Source
Extreme distribution of in-channel water levels or coastal overtopping

Pathway
Reliability analysis of assets e.g. defences (load dependent)

Pathway
Flood probability, flood extent and depth, reflecting asset performance and source terms.

Consequences
Flood damage or harm related to depth. Risk is assessed by the probability that particular damage values are exceeded.
Fragility Curves

– Where levees are present, the fragility curve concept expresses probability of failure given load.

– Fragility concept was developed by USACE 1991-3. Applied by USACE and internationally

– Key Challenge in U.S.: lack of data availability throughout National levees
Fragility Curves

- Fragility needs to be representative of levee by segment

Defence Fragility Curve:
Rasp type 8, Condition grade 2

Probability of failure vs. Hydraulic load

Lower Bound
Upper Bound
Tools for Generating Site Specific Fragility Curves: RELIABLE (U.K.)
Existing Breach Software: EMBREA

- Breaches in levees have a strong influence on flood extents and impacts
- Inherent complexity and uncertainty
- Numerical models and software that simulate these processes
- Examples of these models include EMBREA (HR Wallingford), SIMBA (USDA ARS), and existing US software such as NWS BREACH (NOAA NWS)
Risk Based Approaches in the U.S. and Abroad

RISK BASED ANALYSIS
(FRE MODEL)

Hydraulic loading:
Full distribution of loads

Levee Performance:
Full fragility curve for each defense segment

Breach representation:
Inflow hydrographs for all levee reaches for full distribution of hydraulic loads

Inundation simulation:
Simulations of simultaneously modeled breach scenarios and full distribution of hydraulic loads

Hydraulic loading:
Surgs/waves

Levee segments (L1...Lx)

Inflow (q) – breaching or overtopped defenses

LAMP

Hydraulic loading:
1\% loading level

Levee Performance:
Selection of breach failure locations/parameters for levee segments with structural deficiencies to 44CFR65.10. Overtopping of the 1-percent-annual-chance event

Breach representation:
Inflow hydrographs 1\% hydraulic load (+ sensitivity)

Inundation simulation:
Simulations of multiple, independent breach scenarios for the 1-percent-annual-chance, composited during mapping
Current Applications
U.S. and International Examples
Applications in Risk Based Approaches

– Many U.S. agencies use risk based approaches in some way for applications other than flooding and levees

– U.S. Federal agencies using risk based approaches include:
  • NASA (early application)
  • USACE
  • FERC
  • U.S. Bureau of Reclamation
  • USGS
  • Nuclear Regulatory Commission

– Many countries use risk based approaches for flood evaluation, including:
  • Netherlands
  • UK
  • Japan
Early in the Apollo program, application of Probabilistic Risk Analysis (PRA) on roundtrip missions.
USACE

- Leaders on developing risk based methodologies for levees in the U.S., including fragility curves
- Applying on detailed risk analyses for high consequence levees.
Federal Energy Regulatory Commission

- Evaluates risk analysis and the process and procedures for conducting a risk analysis for FERC-regulated dams
- Concepts of tolerable risk and as-low-as-reasonably-practicable, how risks are to be assessed, and dam safety decision making
- A 2016 report compared two general approaches:
  - standards-based approach (SBA)
  - risk-informed decision making (RIDM) approach
California Department of Water Resources study, based on USACE principles

- 2009 Study on the Sacramento-San Joaquin Delta levee system
- Risk of failure from earthquakes, high water, dry weather, land subsidence, and combined events
- Quantified risk analysis using fully probabilistic methods was implemented for all hazards.
- Resulting output of economic losses or loss of life is defined probabilistically

Probability of exceeding an amount in total economic costs due to high water-related levee failures over a 25-year period (2005-2030)
Netherlands

– Computes levee risk of both individual risk and societal risk values for neighborhoods.

– Use of a quantitative risk analysis program for each levee system, considering:
  • failure mechanisms
  • consequences
  • spatial correlations.

– Factors in a ‘length effect’ – the longer the dike section, the higher probability of a weak spot (due to spatial variability of properties).

– Plans for infrastructure expenditures with considerations to climate change scenarios
**Japan**

- Japan has a tradition of dealing with natural hazards, resulting in policies covering the “safety chain” (i.e. prevention, protection, preparedness, response and recovery.)

- Particular interest in addressing preparedness for increases in flood peaks as a result of climate change.

- Evaluates flood consequences including correlations between increased number of deaths and increased flooding.

- Proactive approach for improving the reliability of levees and response in the wake of disasters.
U.K.

- NaFRA and Foresight flooding studies for future conditions led to national surface, reservoir and groundwater flood risk maps
- System Asset Management Planning
- Inclusion of probabilistic risk analysis methods at a range of spatial scales using a hierarchical structure
- Attribution of risk to individual levee reaches to aid maintenance prioritization
U.K. Levee Study Example – Probability of Flooding
U.K. Levee Study Example – Total Risk

EAD (£K)

Humber Estuary
Strategy modelling - Maintain 2115
November 2010

Total Risk (£)
- 0
- 1 - 100
- 101 - 200
- 201 - 500
- 501 - 1000
- 1001 - 2000
- 2001 - 5000
- 5001 - 10000
- 10001 - 20000
- 20001 - 50000
- 50001 - 100000
- 100001 - 200000
- 200001 - 500000
- 500001 - 1000000
- > 1000000

Flood Area

N
0 2.5 5 10 Km

Humber NHS Trust
Humber Risk Assessment
Humber Environment Agency

Humphrey Wallingford Ltd

HR Wallingford Ltd, Newby Park,
Wallingford, Oxon, OX10 8BA, UK.
Tel: +44 (0) 1491 52 6281
www.hrwallingford.co.uk

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Potential Application to Flood Insurance Program
U.S. and International Examples
Breaking down the barriers to the update of risk-based methodologies

- **Difficulty in communicating uncertain results to the public and other professionals**
  - Explicit acknowledgement of uncertainty and better communication techniques

- **Scepticism as to the ignorance of the techniques**
  - Routine application of risk techniques

- **Lack of data adequate to specify parameters probabilistically**
  - Recognition that estimating probabilities is a relatively minor extension to present practice. Requiring no increase in data per se

- **Entrenched belief in deterministic outcomes and a reluctance to manage uncertainty**
  - Risk assessment enables uncertainty to be understood and handled transparently - not hidden

- **Fear that the techniques are too expensive**
  - Tiered methodologies provide a range of approaches, from the simple to more comprehensive, appropriate to the decision

**Key**
- Blue: Barriers
- Brown: Opportunities
Thank you for participating!

Mike Seering: Mike.Seering@aecom.com
David Powers: D.Powers@hrwallingford.com