Risk management of extreme flood events

IGS Institut für Geotechnik

Reliability Analysis of River Embankments --using analytical methods and finite elements--

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Funding

Project Management

Coordination

Benefits of reliability analysis

Aim of a reliability analysis in river flood protection

Systematic determination of flood risk as cost-benefit-analysis

Risk = Failure probability x Consequence

Not: „This is a potential weak spot!“

But: „Those are the sections to start improving the flood protection.“

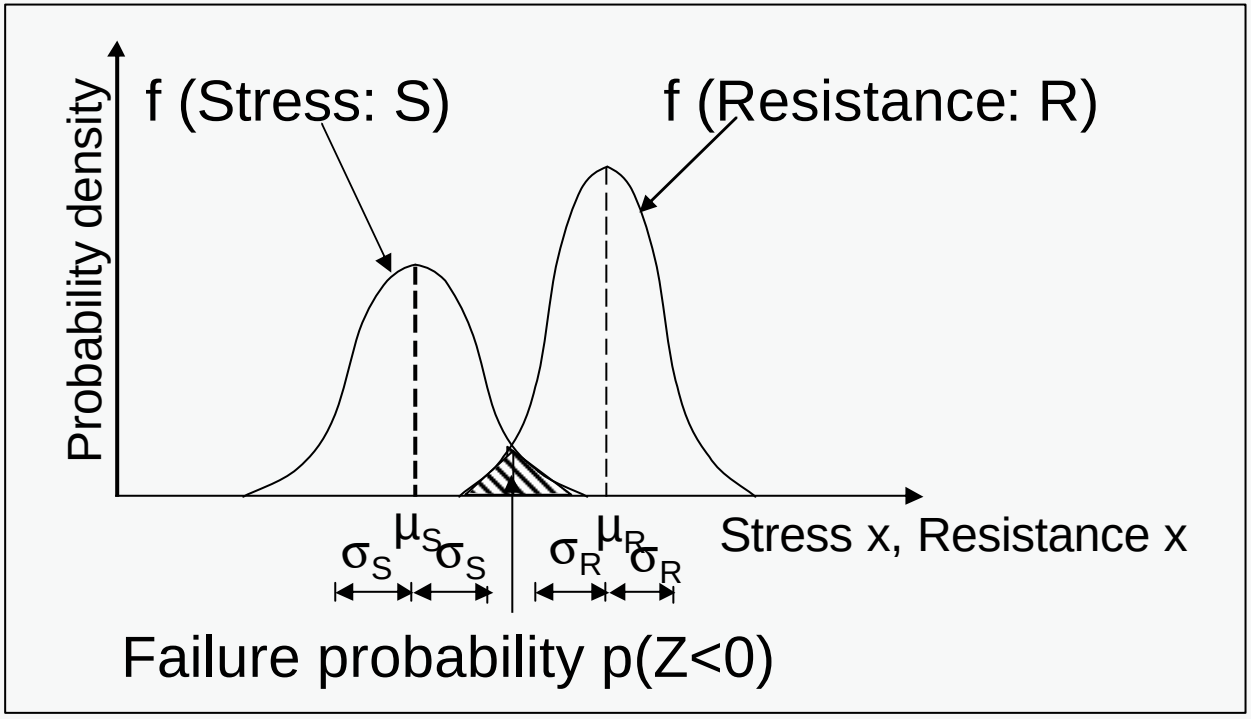
And: „Those are the most cost-efficient measures.“

Outline

- Introduction into reliability analysis
- Case study Elbe river
- Probabilistic Finite-Element Analysis of embankment stability
- Conclusions and Outlook

Introduction into reliability analysis

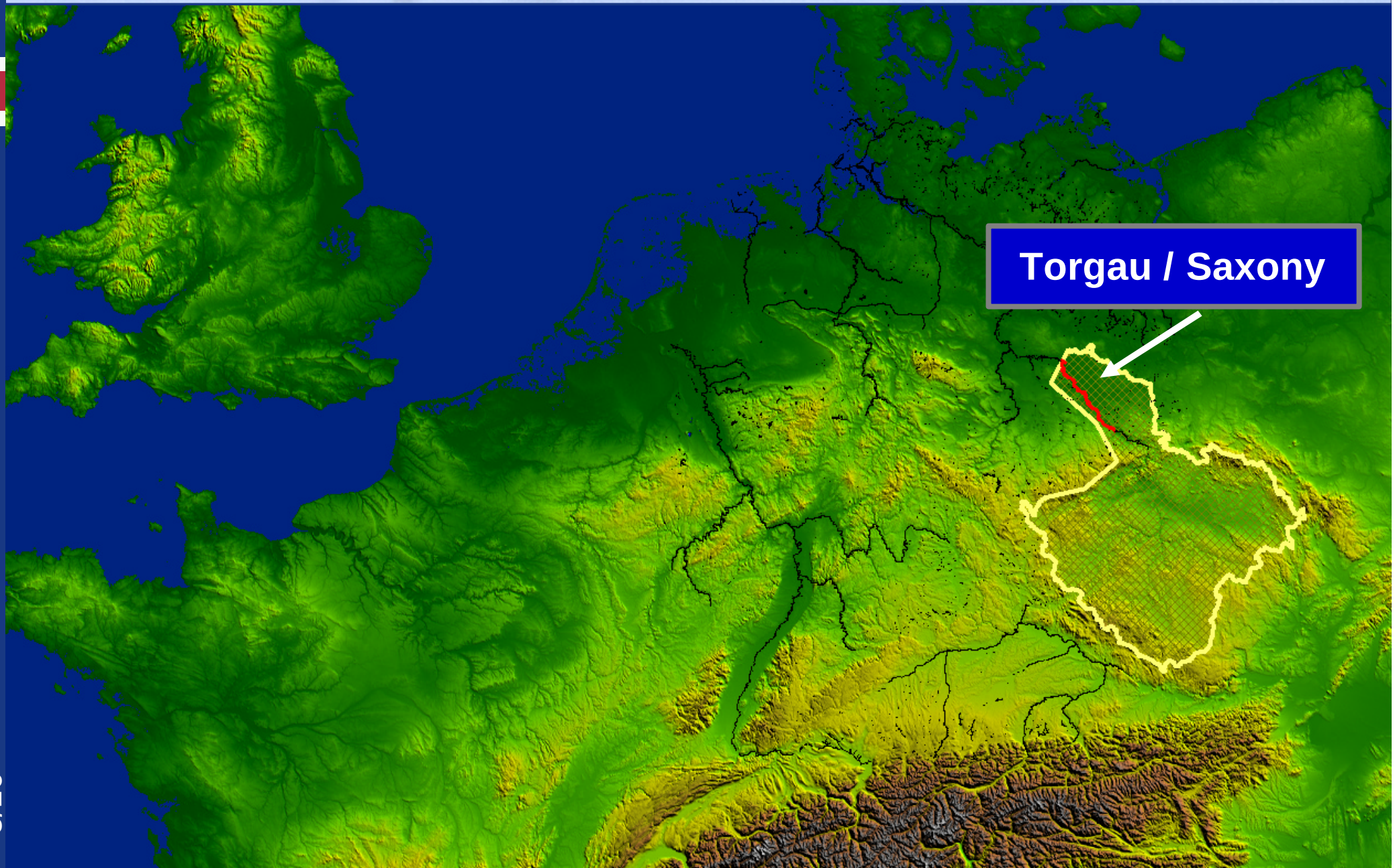
Limit state equation: $Z = R - S$ R: Resistance, S: Stress



Reliability index for Gaussian (normally) distributed variables and Z = R - S:

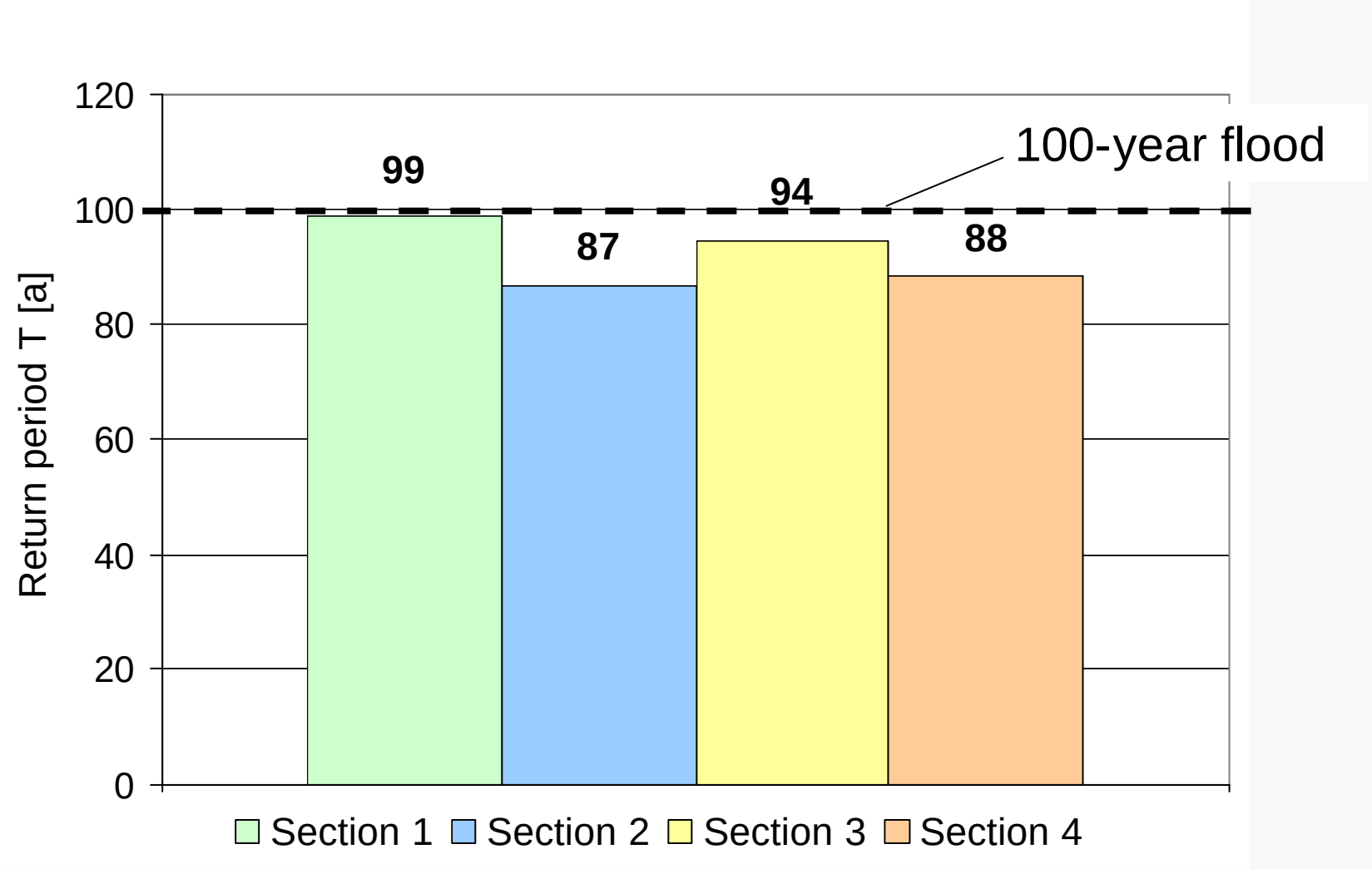
$$\beta = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}} = \frac{\mu_Z}{\sigma_Z}$$

Case study Elbe river



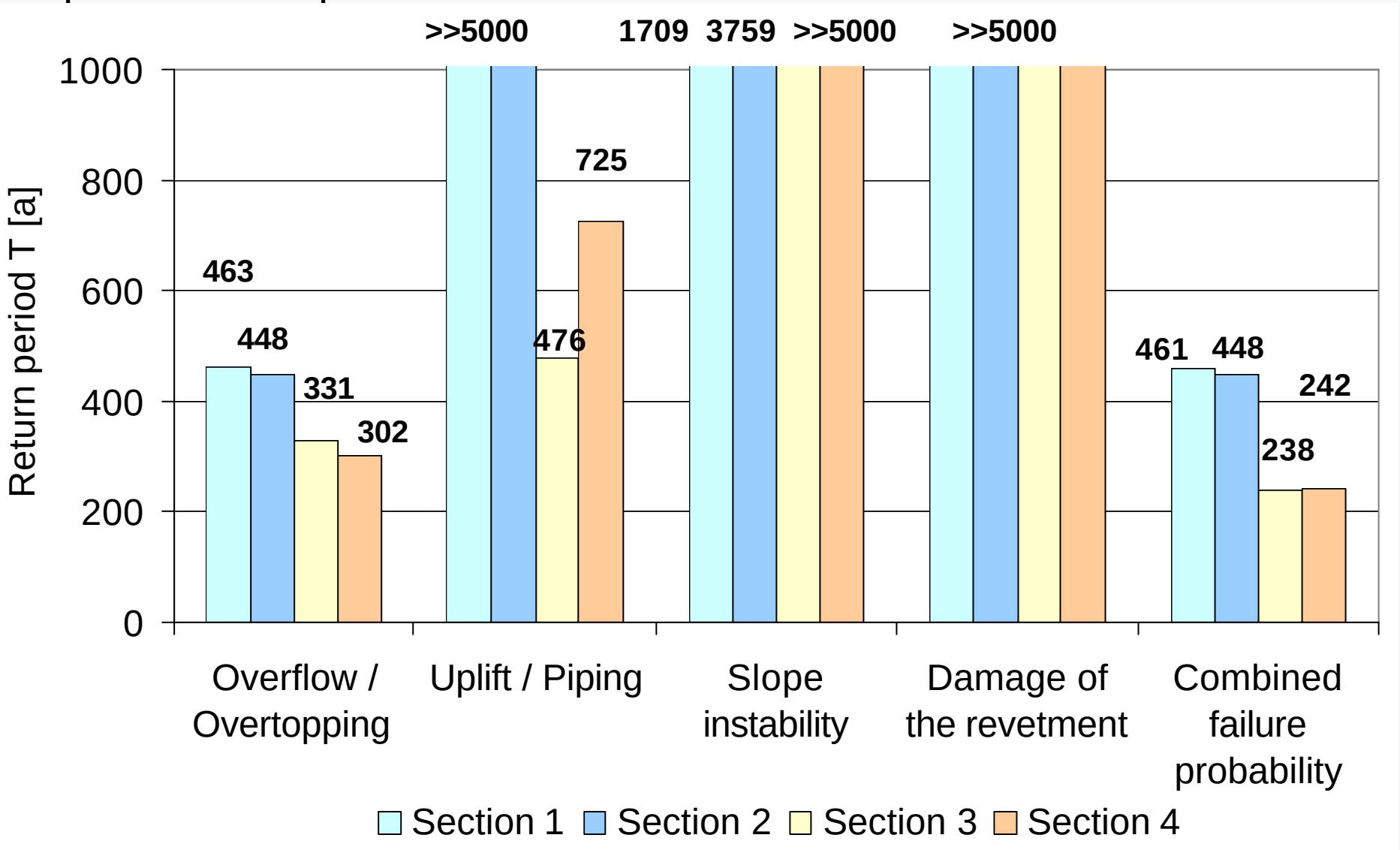
Case study Elbe river

Comparison to a 100-year flood only considering overflow (Dike stretch B)



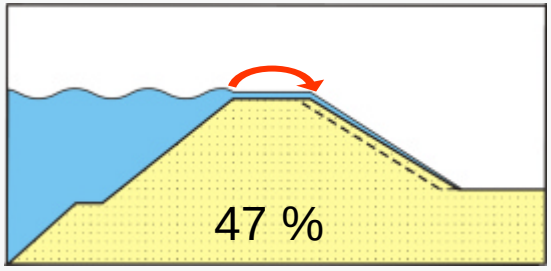
Case study Elbe river

Computed failure probabilities for dike stretch B

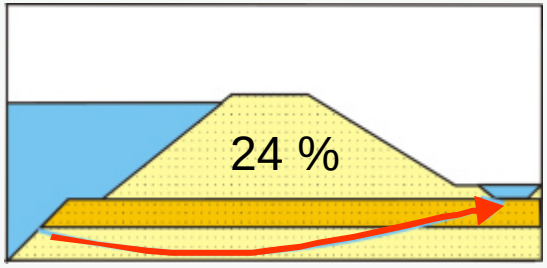


Case study Elbe river

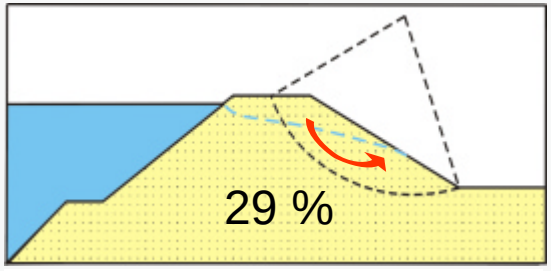
Comparison to Elbe flood 2002 - dike failure statistics (Horlacher, 2005)



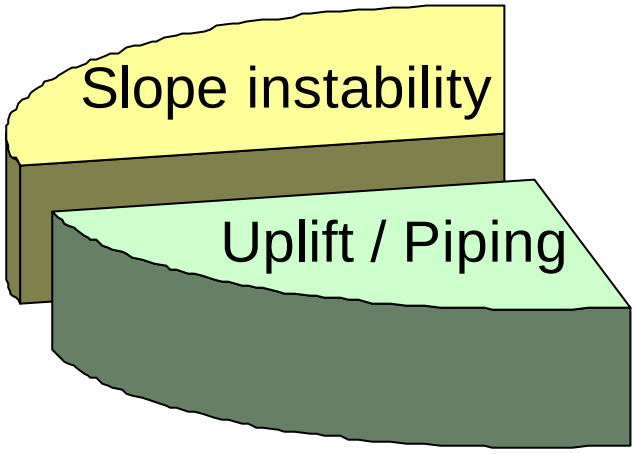
Overflow / Overtopping

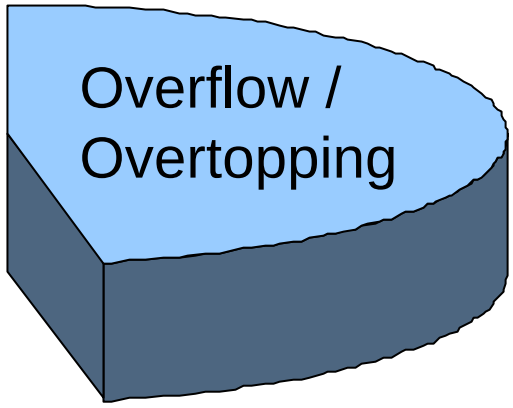


Uplift / Piping



Slope instability

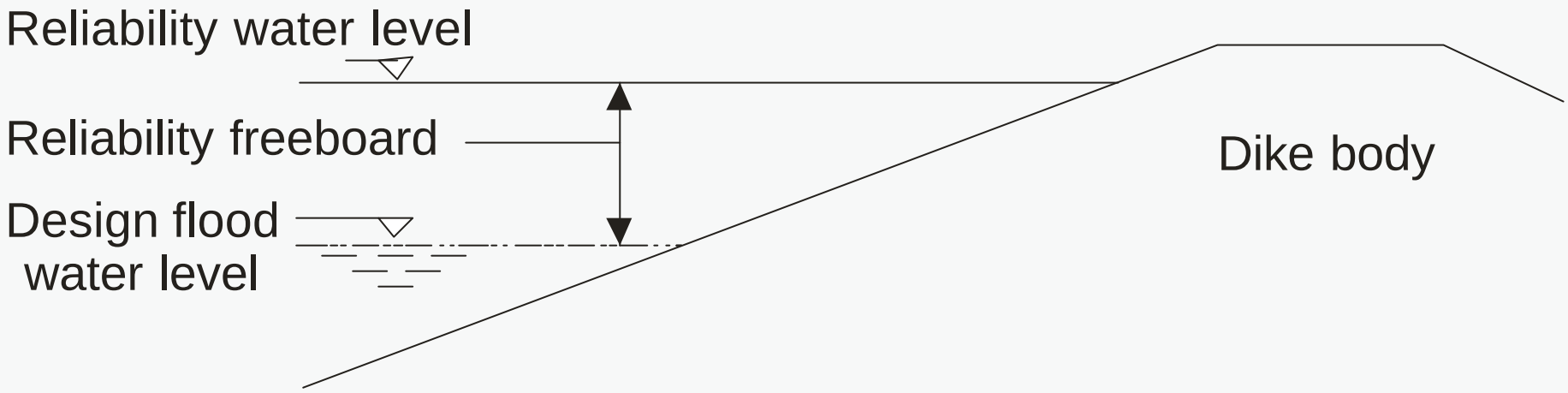


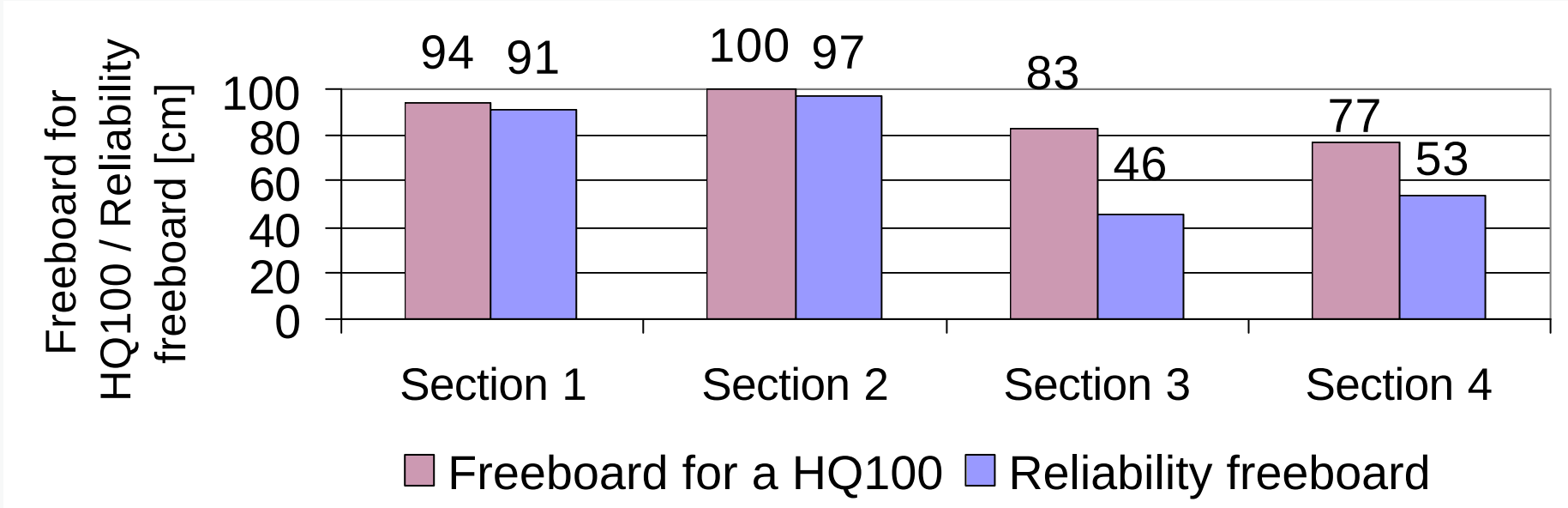


Failure mode	Dike failure statistics	Relative failure probability (PC-Ring)
Overflow / Overtopping	47 %	66 %
Uplift / Piping	24 %	28 %
Slope instability	29 %	6 %

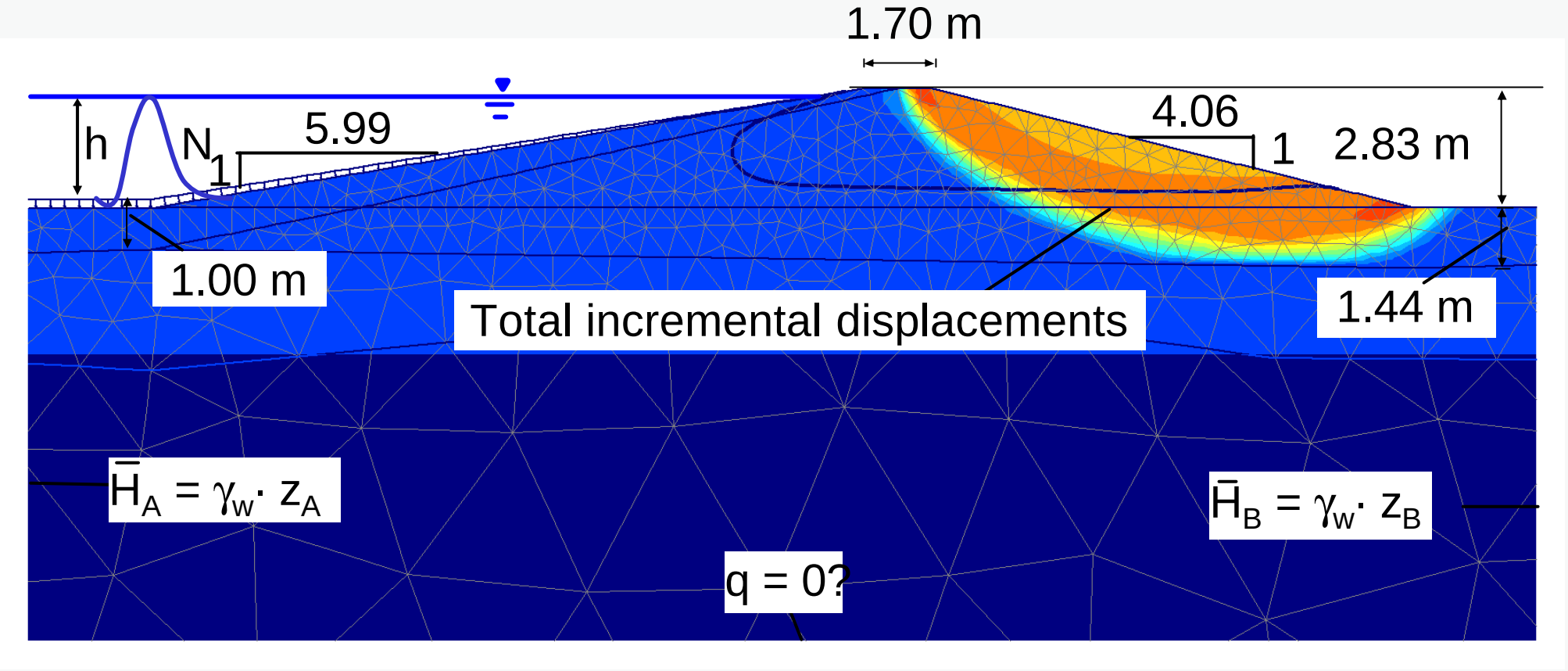
Case study Elbe river

Reliability water level and reliability freeboard





Probabilistic Finite-Element Analysis of embankment stability



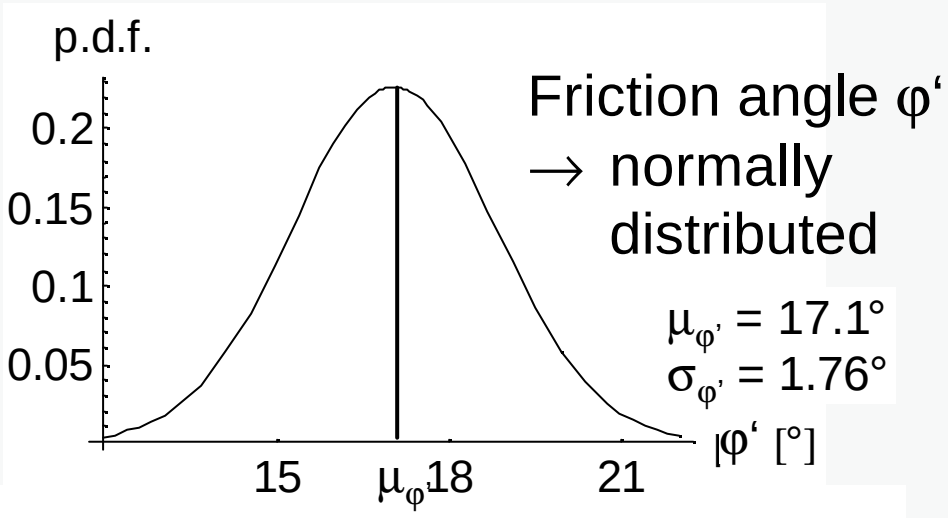
Benefits:

→ Stability reserves due to transient seepage effects can be quantified.

→ Zoned dike structure can be taken into account.

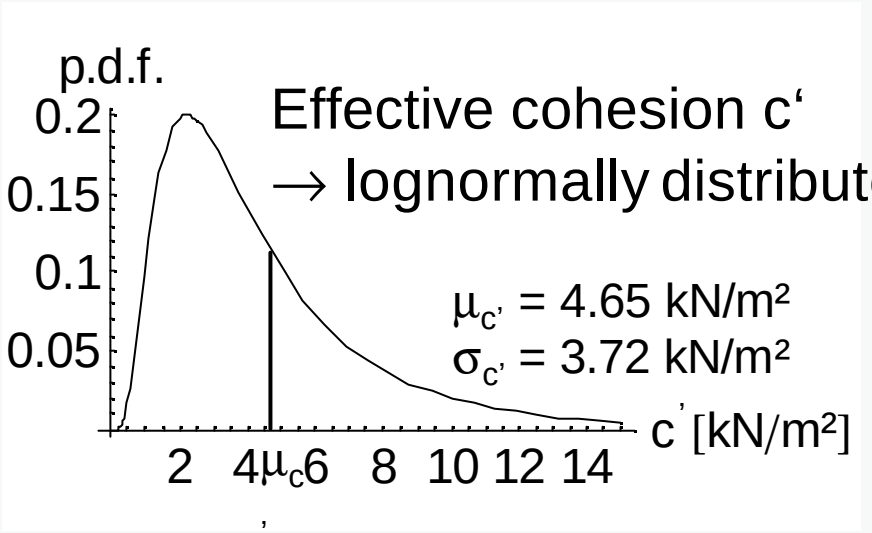
Probabilistic Finite-Element Analysis of embankment stability

Stochastic input parameters



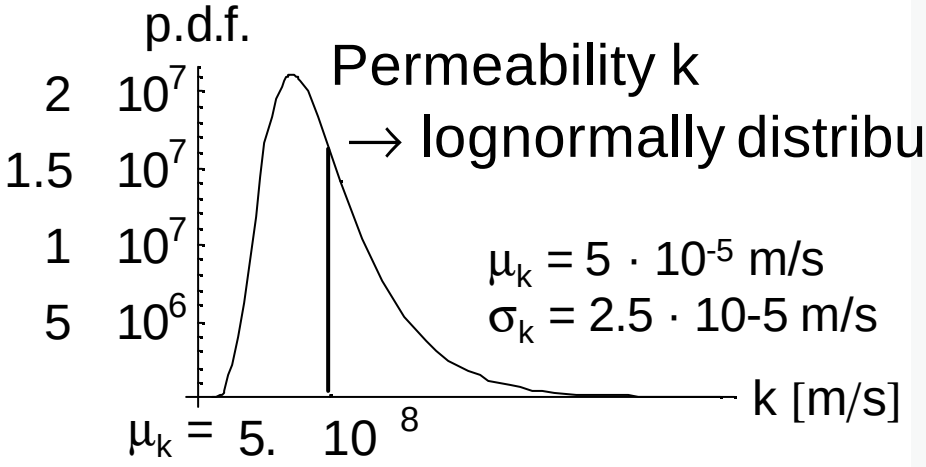
Friction angle φ‘
→ normally distributed

$\mu_{\varphi'}$ = 17.1°
$\sigma_{\varphi'}$ = 1.76°



Effective cohesion c‘
→ lognormally distributed

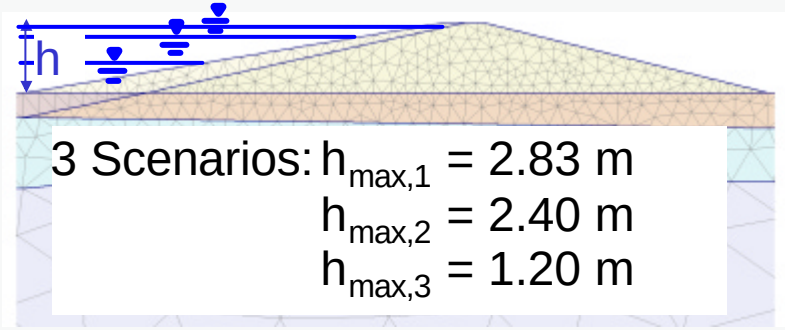
$\mu_{c'}$ = 4.65 kN/m²
$\sigma_{c'}$ = 3.72 kN/m²



Permeability k
→ lognormally distributed

$\mu_k = 5 \cdot 10^{-5}$ m/s
σ_k = 2.5 · 10-5 m/s

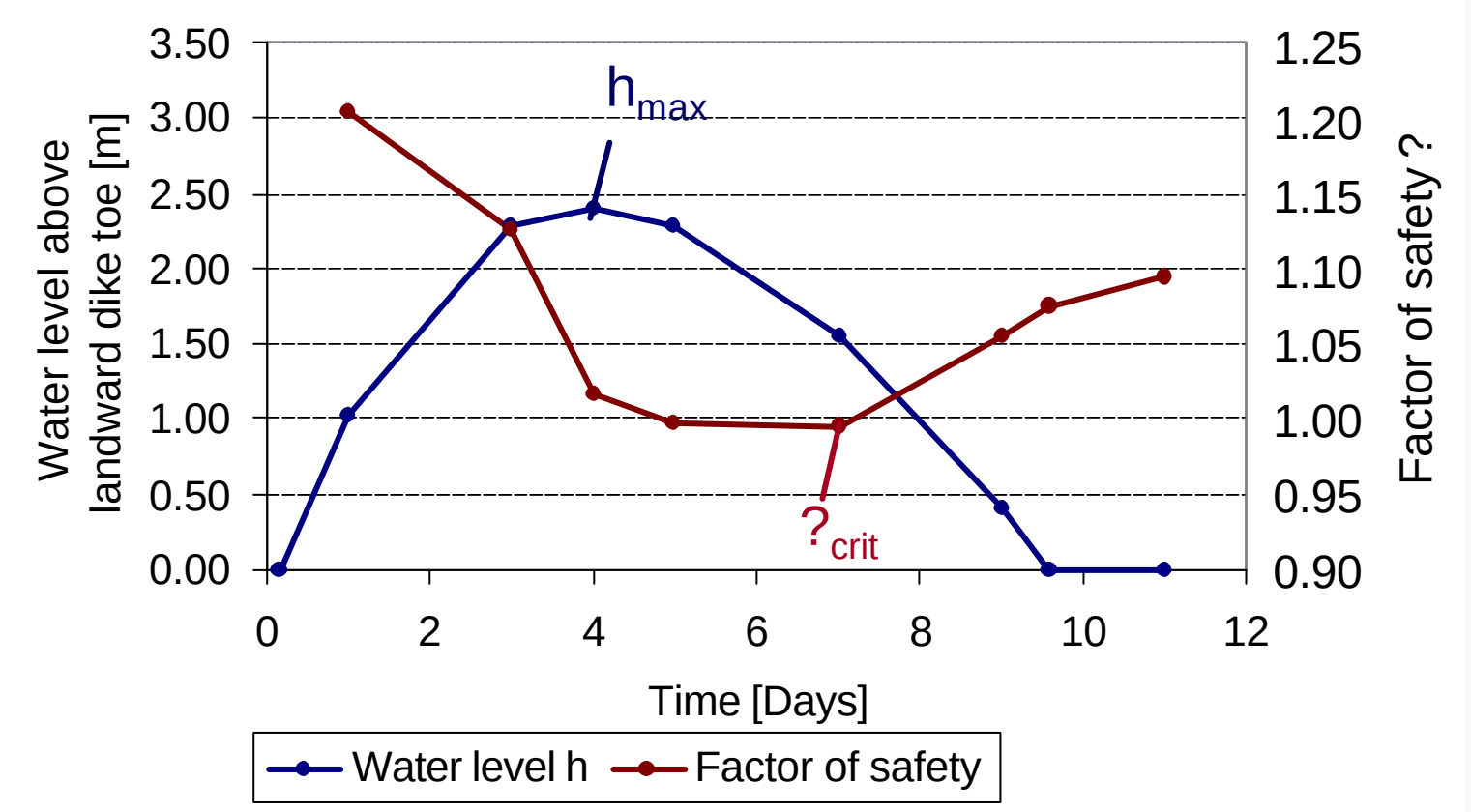
→ Correlated river water level h and duration of the flood wave N



Probabilistic Finite-Element Analysis of embankment stability

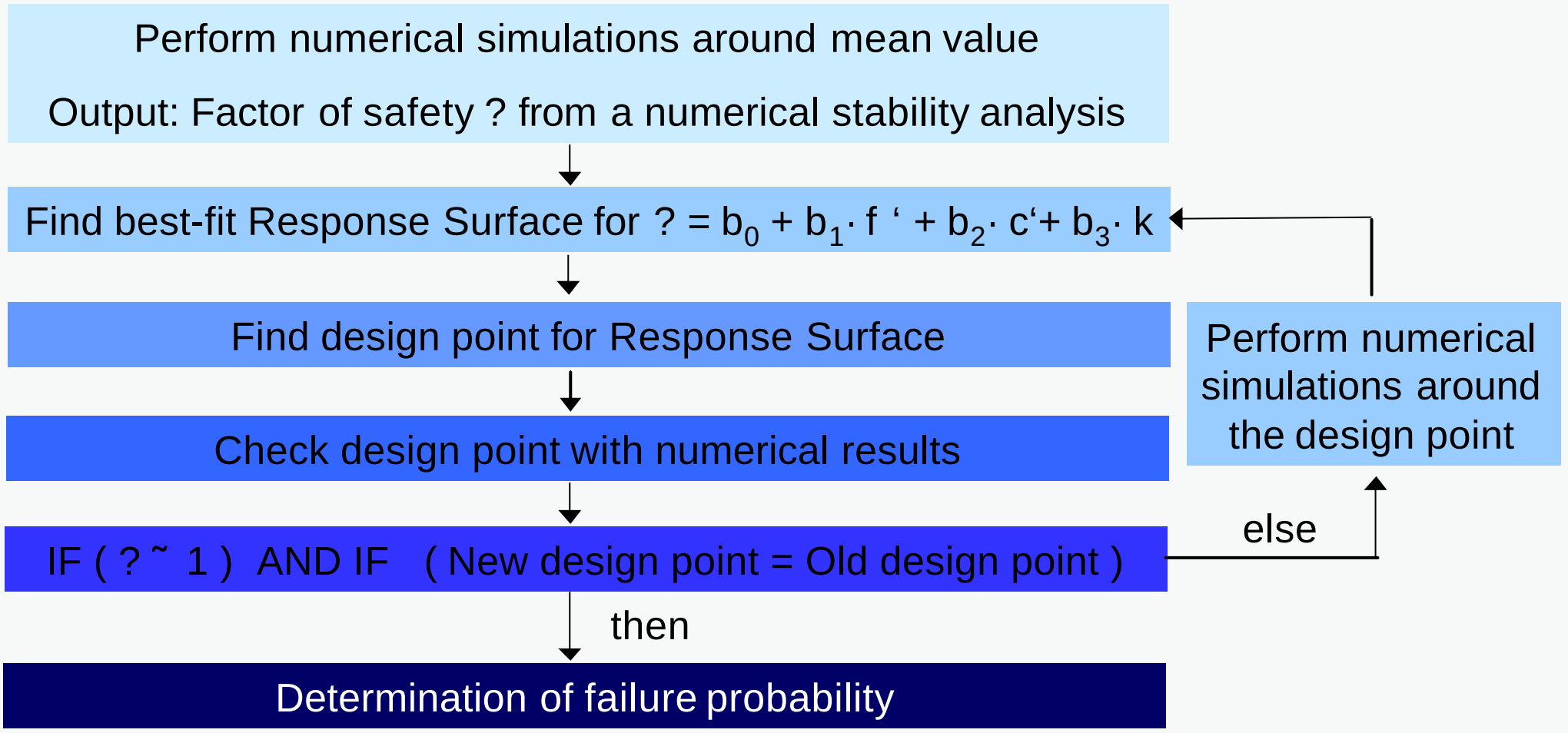
Phase shift between maximum water level and minimum factor of safety

→ Factor of safety ? needs to be checked for various time steps for various flow patterns



Probabilistic Finite-Element Analysis of embankment stability

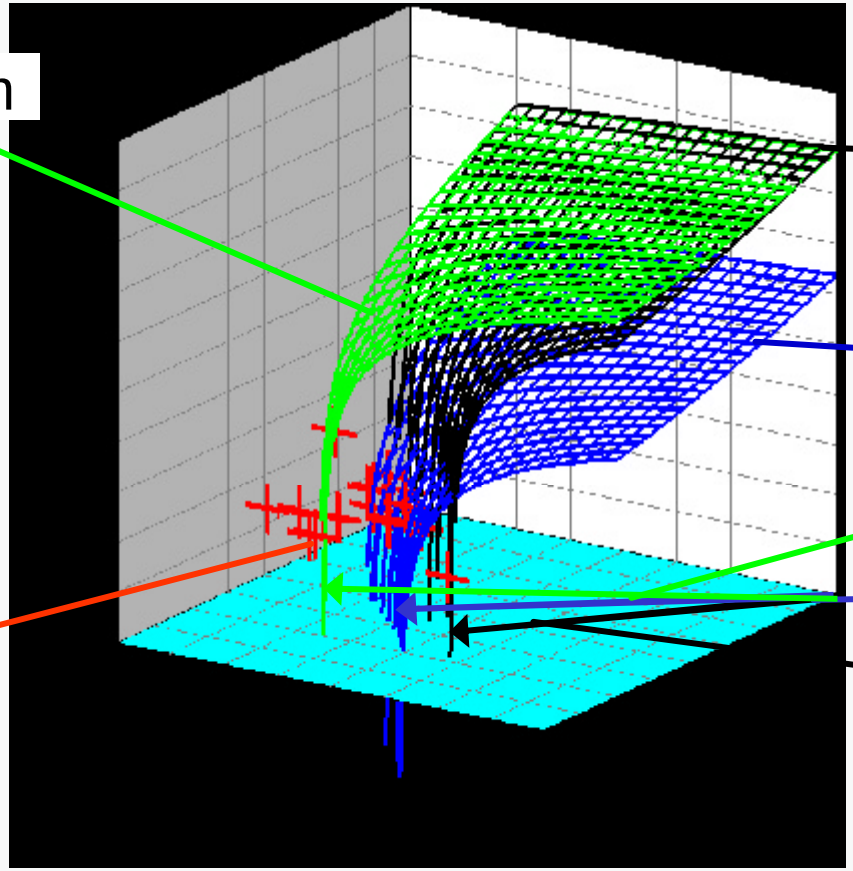
First Order Reliability Method with Adaptive Response Surface (FORM-ARS)



Probabilistic Finite-Element Analysis of embankment stability

Response Surfaces for three different maximum water levels

Transformation into standard-normalized variables: $u_i = \frac{X - \mu_x}{\sigma_x}$



→ 240 Finite-Element calculations → Return period of failure: ~ 40,000 years

Conclusions and Outlook

- Reliability analysis as basis for a reliable flood risk management
- Comparable tendency with dike failure statistics during the flood in 2002
- Integration of a probabilistic FE-analysis for slope instabilities which regards zoned dikes and transient seepage effects
- Provision of a tool for risk-based river flood protection
- Accompanying paper at ISFD4 2008 by Merkel and Westrich

Thank you for your attention!

Questions?

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