

Fragility Curves

Jonathan Simm
Flood Management Group, HR Wallingford

Practitioner workshop on asset management

Questions/topics addressed in presentation

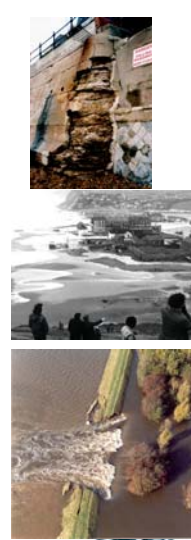
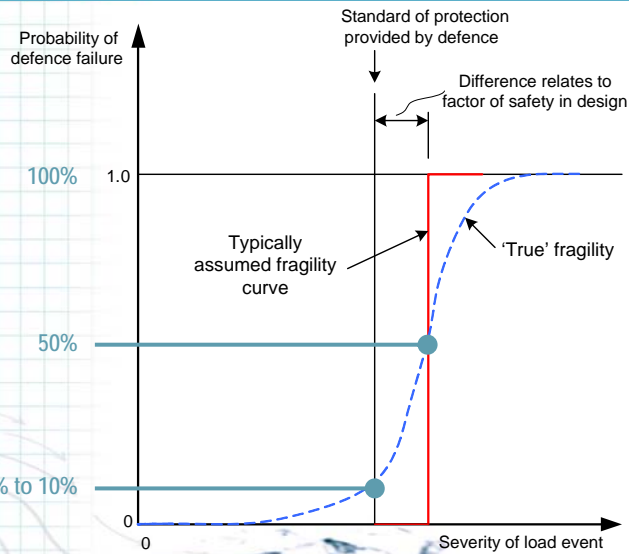
1. What is a fragility curve (and how do fragility curves relate to design thinking)?
2. Why are fragility curves important in FRM?
3. Generalised fragility curves (with ref. to asset types and condition grades)
4. Challenging accuracy of generic curves.
5. Generating bespoke fragility curves
6. Conclusions

1. What is a fragility curve?

Answer:

A curve which expresses the probability of failure of a defence as a function of the loading

Estimating fragility curves (Simm *et al*, 2008)



Establishing fragility different from design

$$\frac{\text{Strength } R_{rep}}{\gamma_R} > \gamma_S \text{ Load } S_{rep}$$

← partial load factors

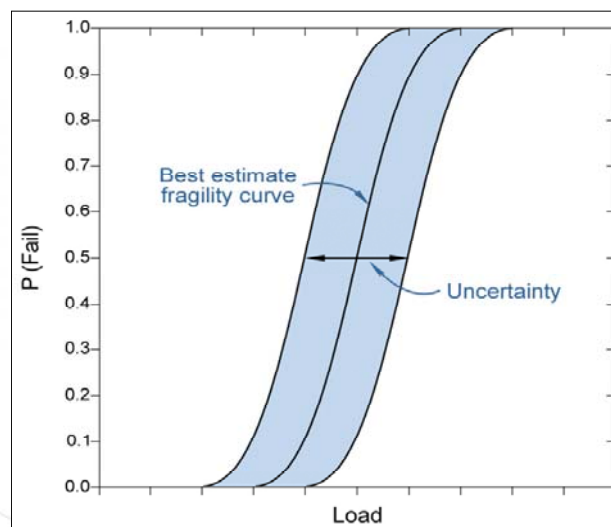
Statistical variability reflected by setting design values a certain number of standard deviations away from the mean:

$$R_{rep} = \mu_R + k_R \sigma_R$$

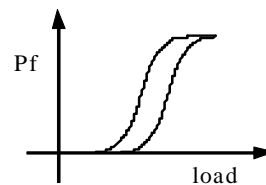
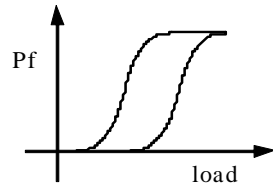
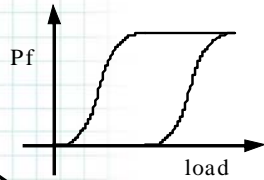
$$S_{rep} = \mu_S + k_S \sigma_S$$

To generate fragility curves we must change approach and use the mean values. (Otherwise, for example, we would not get pf = 50% when FS=1)

Fragility curve - uncertainty



Better data/models reduce uncertainty



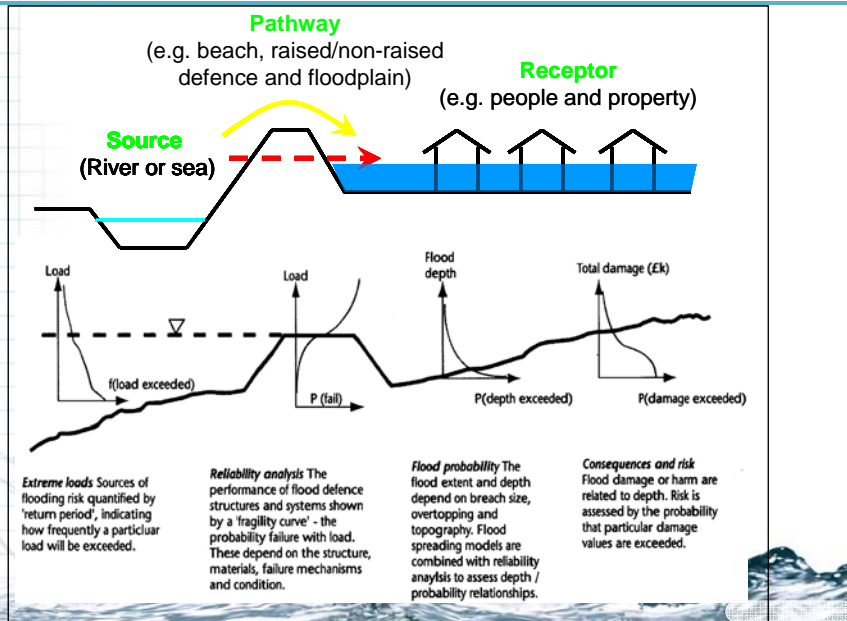
**Increasing
certainty in
defence
performance**

**Increased
defence data
and analysis**

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Fragility curves in flood system analysis

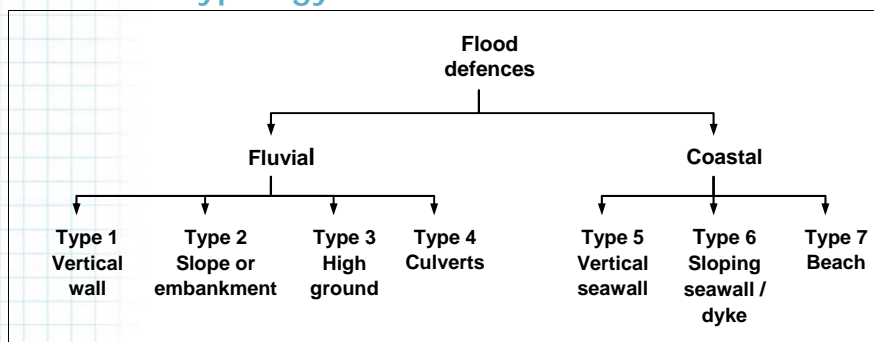


Fragility curves importance in FRM

- In flood systems analysis
- In determining flood risk attributable to individual defences
- In providing a rigorous discipline for understanding our flood defences

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Asset typology:

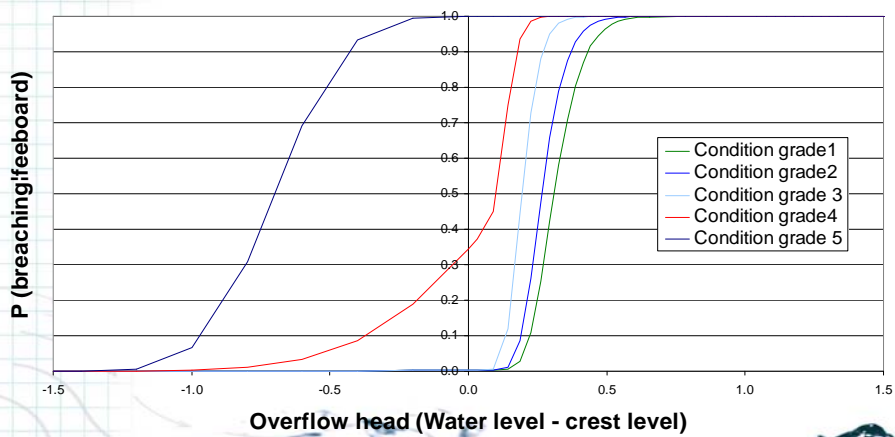


Within this framework there are 61 asset types.
For each type, a generic fragility curves is available for each of 5 condition grades.

Example generic fragility curves

(cf. presentation on condition assessment)

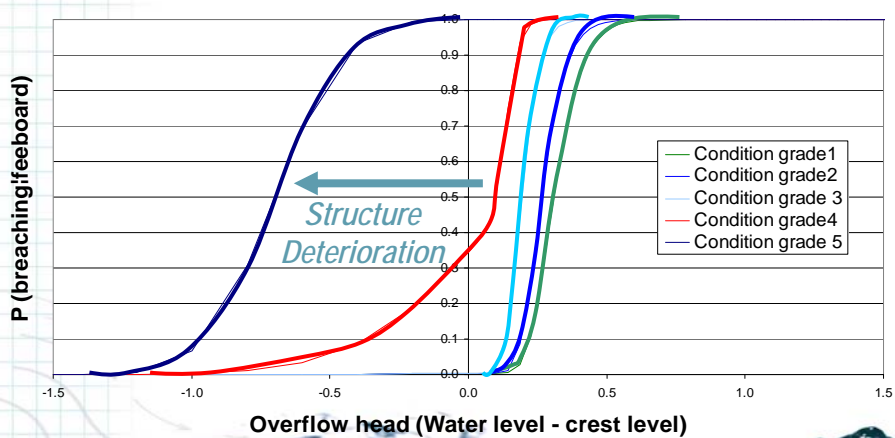
HLM+ Fragility curve - Condition Grades 1 to 5 (Central estimates)



Example generic fragility curves

(cf. presentation on deterioration)

HLM+ Fragility curve - Condition Grades 1 to 5 (Central estimates)



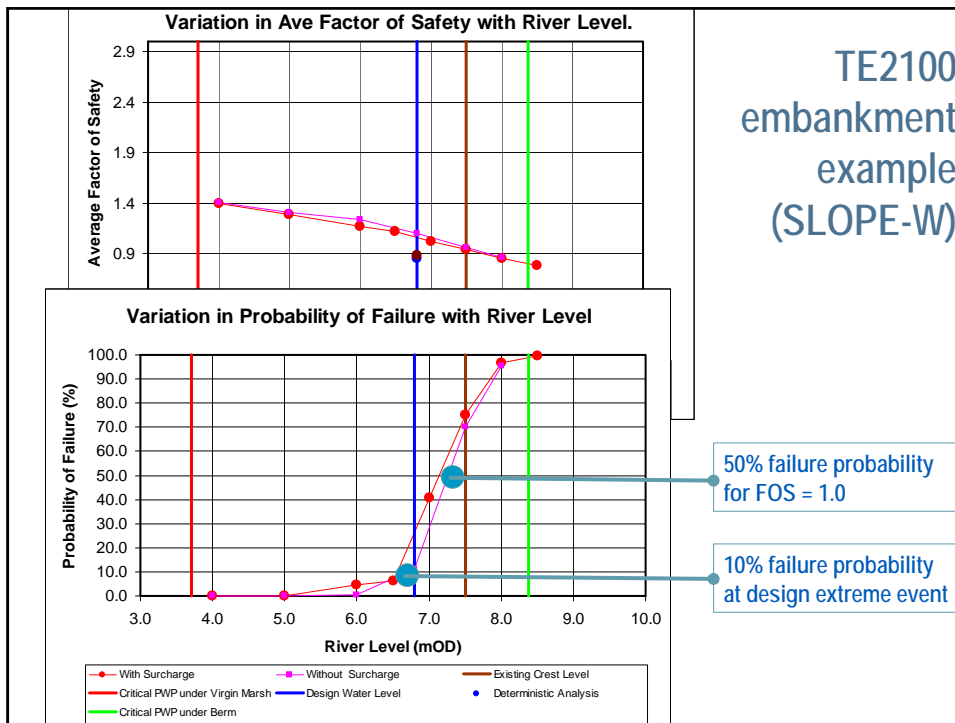
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- **FloodProBE workpackage 3 addressing:**
 - Internal erosion (piping etc)
 - External erosion of grass cover (riverine)
- **Asset Performance Tools**
 - Extension of RELIABLE fragility curve generation tool to cover most asset types and most failure modes
 - Overtopping research to look at coastal grass cover erosion
 - Guidance for practitioners

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BASIC STEPS:

1. Identify and analyse all relevant failure modes (key issue emerging in production of International Levee Handbook)
2. Identify Limit State Equations (LSE) or models for all failure modes and recast them in reliability format:
$$Z(\text{reliability}) = R(\text{strength}) - S(\text{loading})$$
3. Prepare schedule of engineering parameters and their uncertainties.
4. Prepare fault trees that specify the logical sequence of all possible mechanisms leading to defence failure.
5. Perform many reliability analyses, for a single hydraulic loading across range of parameter uncertainties (Monte-Carlo sampling). For each loading analysed, probability of failure is proportion of times that $Z < 1$. Repeat for other hydraulic loadings and draw the resulting fragility curve.



Reliability analysis – multiple failure modes

Can combine using De Morgan's Law

$$\Pr(f) = 1 - \{[1 - \Pr(f_r)] \times [1 - \Pr(f_s)]\}$$

if failure modes are independent

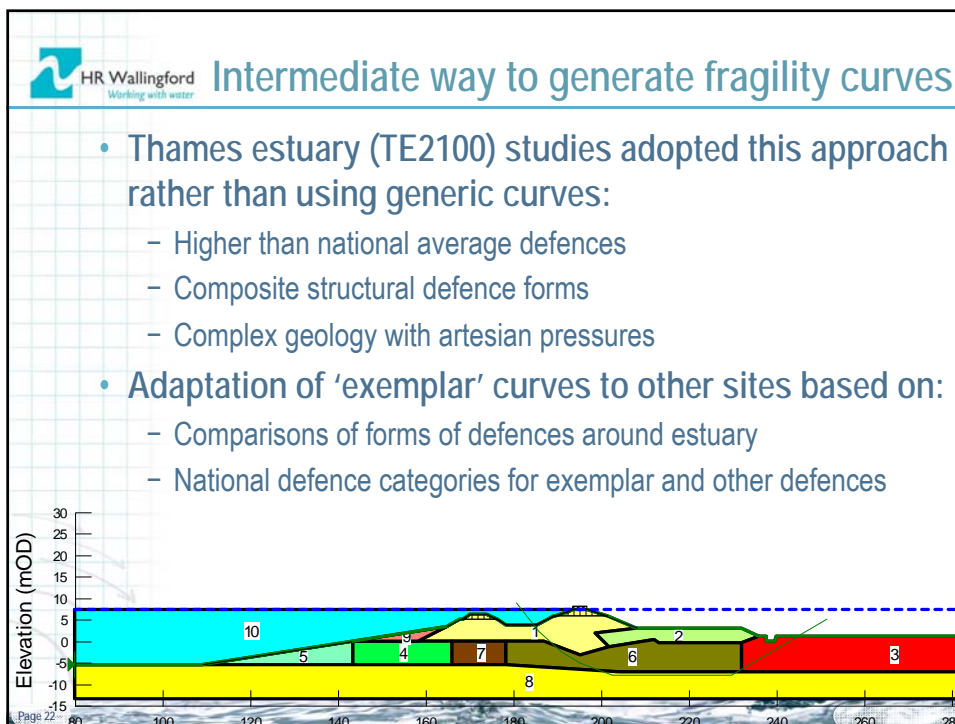
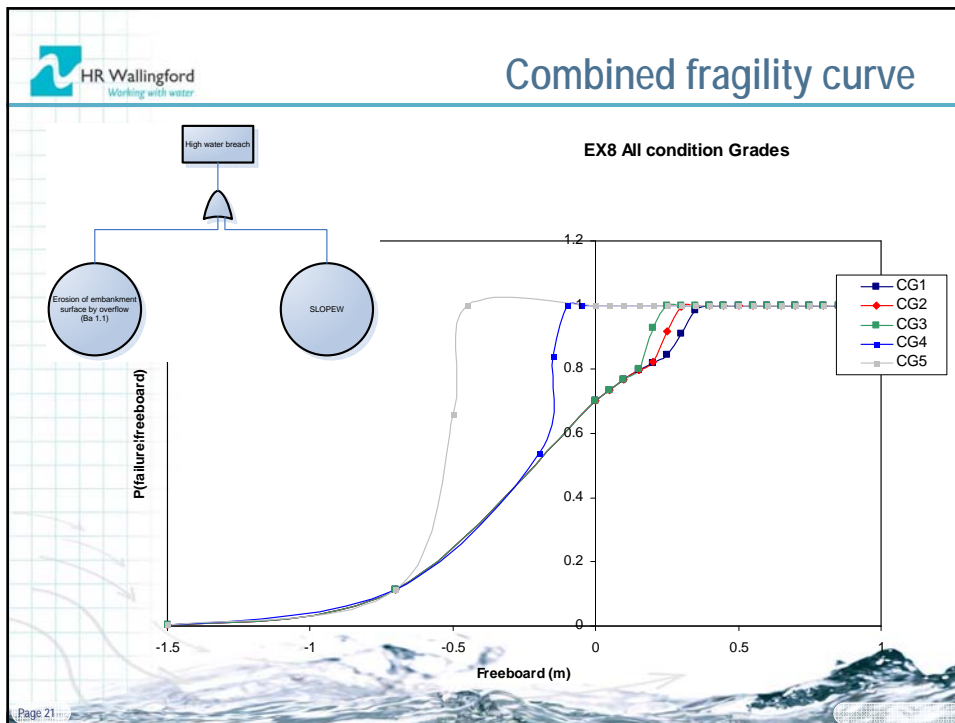
If not, better to use RELIABLE tool generated under FLOODsite and UK FRMRC projects

High water breach

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SLOPEW

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- **Engineers and researchers**
 - who create generic and bespoke fragility curves
 - who use the curves in flood risk systems modelling
 - who want to enhance conventional analysis of asset failure modes by providing information about uncertainty in deterministic factors of safety (Duncan, 2000)
- **Operational flood risk management personnel**
 - need to understand the basic concept
 - will use the curves indirectly because of their embedment within operational tools (UK example 'RAFT')
 - *next presentation by Marta Roca will explain this*
 - and within systems analysis tools
 - *presentations in final session will explain this*

- Fragility curves are a fundamental tool in flood risk management. They
 - express the varying probability of breach of levees with load
 - allow flood systems analysis to properly include the effect of defences
 - can be generalised for broad scale analysis of bespoke for local system or project analysis
- Demystifying the basic concept for non-experts is worthwhile so that they can be used in operational tools
- Contributions of shared experiences on fragility and more generally on the performance, design, and management of levees are sought for the International Levee Handbook www.leveehandbook.net

- Simm, J., Gouldby, B., Sayers, P., Flikweert, J, Wersching, S. and Bramley, M. (2008) Representing fragility of flood and coastal defences: getting into the detail. *Proc. Eur. Conf. on Flood Risk Management: Research into Practice* (FLOODrisk 2008). London: Taylor & Francis, 621-631.
- Flikweert, J. and Simm J. (2008) Improving performance targets for flood defence assets. *J Flood Risk Management* 1, 201-212.
- Simm, J. and Flikweert, J. (2009) PAMS (Performance-based Asset Management System) – Phase 2: Development of fragility curves for use in management of flood defence assets. Report SC040018/SR5. Environment Agency
- Schultz, M., Gouldby, B., Simm, J. and Wibowo, J. (2010) Beyond the factor of safety: developing fragility curves to characterize system reliability. *USACE 'white paper' ERDC SR-10-1.*



The Use of Fragility Curves for UK Flood Defences and their Implications for Flood Risk Management

Jonathan Simm
Flood Management Group, HR Wallingford

