Queensland Tailings Group

55^{th} Rankine Lecture

Reprise in Brisbane 25 July 2024

Hazard, Risk and Reliability in Geotechnical Practice

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THE BRITISH GEOTECHNICAL ASSOCIATION

Institution of Civil Engineers

Three key questions

- How can reliability and risk concepts help to ensure adequate safety while achieving cost-effective designs?
- What are the advantages and challenges of the hazard, risk and reliability approach?
- Why aren't reliability and risk concepts used more today (2015)?

Strategy in answering these questions

Present examples that are so convincing that they will make you want to use some of the methods.

Show that probabilistic and deterministic analyses are, in many cases, necessary complements to each other.

Contents of lecture

1. Basic concepts and early work
2. Reliability analyses to ensure adequate safety and lead to cost-effective design - "Real-life“ cases
    - Design of piles for offshore installations
    - Debris flow in Barcelonnette Basin, France
    - Water-retaining dams
    - New Orleans levees
3. Calibration of safety factor in codes
4. Challenges, emerging topics, summary and conclusions

Personal career insights

Basic definitions

Risk = f (Hazard and consequences)

Risk = f (H, V, U)

H = Hazard (temporal probability of a threat)

V = Vulnerability of element(s) at risk

U = Utility (or value) of element(s) at risk

Munkedal Sweden 2006
Landslide due to non-adherence to construction protocol

Area with high l
hazard, but very
consequences (c
farmland, desert

→ low risk

Slope stabilisation
done in the one a
the landslide haza

Early work
[Lumb, 1966]

Properties of four natural soils were shown to be random and essentially normally distributed: (grain size distribution, strength (s_u and ϕ') and compressibility characteristics).

Lumb suggested, based on "what never fails":

«a suitable value of probability of failure for design (bearing capacity) should be 10^{-4} to 10^{-5}».

Early work

[Wu and Kraft, 1967; 1970]

Probability of foundation safety

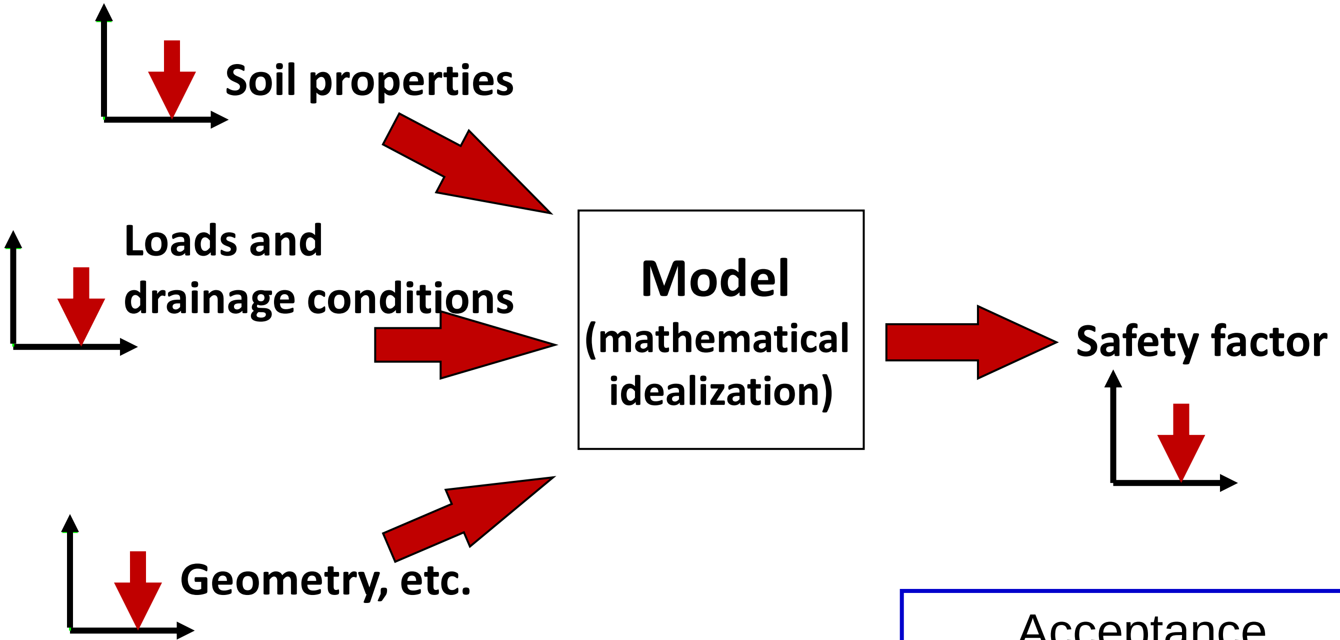
A 'measure of safety' was found probabilistically for

- Excavation in clay
- Bearing capacity failure in clay
- Slope in clay
- Settlement in sand

The factor of safety is not a "unique quantity".

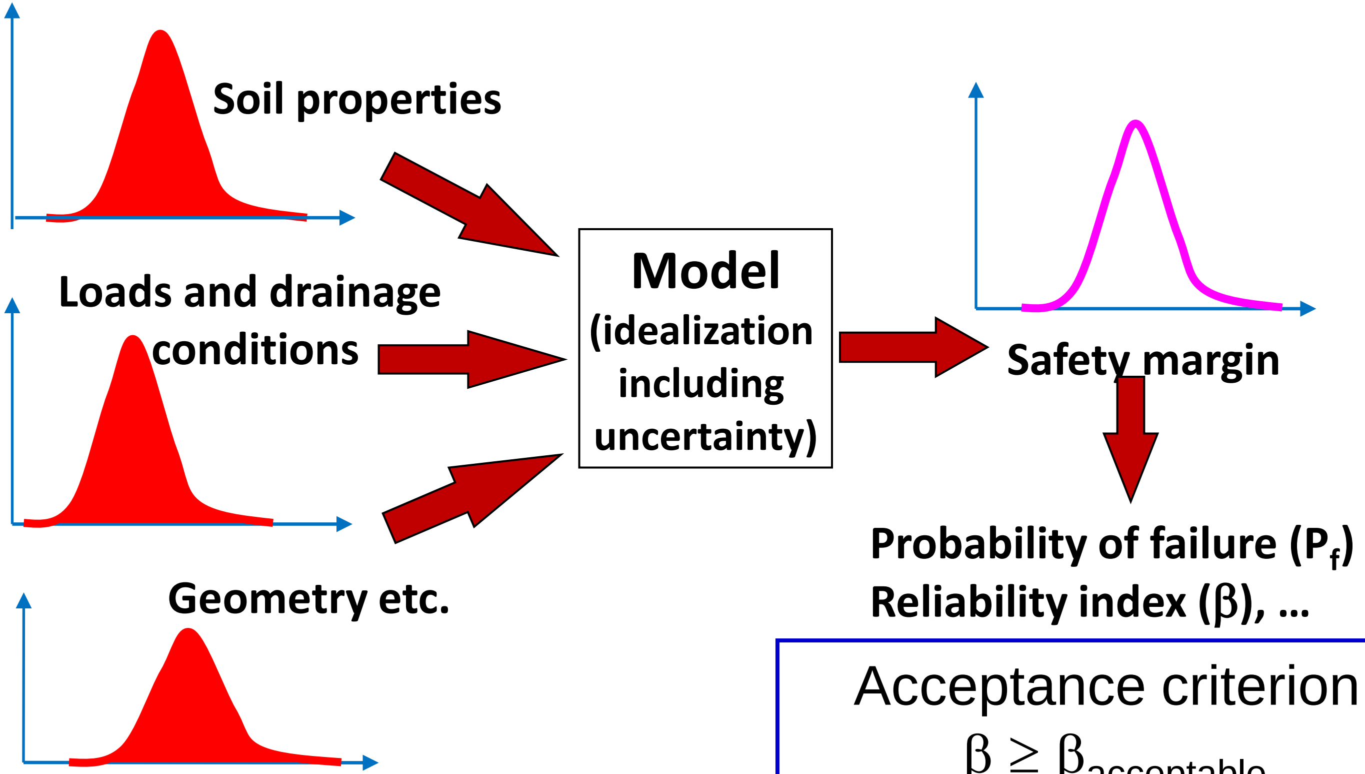
"Probability analysis leads to rational means of foundation design […] and is a step forward to the optimum design of structures."

Deterministic (conventional) analysis



Acceptance
criterion:
$FS \geq FS_{acceptable}$

Probabilistic analysis

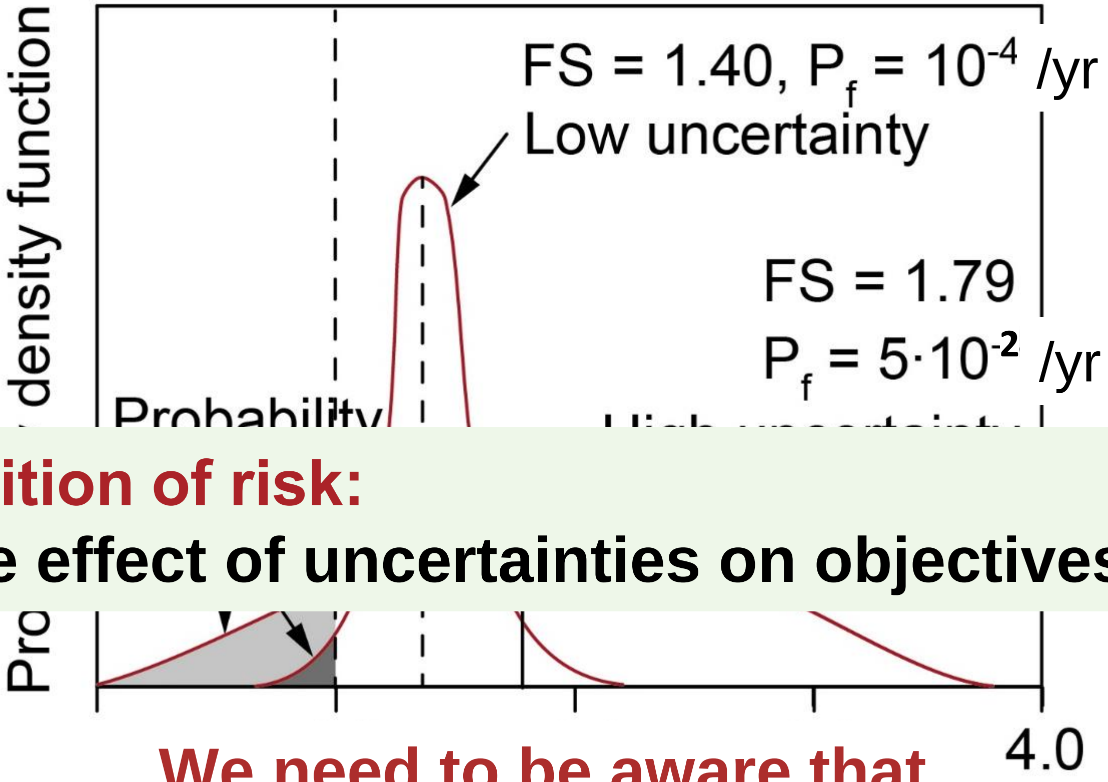


Acceptance criterion:

$$\beta \geq \beta_{acceptable}$$

$$P_f < P_{f\ tolerable/acceptable}$$

Factor of safety and probability of failure



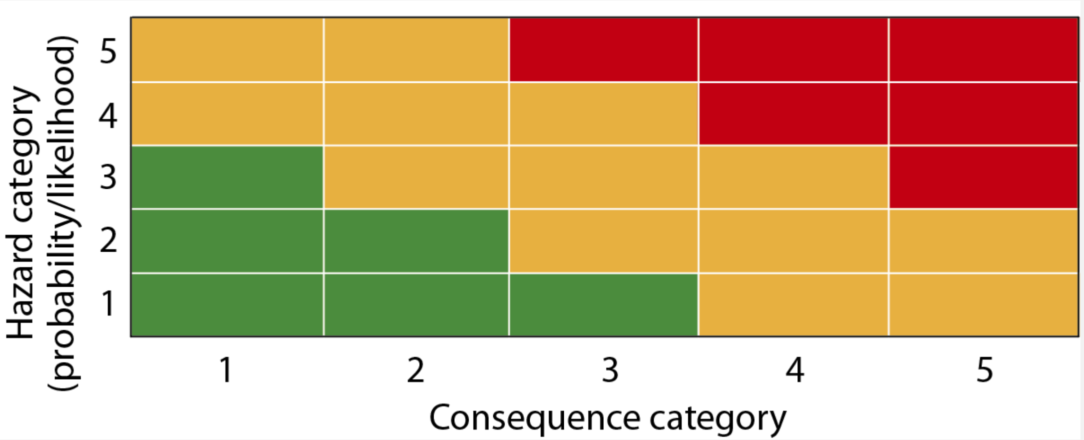
ISO's definition of risk:

"Risk is the effect of uncertainties on objectives"

We need to be aware that the P_f is never zero!

How can we describe risk?

Qualitatively: risk matrix



Green: Low risk
Orange: Medium risk
Red: High risk

A discussion of the uncertainties, even with the simplest methods, provides added insight into the safety and what are the important factors affecting it.

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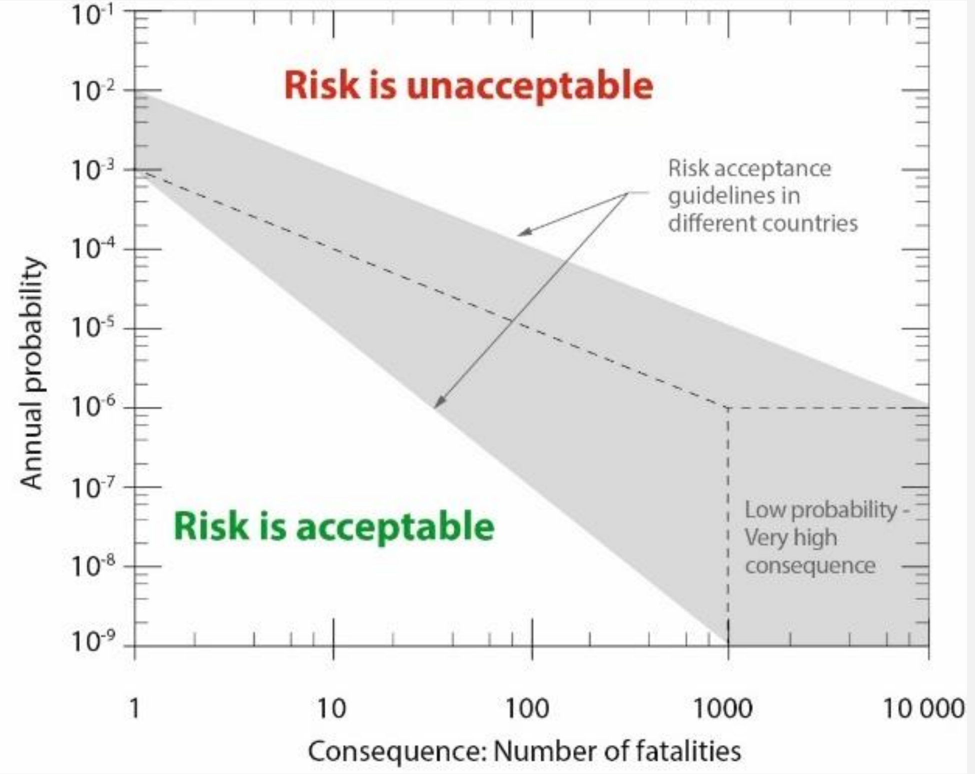
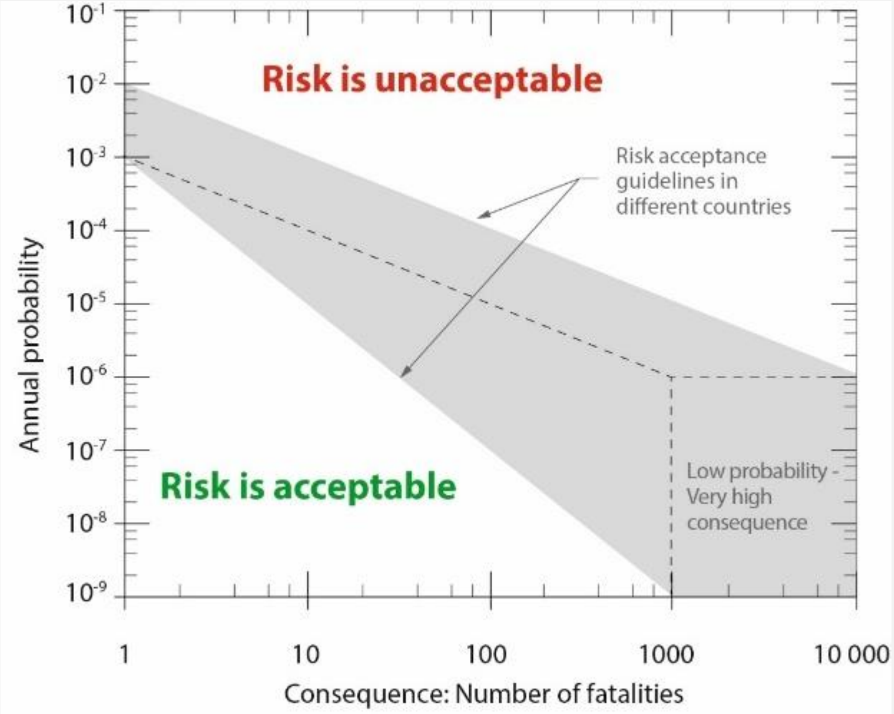
How can we describe risk?

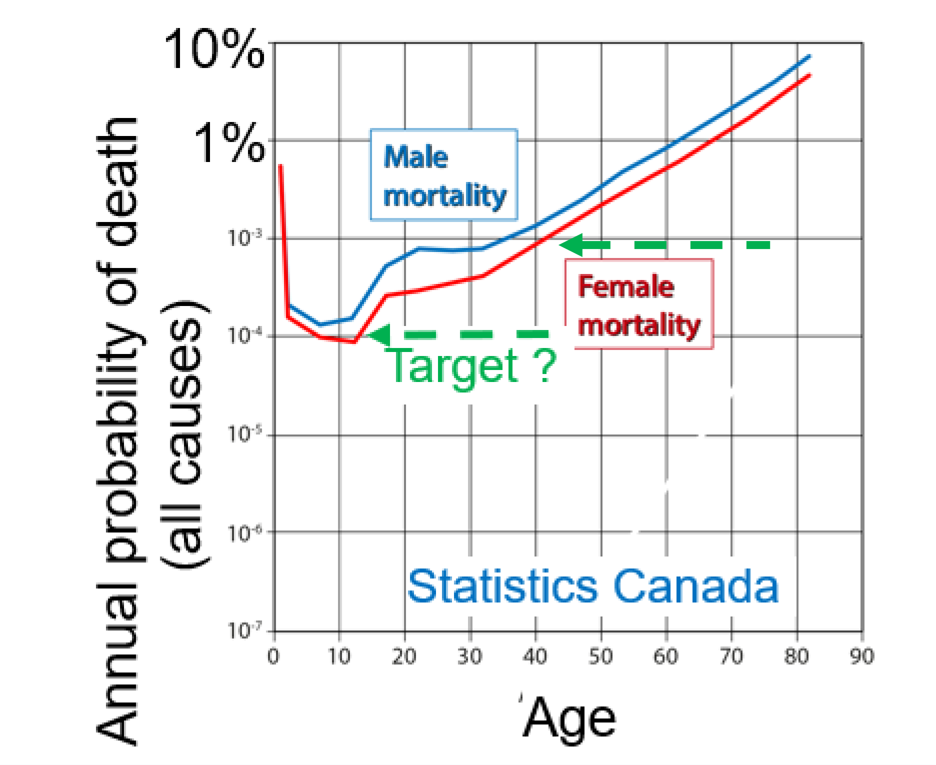
Quantitavely - Risk diagram

A series of temporal probabilities and consequences on a so-called F-N diagram



What is acceptable risk?





NGI

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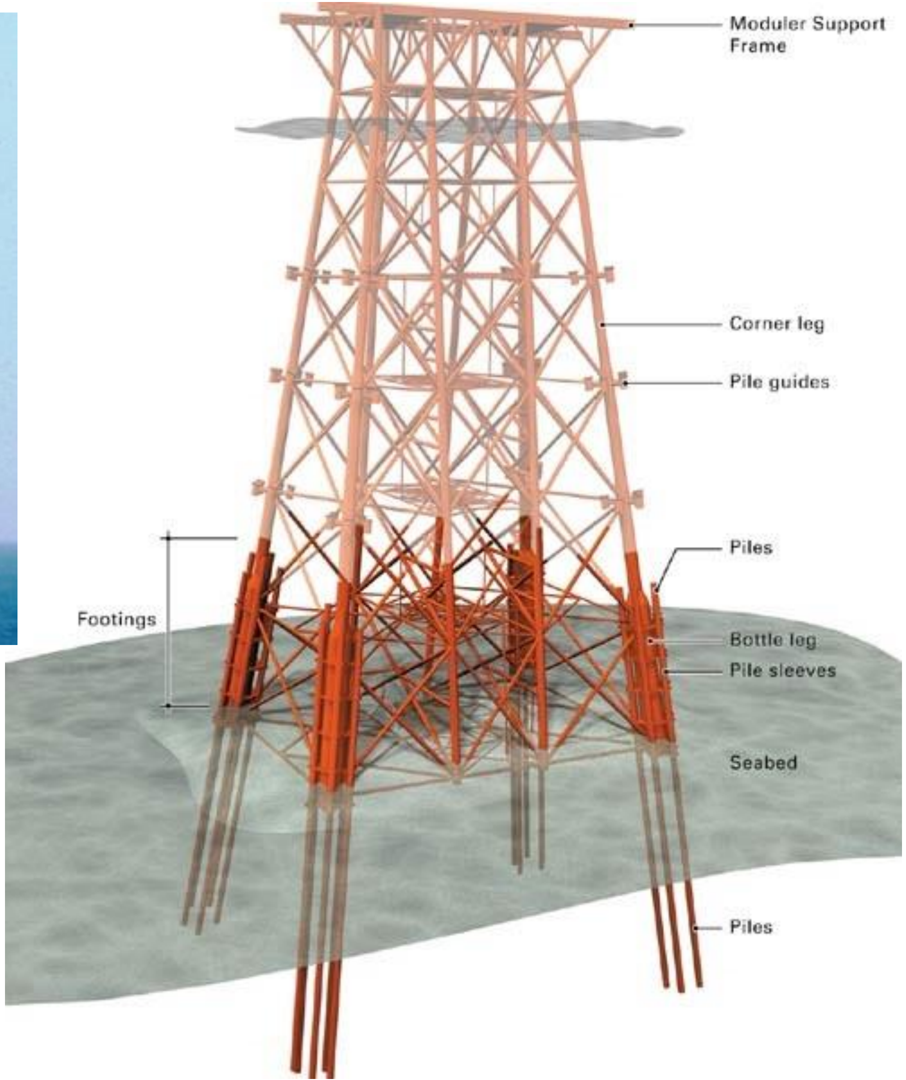

Moduler Support
Frame
Corner leg
Pile guides
Piles
Footings
Bottle leg
Pile sleeves
Seabed
Piles

Motivation

- Guidelines require the same level of safety for the new CPT-based pile capacity design methods as for the older API method.
- The designer is required to select an "appropriate" safety factor when using the new CPT-methods.
- The designer can choose to:
    1) be conservative and apply a "high" safety factor or
    2) document the level of safety (“probability of failure").

Load and resistance factors

Design Criterion

$$[\gamma_{l\ stat} \bullet P_{stat} + \gamma_{l\ env} \bullet P_{env}^{100\text{-}yr}] \leq Q_{ult\ char} / \gamma_m$$

$\gamma_{l\ stat}$	=	Load factor on static load
P_{stat}	=	Characteristic static load
$\gamma_{l\ env}$	=	Load factor on environmental load
$P_{env}^{100\text{-}yr}$	=	Characteristic environmental load (typically the 100-yr load, $P_{env}^{100\text{-}yr}$)
$Q_{ult\ char}$	=	Characteristic ultimate axial pile capacity deterministic
γ_m	=	Resistance factor on capacity

Design of offshore pile foundations

- 3 sites (A, B, C), 100 m water depth
- Pipe piles, 2.5 m dia; t= 90 - 100 mm
- Loading in compression was governing

4 'newer' CPT design methods:
ICP-03, NGI-05, UWA-05 and Fugro 96/05.

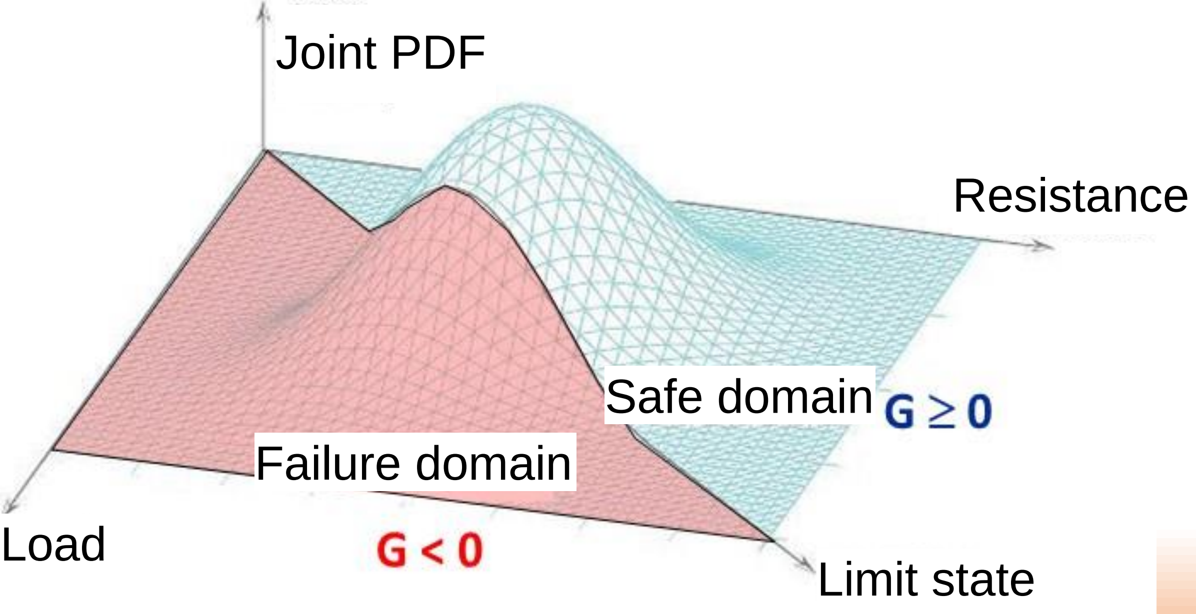
For deterministic analyses, the company required a resistance factor γ_m = 1.5 with the CPT-methods.

For probabilistic analyses, the target annual probability of failure was set to $P_f \leq 10^{-4}$, to follow NORSOK’s 'guideline'.

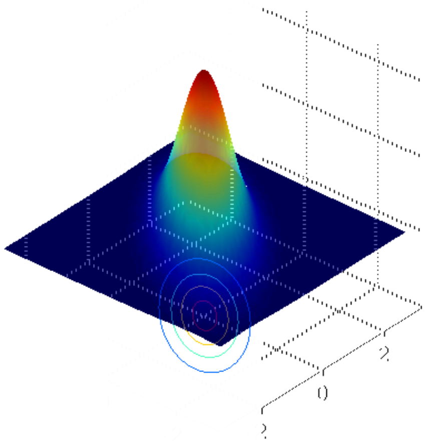
Probabilistic analysis with FORM

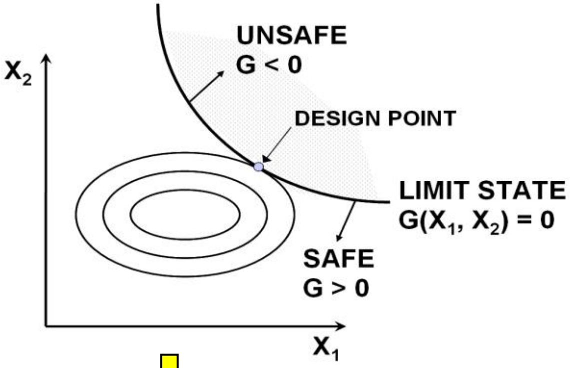
One defines a performance function e.g. $G(X) = R - L$,
where $G(X) \geq 0$ means satisfactory performance
$G(X) < 0$ means failure

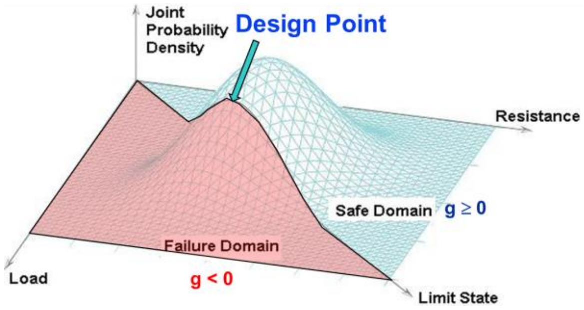
X is a vector of basic random variables (resistance, load effects, geometry and model uncertainty).

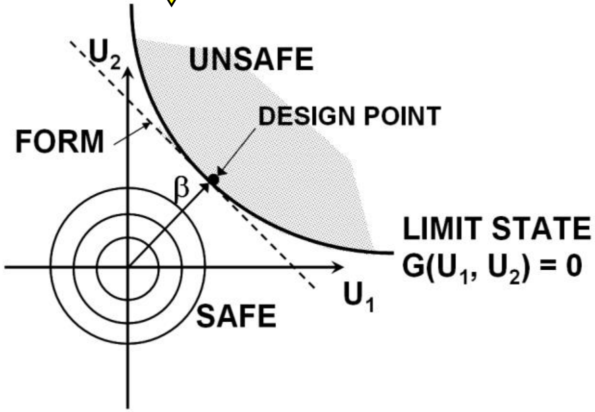


FORM/SORM approach

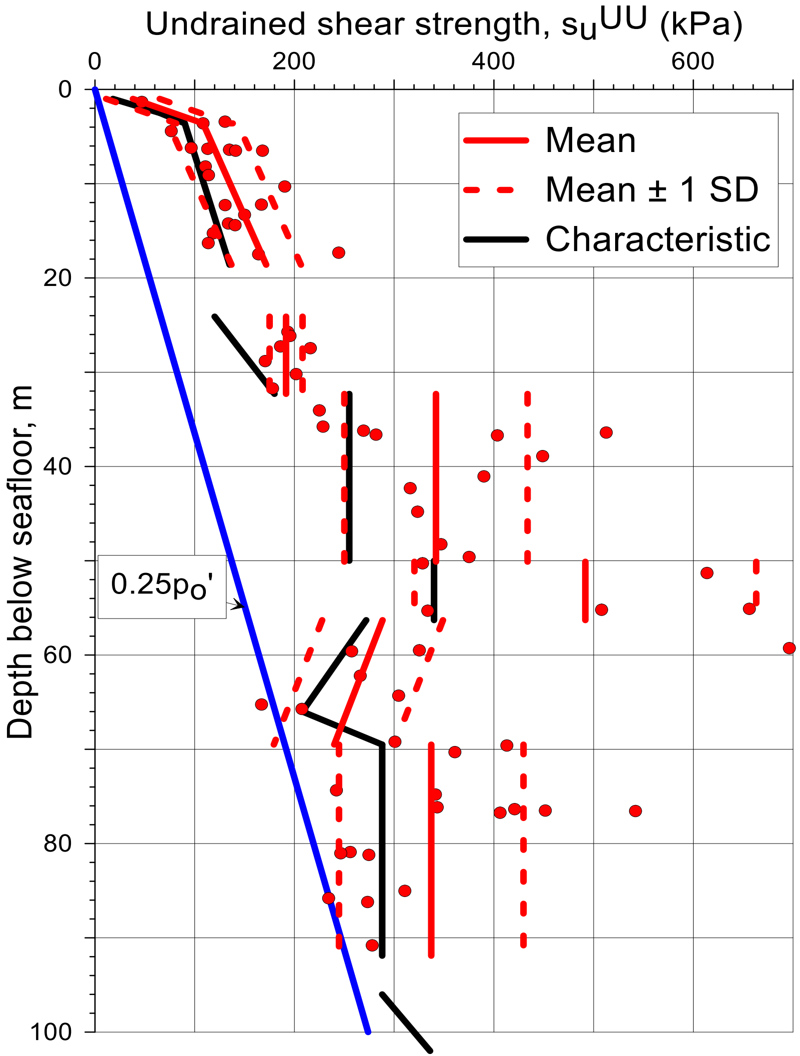




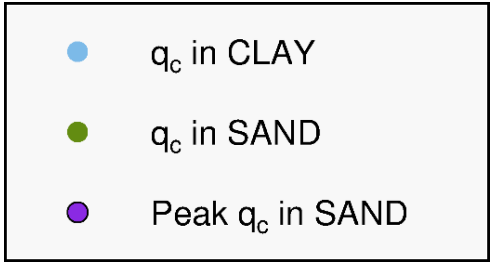


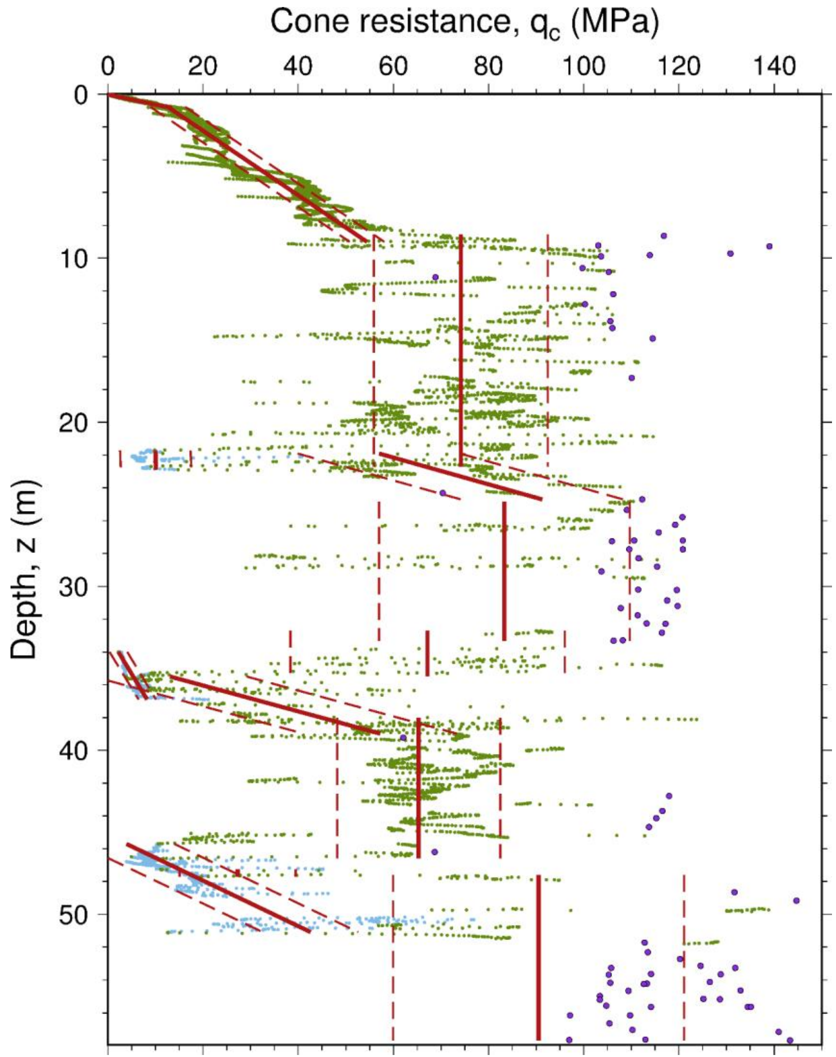


Undrained shear strength, S_u^{UU} Site A "clay site"

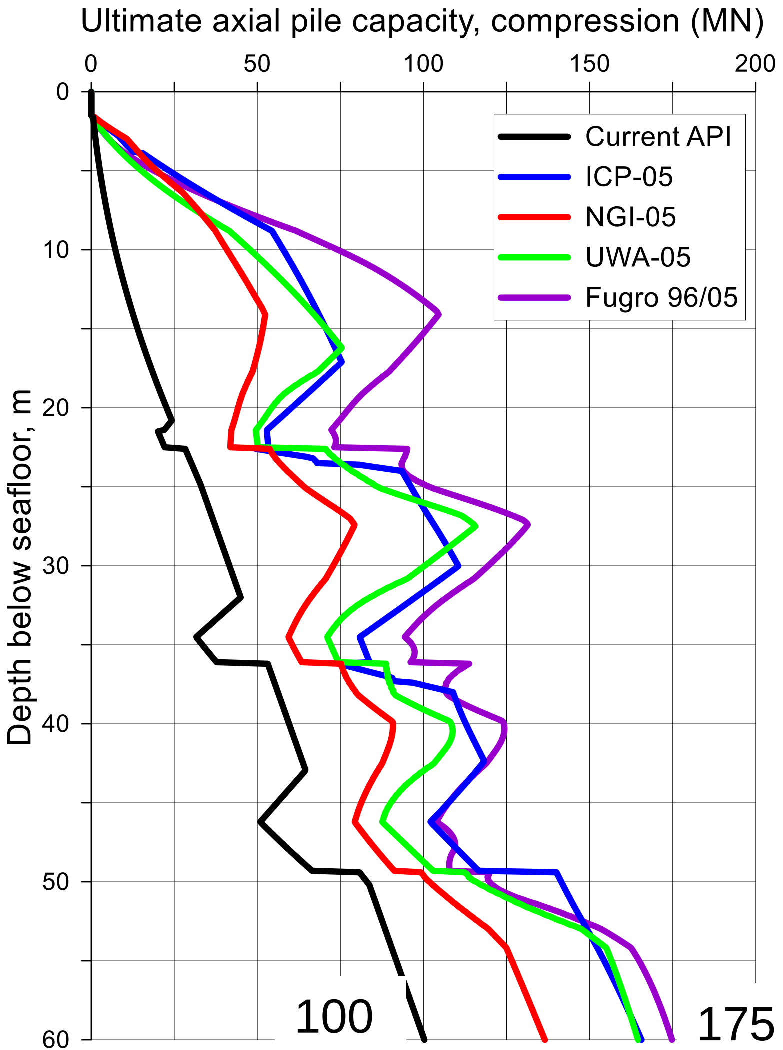


Statistical analysis of cone resistance, Site C

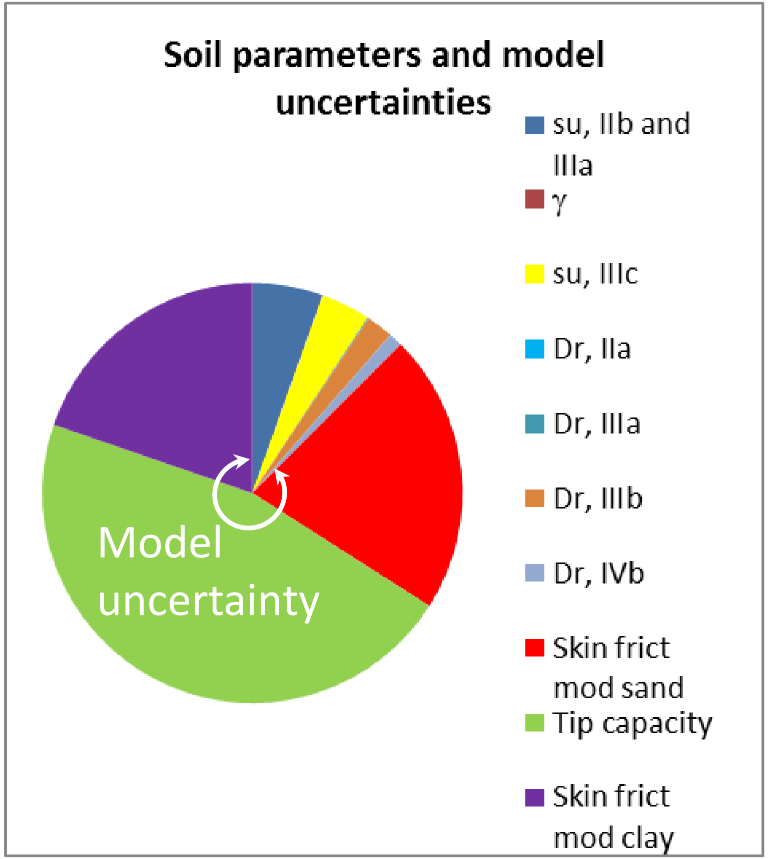




Deterministic Q_{ult} with <u>characteristic</u> shear strength parameters, Site B

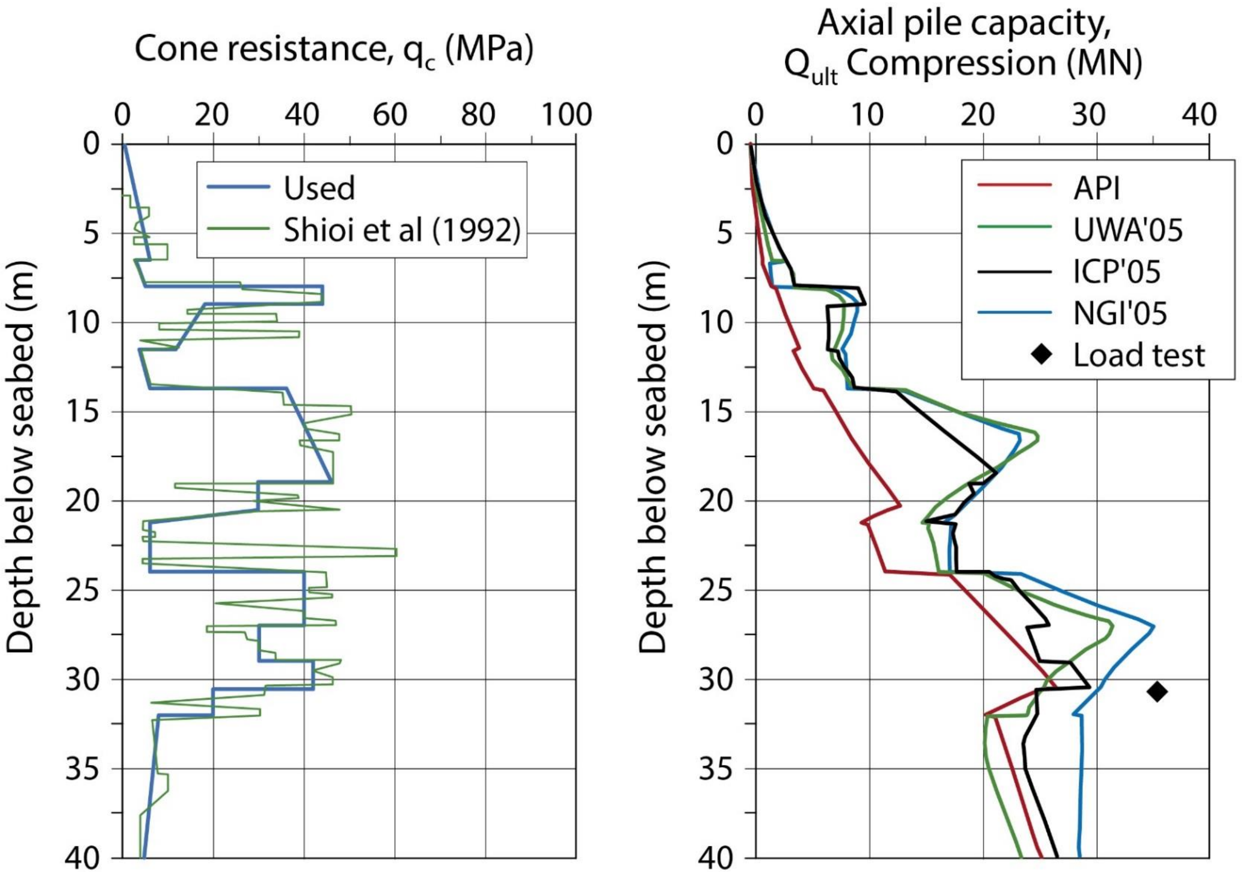


Parameters contributing to uncertainty in Q_u



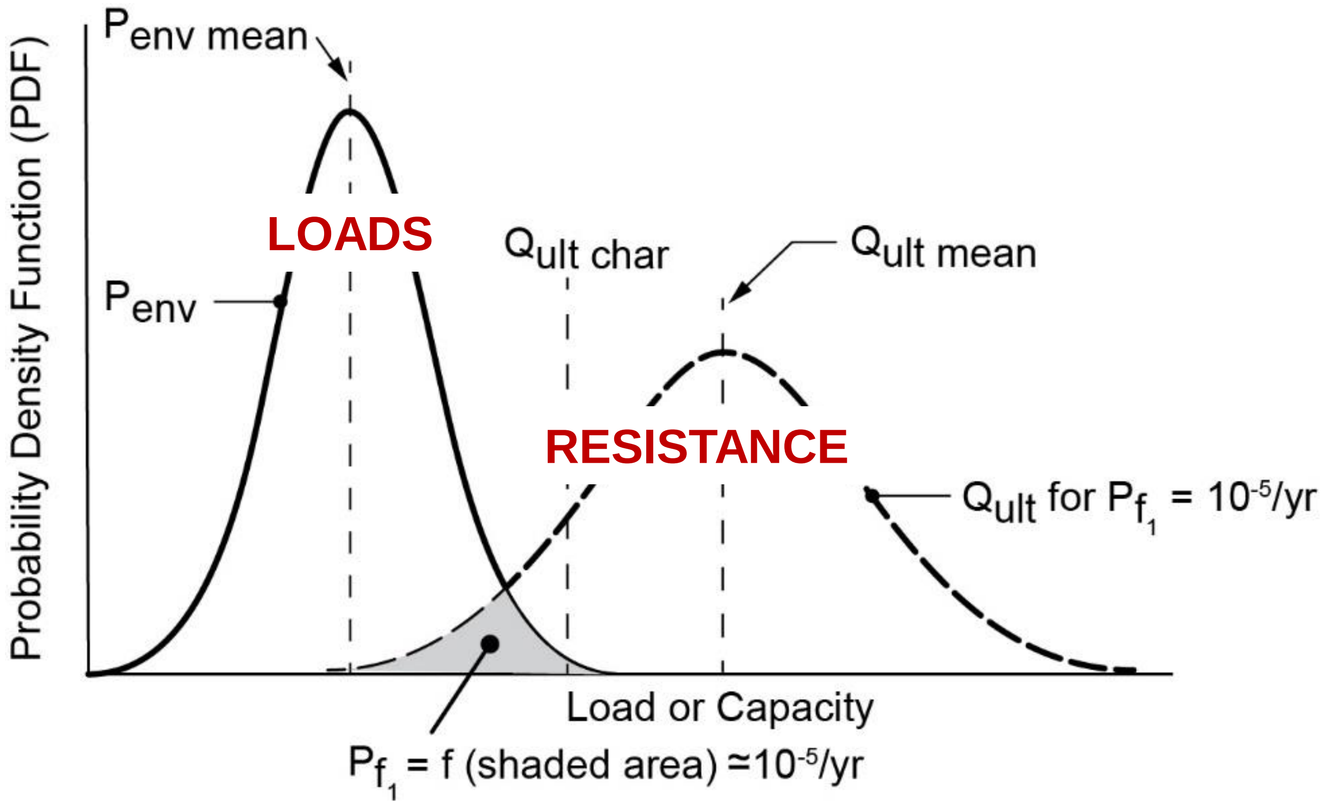
Model uncertainty in skin friction - pile load test

Predicted and measured capacities (dia_{pile}= 2.0 m)



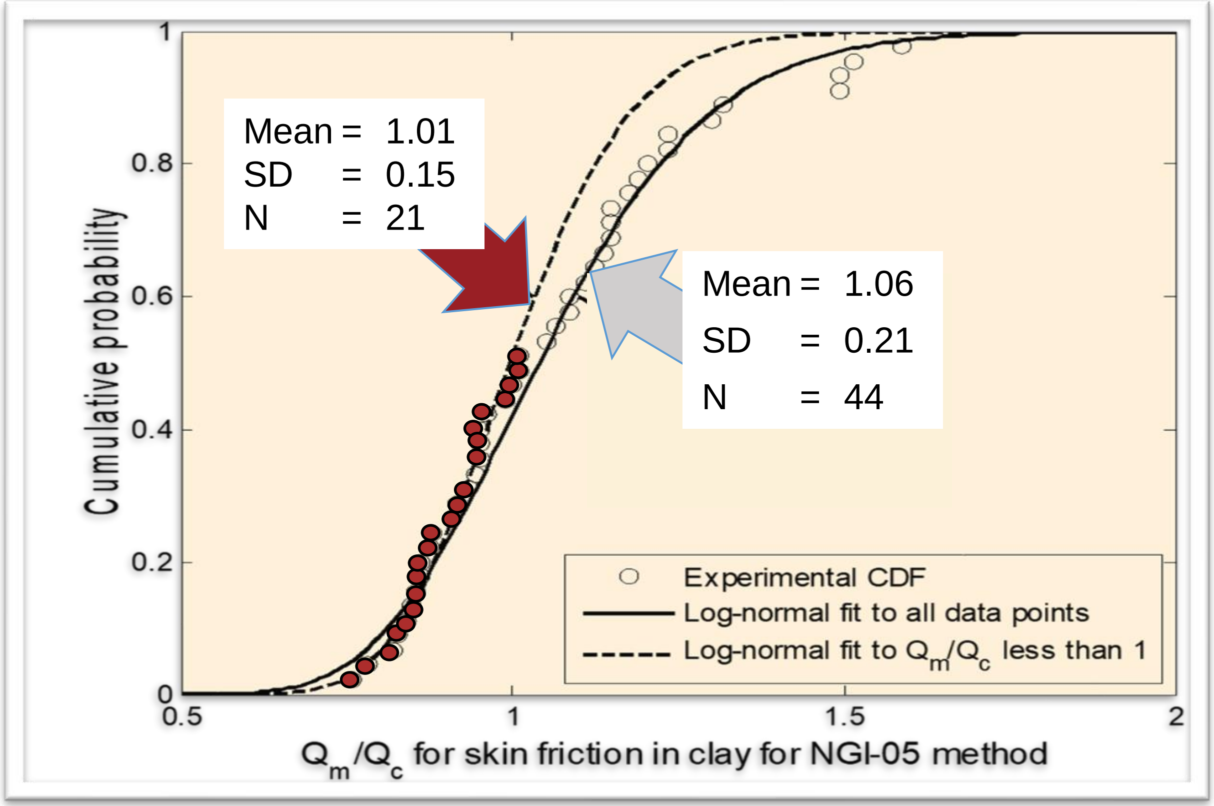
Calibration of partial safety factors

$$[\gamma_{I\,stat} \bullet P_{stat} + \gamma_{I\,env} \bullet P_{env}^{100\text{-}yr}] = Q_{ult}/\gamma_{m}$$



Quantification of model uncertainty

Curve fitting only to Q_m/Q_c < 1 data points



Calibrated resistance factor, γ_m, related to $Q_{ult\ char}$, for target $P_f < 10^{-4}$/year ($\gamma_{l\ env}$=1.3)

Pile design method	Required resistance factor, γ_m		
	Site A (clay)	**Site B** (sand)	**Site C** (clay and sand)
NGI-05	1.23	1.35	1.20
ICP-05	1.52	1.45	1.32
Fugro-05	1.31	1.72	1.55
UWA-05	---	1.55	1.50
Current API	1.35	2.36	1.93

Consequence for required pile penetration depths at 3 sites

Method	Required pile penetration depths		
	Site A (clay)	Site B (sand)	Site C (clay and sand)
NGI-05	90 m to **75** m	51 m to **27** m	45 m to **36** m

Reduction of the deterministic pile penetration depth (NGI-05 method), because it was documented that $P_f < 10^{-4}$/yr.

Added value of reliability analysis?

- The probabilistic design with target annual P_f of 10^{-4} resulted in very significant savings, compared to the deterministic design.
- The reliability approach allows one to design with a uniform margin of safety and to "calibrate" the safety factors prescribed in codes.
- The newer CPT-based design methods are more reliable than the API method.
- The results are most affected by the model uncertainties, especially for piles in sand.

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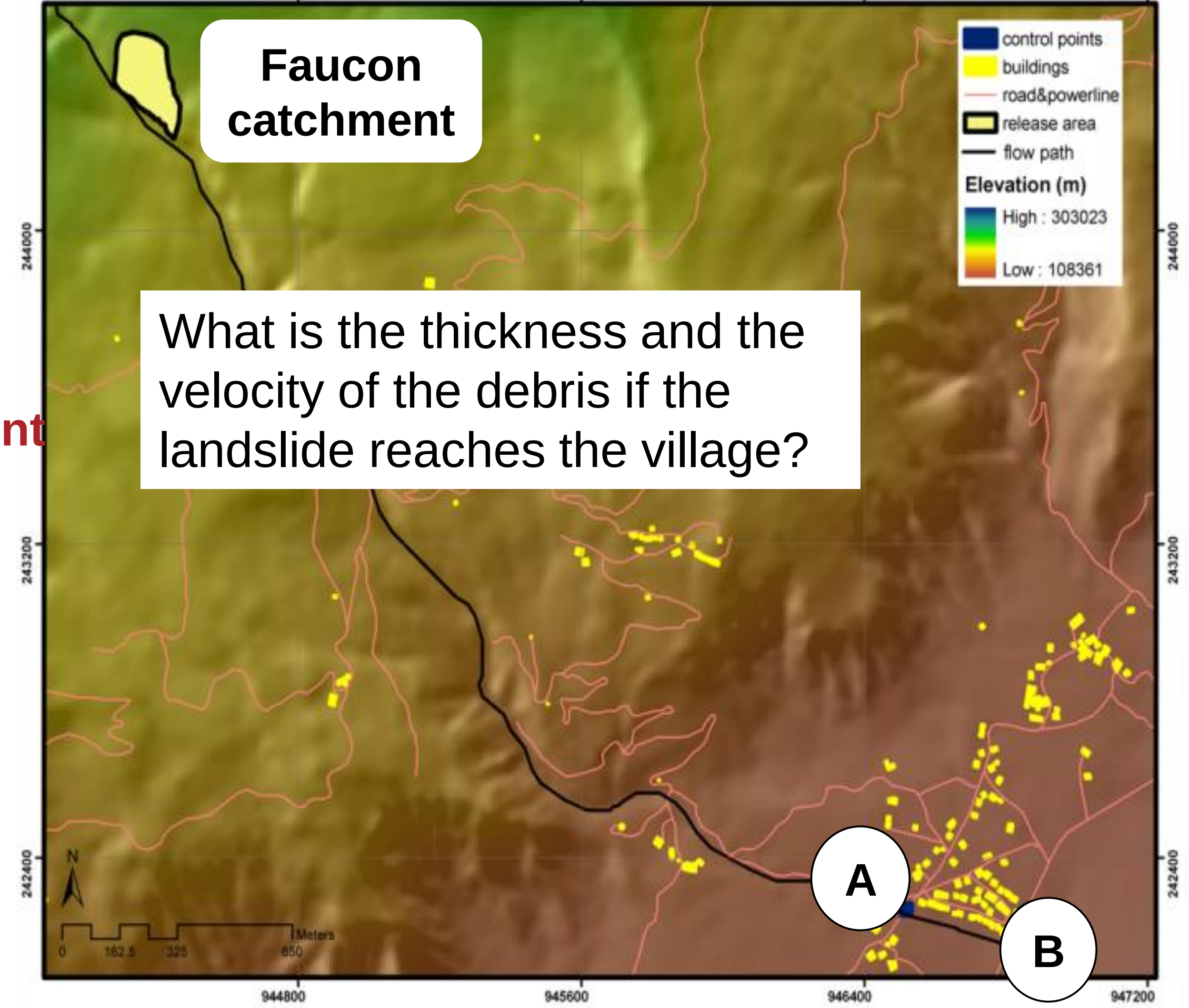
Debris flow

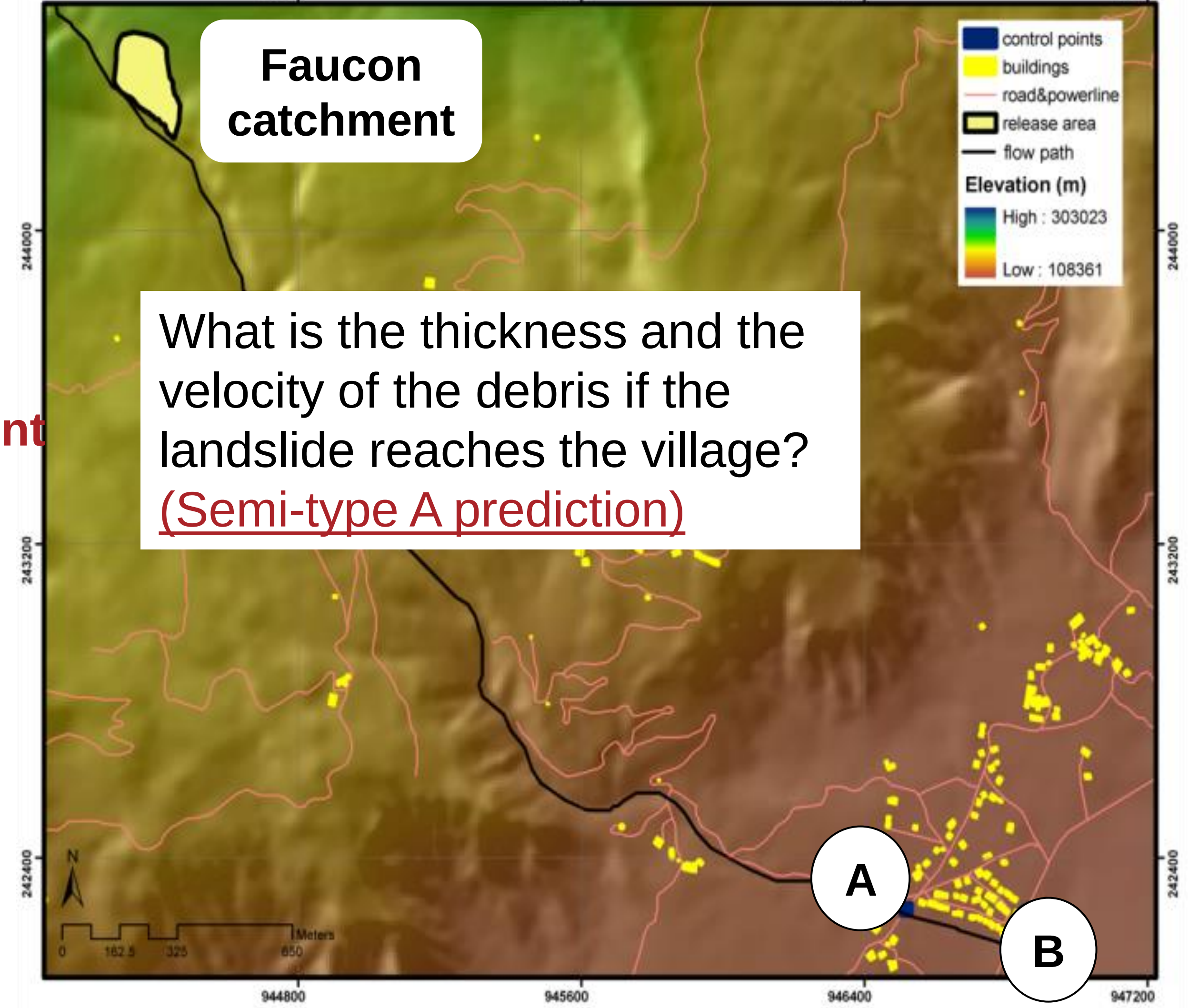
Faucon catchment



What is the thickness and the velocity of the debris if the landslide reaches the village?

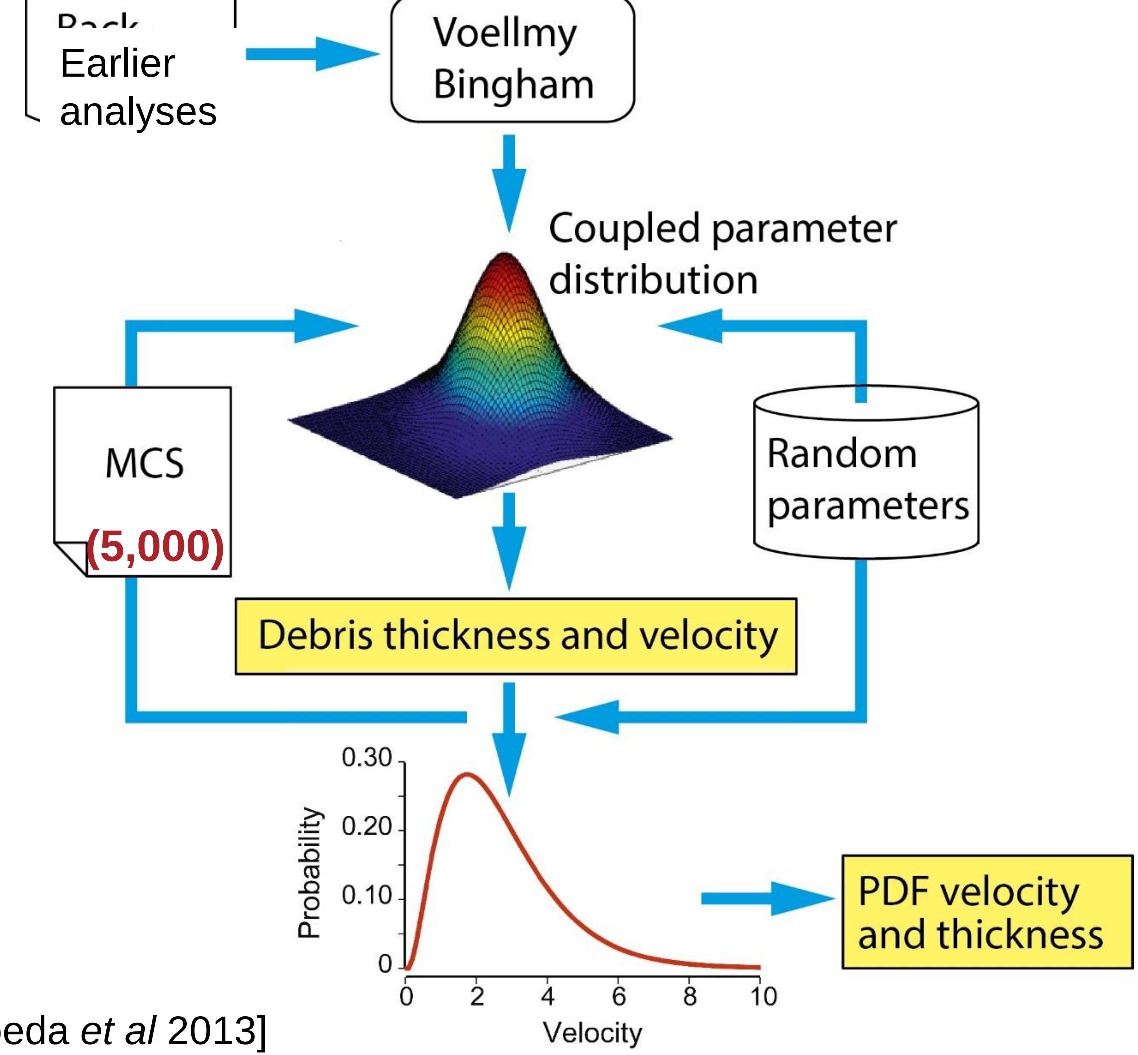
Debris flow

Faucon catchment



What is the thickness and the velocity of the debris if the landslide reaches the village? (Semi-type A prediction)

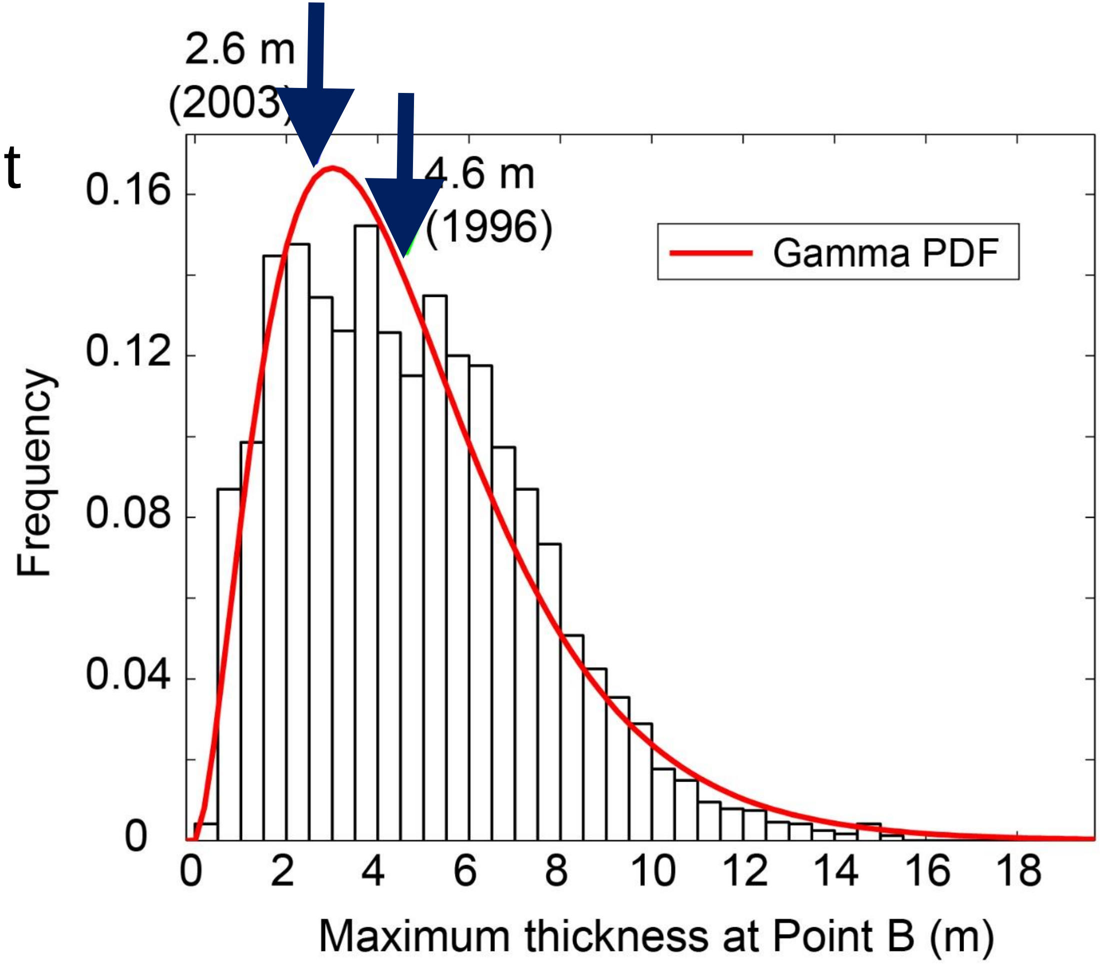
Approach: Monte Carlo simulation



[Cepeda *et al* 2013]

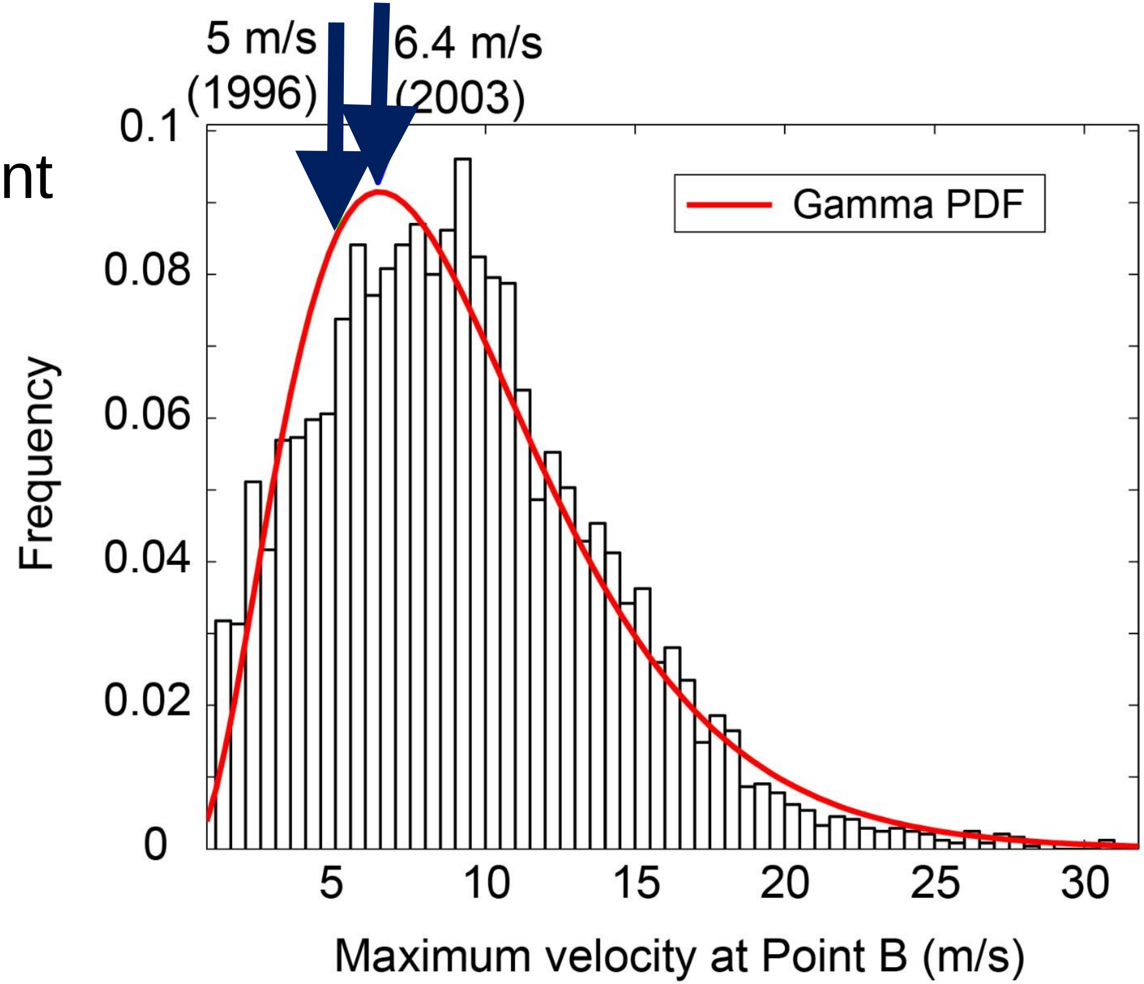
Faucon catchment

Debris thickness Point B



Faucon catchment

Debris velocity Point B



Added value of Monte Carlo analysis?

- Monte-Carlo simulation is an excellent tool if the mean and standard deviation are of main interest. For modelling the "tails" of the PDF (very low P_f), one needs a very large number of simulations.
- MCS can be used to "experiment" and validate calculation procedures
  - Accounting for strain-softening in limit equilibrium analyses.

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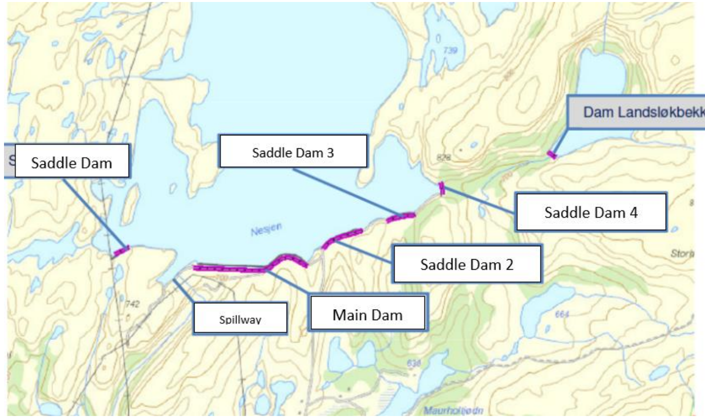
Nesjen dams, Norway



Event tree analysis of dams

6 steps

1 Dam and site inspection to familiarise review team with structure and site conditions

2 Failure mode screening

3 Construction of event tree

4 Probability assessment

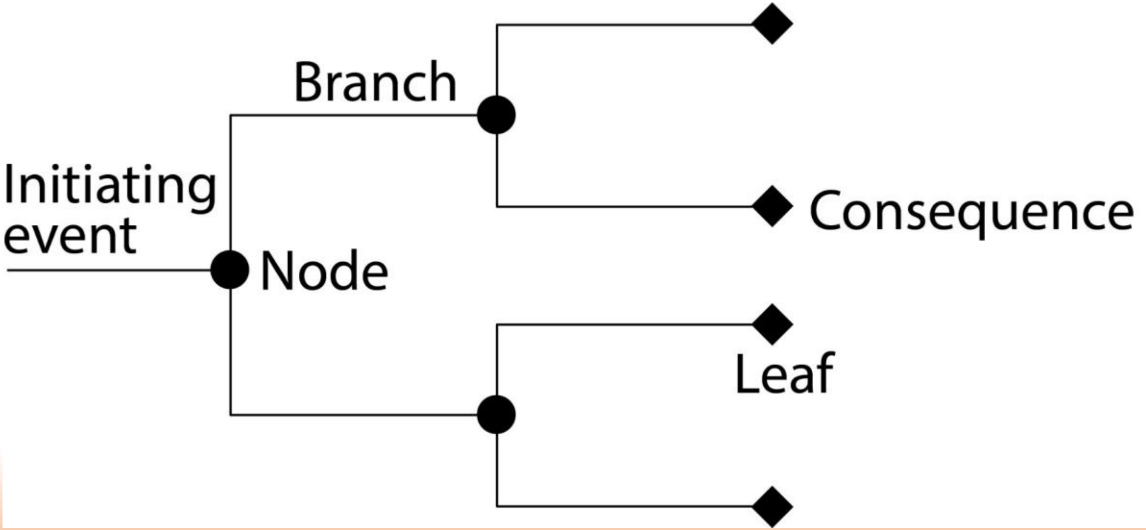
5 Evaluation of results

<u>Usually done with expert teams</u>

The collective judgment of experts, structured within a process of debate, can yield as good an assessment of probabilities as mathematical analyses [Vick 2002].

Event tree analysis (ETA)

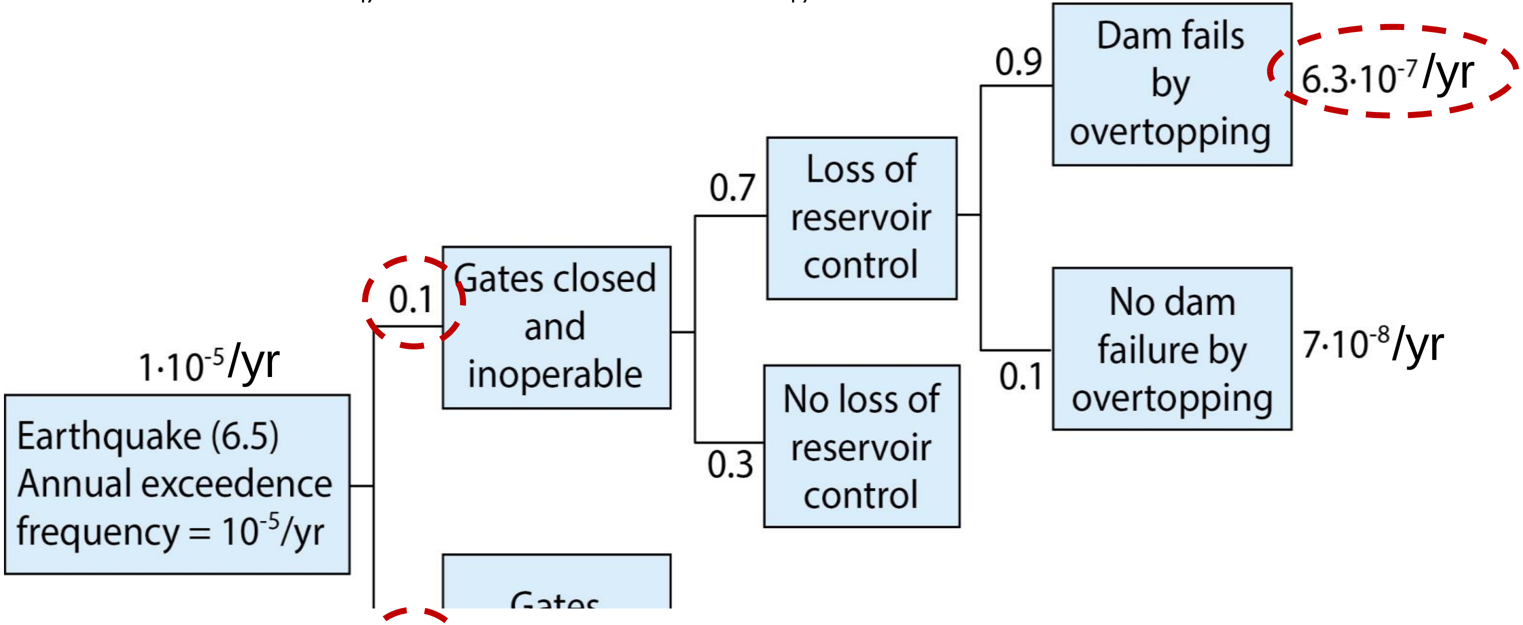
An event tree is a graphical representation of chains of events that might result from an initiating event, a few of which could lead to system failure. As the number of events increase, the diagram fans out like the branches of a tree.



Event tree analysis (ETA)

A "What happens if " type of analysis

Initiation ⇨ continuation ⇨ progression to failure



In an event tree, the events at a node should be defined such that they are mutually exclusive (cannot occur simultaneously).

Event tree analysis (ETA)

Probabilities at a node of the event tree

- Statistical estimates based on observations, test results etc.
- Engineering calculations with models based on physical processes.
- Expert judgment developed through evaluated experience.

The probability estimates should be based on a demonstrable chain of reasoning and not on speculation. Consensus is achieved through discussion, using standard descriptors of uncertainty.

Nesjen dams – Failure mode screening

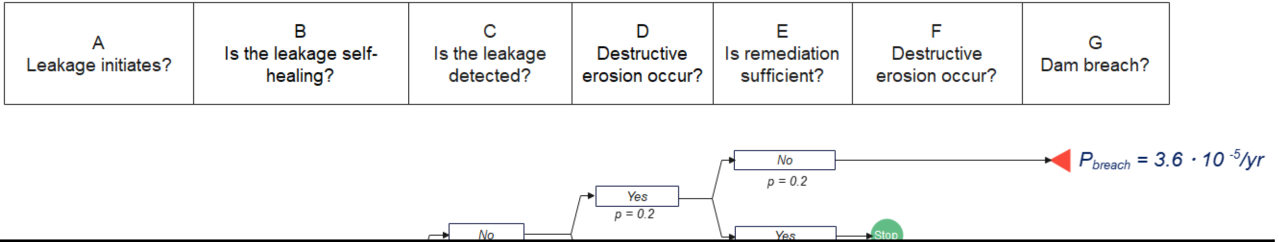
Potential weaknesses

- Internal erosion
- Stability of upst/dwnstr embankments
- Landslides in reservoir, overtopping
- Weakness/erosion in rock foundation
- Blocking of spillway
- Operative measures leading to failure
- Ageing of concrete for the concrete dam

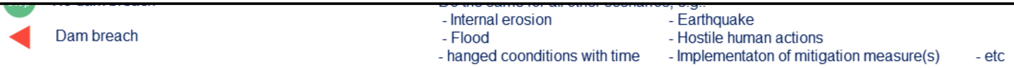
Potential external triggers

- Extreme precipitation, snow
- Glacier melting
- Ice/hard-packed snow blocking spillway
- Climate change impacting the dam
- Wave/ice loading, instability upstream
- Earthquake loading
- Meteorites, airplane crashes

Nesjen dams, Norway

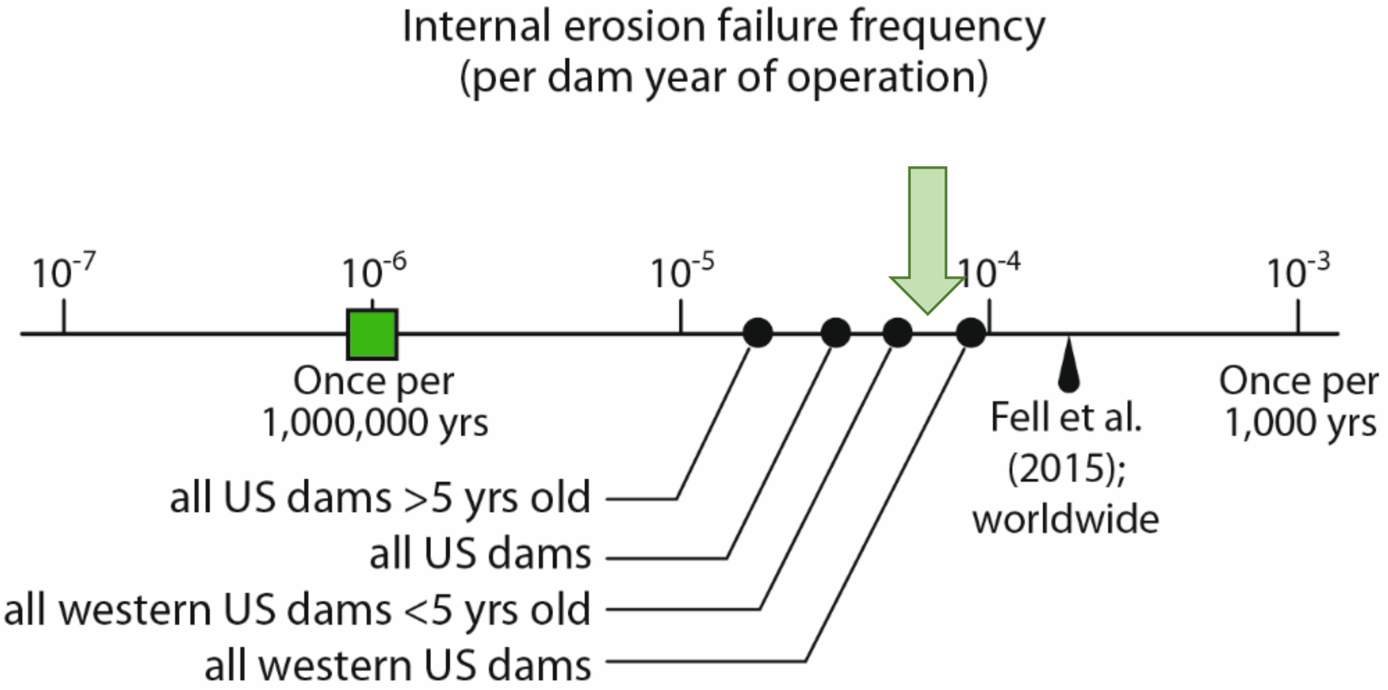


Failure scenarios	Annual failure probability P_f Before rehabilitation	Annual failure probability P_f After rehabilitation
Internal erosion	$7.6 \cdot 10^{-5}$	$8.4 \cdot 10^{-6}$
Flood	$2.9 \cdot 10^{-7}$	$2.0 \cdot 10^{-8}$
Earthquake	$1.0 \cdot 10^{-8}$	$1.0 \cdot 10^{-8}$
Erosion in rock foundation leading to erosion of core	$5.0 \cdot 10^{-6}$	$5.0 \cdot 10^{-6}$
Total failure probability	$8.1 \cdot 10^{-5}$	$8.9 \cdot 10^{-6}$



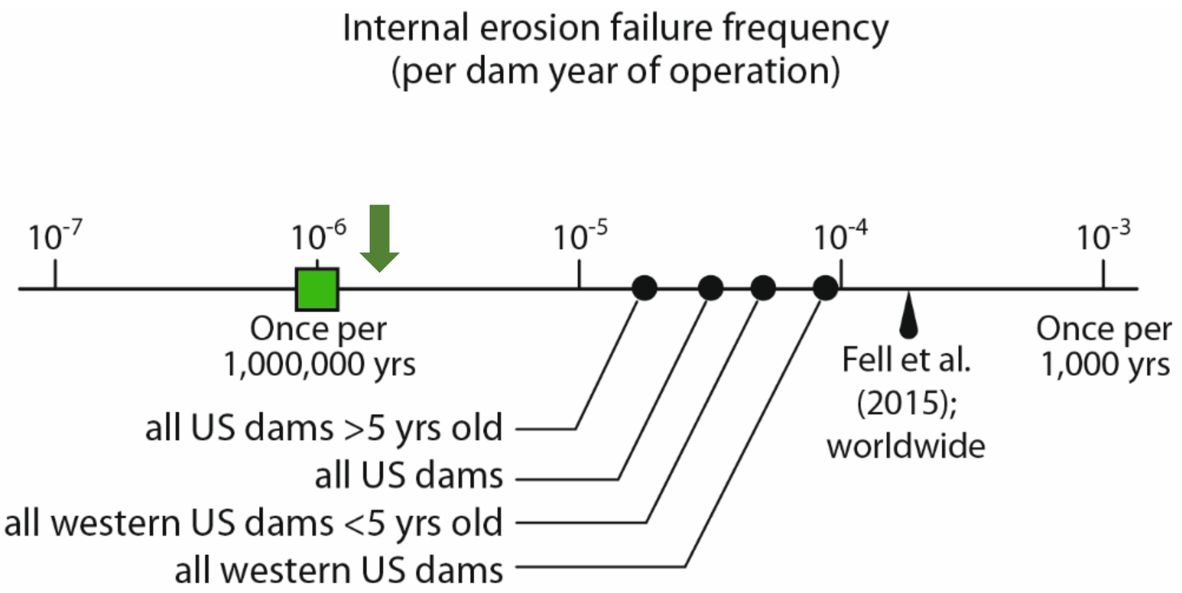
Nesjen dams, Norway

Internal erosion compared to ICOLD database and Fell's statistics, <u>before rehabilitation</u>

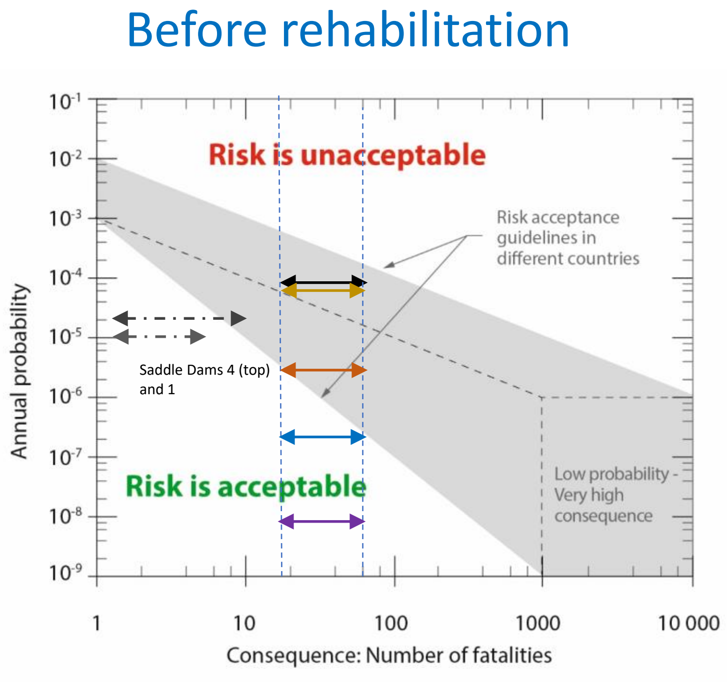


Nesjen dams, Norway

Internal erosion compared to ICOLD database and Fell's statistics, after rehabilitation



Nesjen dams, Norway



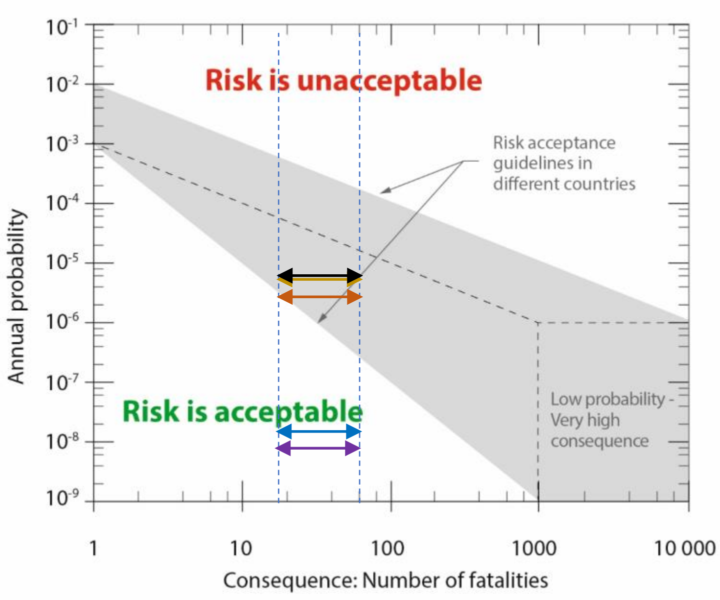
Failure modes Main Dam

- Flood
- Internal Erosion
- Earthquake
- Erosion of rock foundation

Total annual P_f in black

Nesjen dams, Norway

After rehabilitation



Failure modes Main Dam

- Flood
- Internal Erosion
- Earthquake
- Erosion of rock foundation

Total annual P_f in black

Examples of added insight from reliability analyses (1/2)

- The Nesjen Dam system (Main Dam and 5 Saddle Dams): The analyses showed that the optimal solution was a controlled overtopping of Saddle Dam 4 (fused plug) during an extreme flood. Overtopping of Saddle Dam 4 (with no fatalities and few other consequences) reduced considerably the risk of a breach of the Main Dam.
- For Viddalsvatn Dam having evidenced internal erosion during the first 20 of its 50 years, the analyses quantified the risk reduction of several rehabilitation measures and showed that the most extensive and expensive measure was not the most risk-reducing measure.

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Examples of added insight from reliability analyses (2/2)

- For Nyhellervatn Dam, the reliability index (failure probability) of the downstream slope suggested no need for rehabilitation, even if the traditional safety factor suggested the need for strengthening.
- For Dravladalen Dam, the failure mode analysis led to the identification of a so far unidentified high risk associated with the threat of ice/hard snow. The analyses also documented the risk reduction with the rehabilitation.
- For Dam Kalhovd, the planned rehabilitation measures do not reduce the risk. It was recommended to continue surveillance, because of the uncertainties in ice loads.

Added value of ETA analyses?

- ETA looks at all potential failure modes in a systematic manner.
- ETA can be used as a diagnostic and comparison tool (before/after rehabilitation, among dams in a portfolio)
- Probabilistic risk analysis in dam engineering has been coined as a «systematic application of engineering judgment» [Vick 2002; Høeg 1996].
- Today: Risk-Informed Decision-Making recognises the use of engineering judgment and that decision cannot be made on the basis of technical data alone.

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   - Debris flow in Barcelonnette Basin, France
   - Roşia Montaňa tailings management facility
   - New Orleans levees
   - A useful example of Bayesian updating
3. Challenges and emerging topics
4. Summary and conclusions

New Orleans Levees and Hurricane Katrina

<u>Flood control Act of 1965</u>

Flood protection system started in 1965 after Hurricane Betsy

[US Army Corps of Engineers 2005]

Could the failure have been expected and better managed with the help of probabilistic analyses?

New Orleans Levees and Hurricane Katrina

Levees designed for $T_{return} \approx 100$ yrs

$P_f = 1/ T_{return} = 0.01$

What is the probability of a 100-yr hurricane and overtopping for a person living behind the levees for 50 years?

$P(x>0) = 1 - e^{-\lambda t}$ (Poisson distribution)

- x = number of events
- t = time interval
- λ = expected number of events/unit time
- λ = 0.01 for $P_f = 1 / 100$ years

New Orleans Levees and Hurricane Katrina

$P(x>0) = 1 - e^{(-0.01)(50)}$

$P(x>0) = 0.40\ (40\%)$ *[if T_{return} = 200-yr, P = 22%]*

There is therefore a significant probability of levee overtopping in any 50-yr period.

The 3-4 failures that occurred in New Orleans, even without overtopping indicate that the factor of safety, FS, is less than 1, in some locations.

New Orleans Levees and Hurricane Katrina

In comparison:

The primary dikes protecting the Netherlands are set to heights corresponding to between 2,000 and 10,000-year return periods [Voortman 2003; van Stokkom & Smits 2002]

The interior levees protecting the Rhine are set to a return period of 1,250 years [Vrouwenvelder 1987].

New Orleans Levees and Hurricane Katrina

There are 350 miles (560 km) of levees in New Orleans.
Assume that there are 560 reaches (each 1 km long).

What is the annual P_f of each reach?

What is the P_f of the entire levee system?

[US Army Corps of Engineers 2005]

New Orleans Levees and Hurricane Katrina

Assuming that each reach is statistically independent, and if the levee is a series system of *n* reaches (such as links in a chain), the system reliability is the product of the reliability, R, for each link (like combining modes of failure):

$$R = R_1 R_2 R_3 \ldots R_n$$

The probability of failure, P_f, of the system is

$$P_f = 1 - R$$

$$P_f = 1 - (1-P_1)(1-P_2)(1-P_3)\ldots(1-P_n)$$

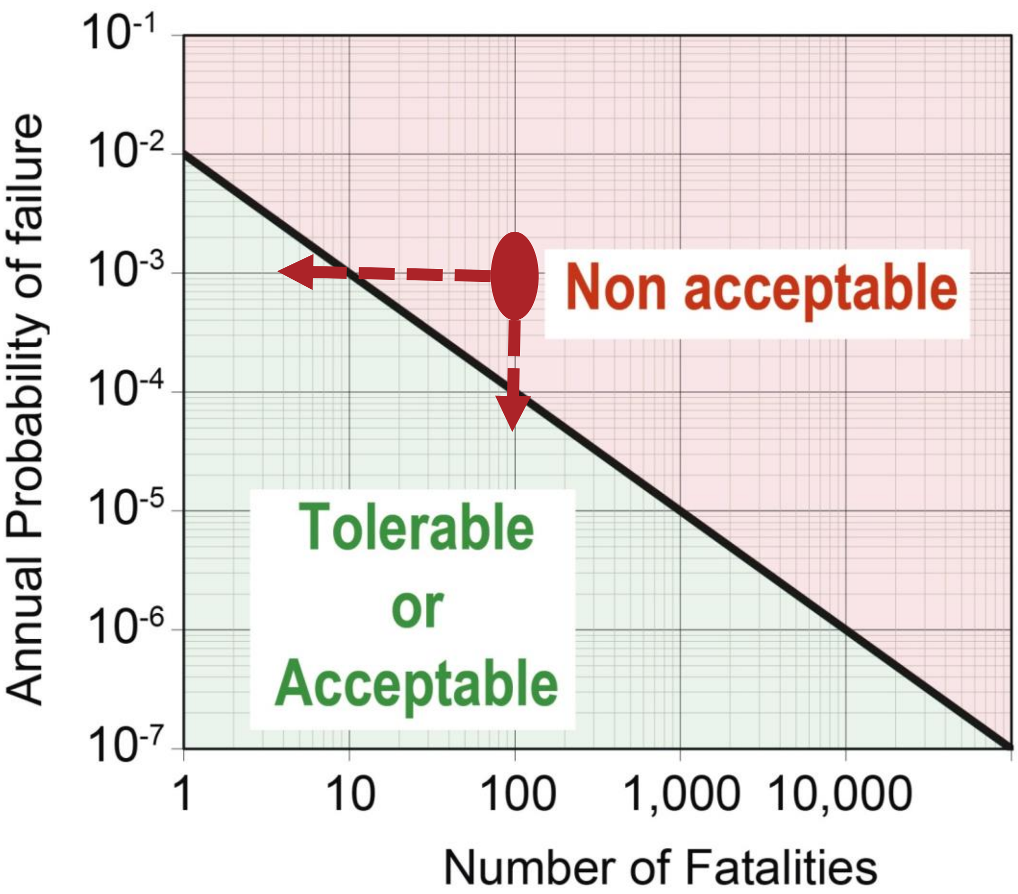
New Orleans Levees and Hurricane Katrina

The probability of at least one failure in the levee system is:

No. of reaches	Reach length (km)	$P_{overtopping}$ (each reach)	P_f (system)
560	1000 m	0.01	**0.99**
280	2000 m	0.01	**0.94**
1020	500 m	0.01	**≈1.00**
560	1000 m	0.001	**0.43**

Emerging issues: Acceptable risk

The F-N plot is one vehicle for comparing calculated probabilities with, e.g., observed frequencies of failure of comparable facilities.



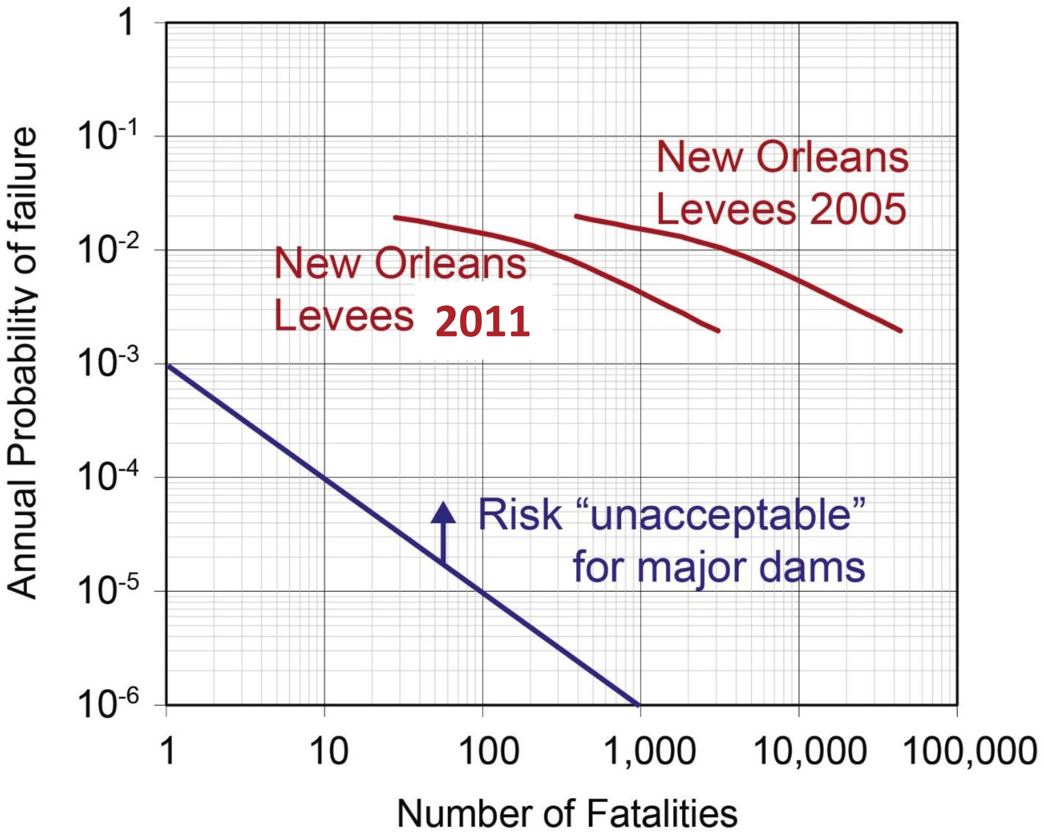
New Orleans Levees and Hurricane Katrina

Risk diagrams (F-N curves)

[Gilbert 2014]

<u>2005</u>
"Hurricane Protection System"

<u>2011</u>
"Hurricane Storm Damage Risk Reduction System"



New Orleans Levees and Hurricane Katrina

The risk, even after the 2011 upgrading is much higher than that considered tolerable for major dams in the world.

Why is the risk so much higher for the levee system?

What is considered as “tolerable risk” is not an absolute, but is relative to the context of the costs and the feasibility of reducing the risk. It was not feasible to achieve that low a risk for a long levee system in an urban area [after Gilbert 2015].

Quantitative risk assess-ment for selection of most appro-priate risk mitigation strategy

[US Army Corps of Engineers 2005]

<u>Emerging question:</u>

Should one have used part of the $18 billion USD on measures to evacuate people in advance of a storm, to avoid fatalities, even with overtopping ?

[after Gilbert et al., 2008]

Added value of reliability analysis?

- Simple reliability-based analyses predict that the New Orleans levees would most probably fail under a strong hurricane.
- Long levees should be designed for very long return periods.
- Reliability analyses should be used to make decisions on the optimum mitigation measures.

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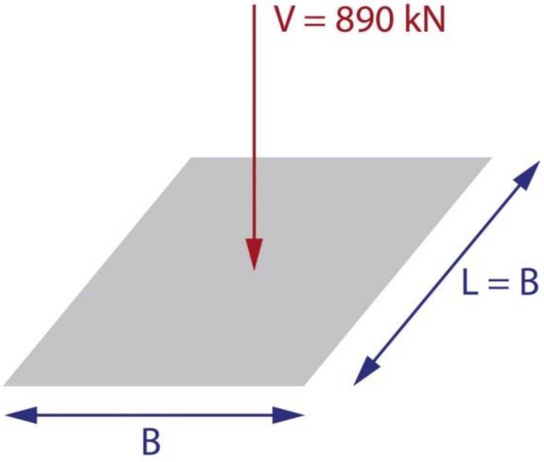
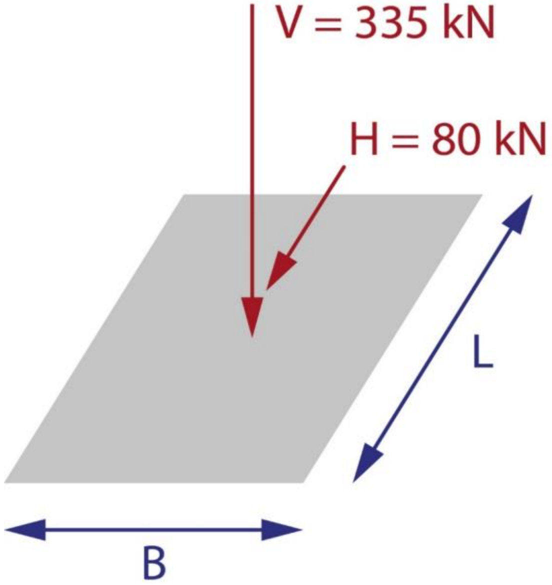
Personal career insights

Comparison of 3 offshore codes of practice



NC clay,
s_u increasing
linearly with depth



Medium dense sand, $\phi' = 30°$

Comparison of 3 offshore codes of practice

Code	Safety parameter	Value
API RP2GEO	Global FS	1.5 (sliding 2.0 (bearing)
API RP 2GEO- LRFD	ϕ (on capacity)	0.8 (sliding) 0.67 (bearing)
ISO 19901-4	γ_m (on soil property)	1.5 (bearing, undr.) 1.25 (bearing, dr.) 1.25 (sliding)

First-Order Second-Moment method (FOSM)

Method to determine the mean and standard deviation of a function with random input variables. It uses the first terms of a Taylor series expansion. One needs to assume the distribution of the limit state analysed (e.g. the FS).

FOSM, FORM and Monte-Carlo simulation

All 3 methods propagate the uncertainties through analytical models to obtain probabilistic descriptions of the behaviour of a structure or a system.

FORM is an improvement of the FOSM, based on the geometric interpretation of the reliability index in a dimensionless space. It requires iterations and gives the relative contribution of the uncertain parameters.

Monte-Carlo simulations compute a function for large numbers of sets of data (need a large number of iterations to define the "tails" of the PDF).

When first developed to improve on the FOSM method, FORM was checked with millions of MCS.

Comparison of 3 offshore codes of practice

Shallow foundation, clay - Undrained bearing capacity

Method	P_f, at required safety parameter		
	API RP2GEO FS = 2.0	API RP2GEO LRFD $\phi = 0.67$	ISO 19901-4 $\gamma_m = 1.5$
FOSM	$\mathbf{3 \cdot 10^{-5}}$	$\mathbf{4.5 \cdot 10^{-5}}$	$\mathbf{3.8 \cdot 10^{-5}}$
FORM	$\mathbf{2.5 \cdot 10^{-5}}$	$\mathbf{4.5 \cdot 10^{-5}}$	$\mathbf{3.8 \cdot 10^{-5}}$
Monte Carlo	$\mathbf{2.5 \cdot 10^{-5}}$	$\mathbf{4.5 \cdot 10^{-5}}$	$\mathbf{3.8 \cdot 10^{-5}}$

I V = 890 kN

- The three codes give approximately same P_f
- FOSM, FORM & MCS give approximately same P_f

Comparison of 3 offshore codes of practice

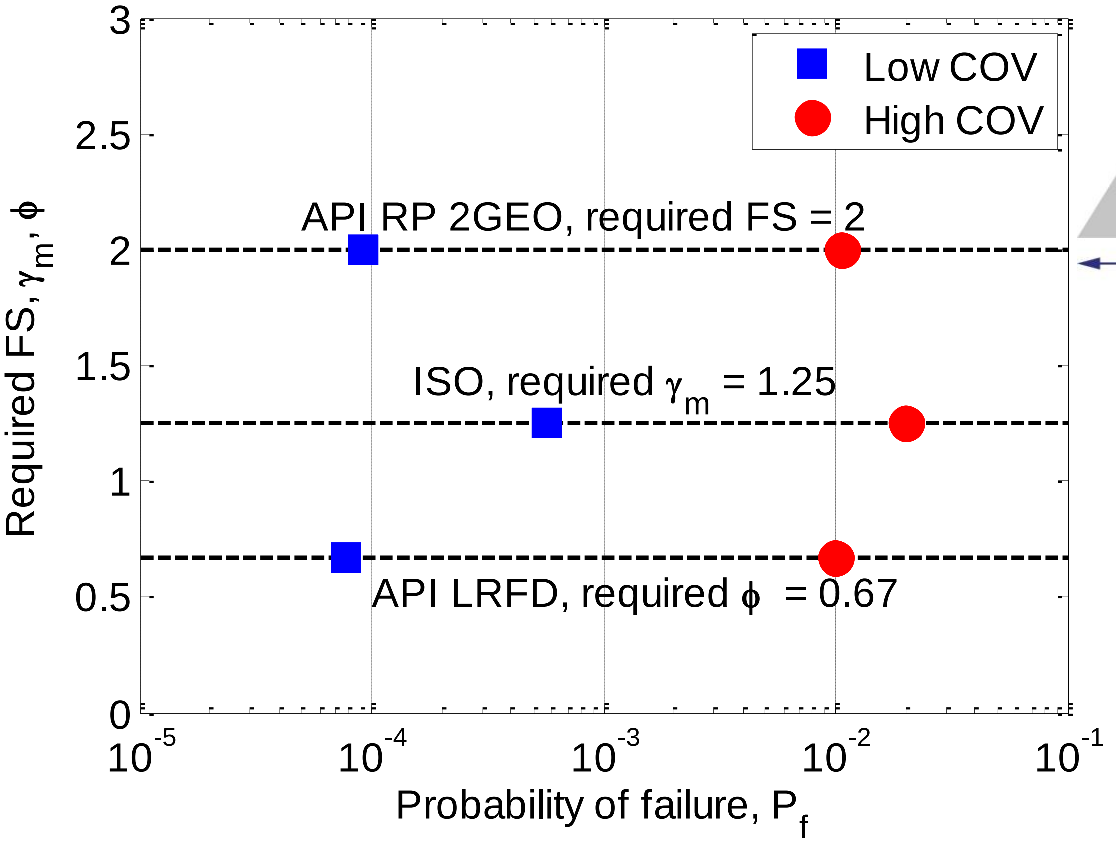
Shallow foundation, sand - Drained bearing capacity

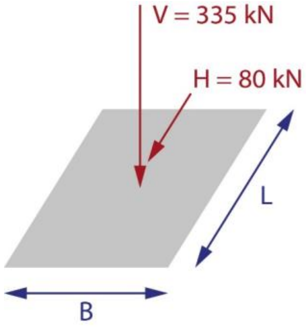
Method	P_f, at required safety parameter		
	API RP2GEO FS = 2.0	API RP2GEO LRFD $\phi = 0.67$	ISO 19901-4 $\gamma_m = 1.25$
FOSM	$4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$2 \cdot 10^{-3}$
FORM	**$9 \cdot 10^{-5}$**	**$7.5 \cdot 10^{-5}$**	**$6 \cdot 10^{-4}$**
Monte Carlo	**$1 \cdot 10^{-4}$**	**$1 \cdot 10^{-4}$**	**$7 \cdot 10^{-4}$**

- The three codes do not give same P_f
- FORM and MCS give the same result
- Be careful with FOSM, solution is not unique
- FOSM not reliable with nonlinear functions

Comparison of 3 offshore codes of practice

Drained bearing capacity, shallow foundation, sand

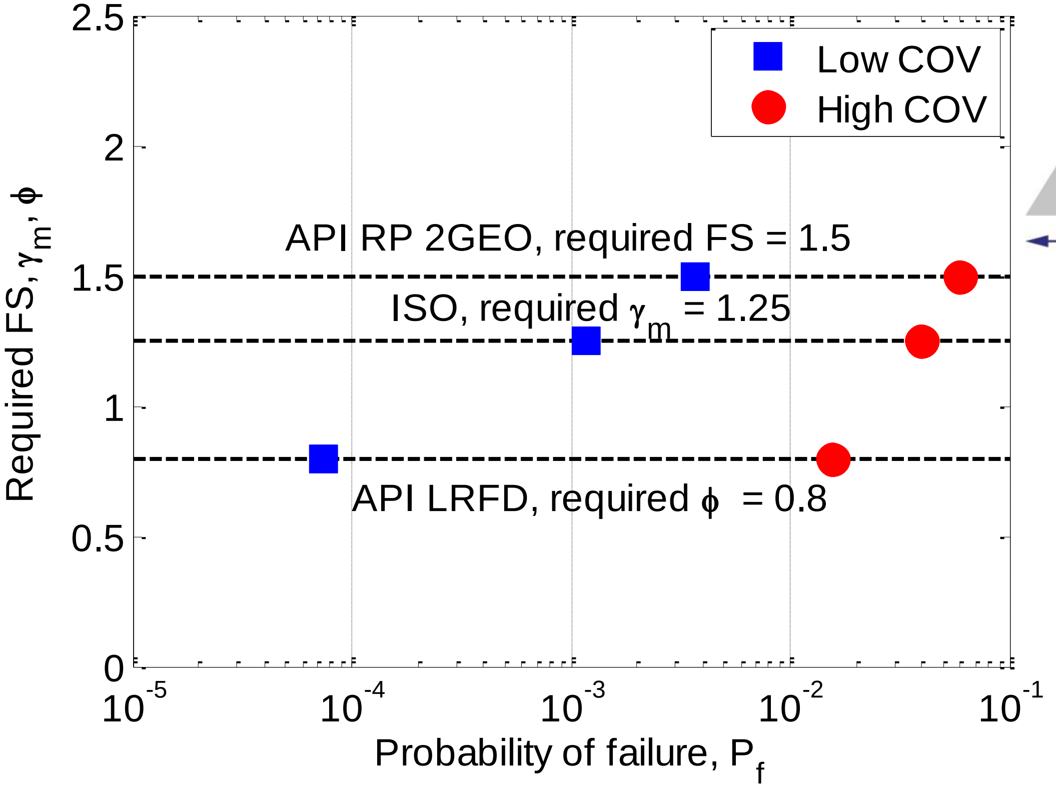


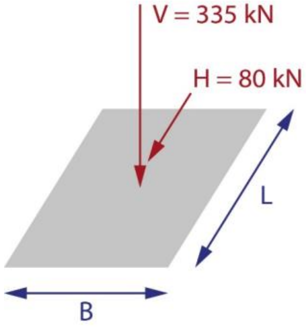


[Liu 2015]

Comparison of 3 offshore codes of practice

Sliding, shallow foundation on sand (FORM)





[Liu 2015]

Comparison of 3 offshore codes of practice

- Reliability studies should be done to compare the actual reliability implied by the total and partial safety factors in codes.
- The use of resistance factor (on the total resistance) in some codes and material coefficient (on the soil parameter) in other codes should be unified.
- FORM and MCS should be used instead of FOSM.
  - FOSM will give a correct solution only for simple linear cases.
  - Only FORM and SORM provide an evaluation accounting for all uncertainties, including the probability distribution function of the parameters.

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Challenges

Communication

Being a good communicator is today one of the most empowering skills that we as engineers can acquire.

Quantitative assessment of hazard and consequences reveals the risk-creating factors and the need for remedial changes. It encourages foresight rather than hindsight.

Vulnerability of the geo-professional

From the standpoint of accountability, the geotechnical engineer finds himself in a particularly vulnerable spot.

He/she works at the interface of natural conditions and man-made structures. Often he/she has little hard information and his/her judgment is continuously taxed.

He/she is called upon to identify and define situations that are potentially hazardous and to, at least, initiate a decision process as to whether the hazards are acceptable or not.

Conclusion on reliability analyses

Reliability approaches do not remove uncertainty nor do they alleviate the need for judgment. They provide a way to quantify the uncertainties and to handle them consistently.

Reliability approaches also provide the basis for comparing alternatives.

Site investigations, laboratory test programmes, limit equilibrium and deformation analyses, instrumentation and monitoring and engineering judgment are necessary parts of the reliability approach.

Deterministic and probabilistic analyses

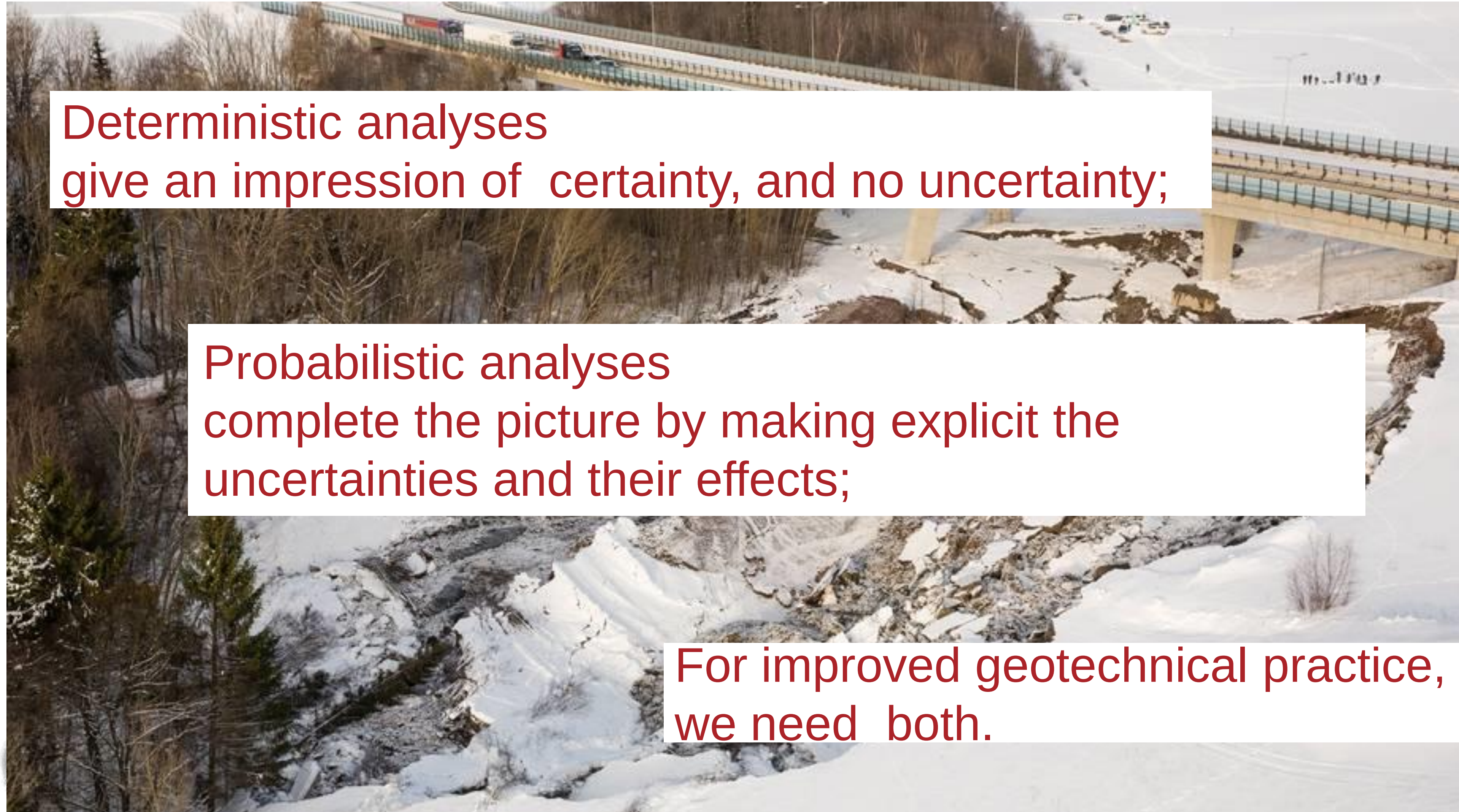
Risk and probability tools have reached a degree of maturity and breadth that make them effective to use in practice. They provide more insight than deterministic analyses alone. They help reduce uncertainty and focus on safety and cost-effectiveness.

Uncertainties

In all geotechnical assessments, one needs to deal with uncertainties, either implicitly or explicitly.

[Photo: SVV 2015]

E18 expressway in Norway, February 2015
Slide in quick clay causing bridge collapse



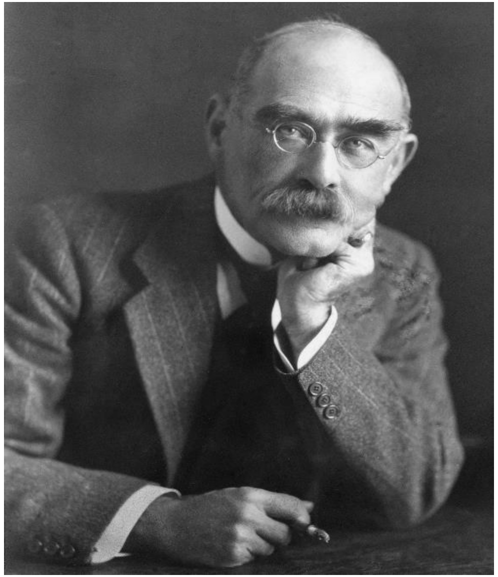
Deterministic analyses
give an impression of certainty, and no uncertainty;

Probabilistic analyses
complete the picture by making explicit the uncertainties and their effects;

For improved geotechnical practice,
we need both.

“Doubt is an uncomfortable condition, but certainty is a ridiculous one.”

Voltaire
(1694-1778)



“A woman's guess is much more accurate than a man's certainty”.

Rudyard Kipling
(1865-1936)

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Personal career insights

A female engineer's career

Contents

- My story as a woman civil engineer
- What is a good career?
- Trends for today's young geo-professionals
- Tips for your own story
- Concluding thoughts

Credentials to give this talk

- Female civil engineer
- Francophone, half-Irish, big family, lots of brothers!
- From a small mining town (Abitibi-Témiscamingue)
- Mining and Building & Construction were the mainstays of the area
- Normal childhood
- Education was very important for my parents – a priority for each chld

Single characteristic, most important (perhaps)

Suzanne Lacasse is a female civil engineer who loves her work. ….

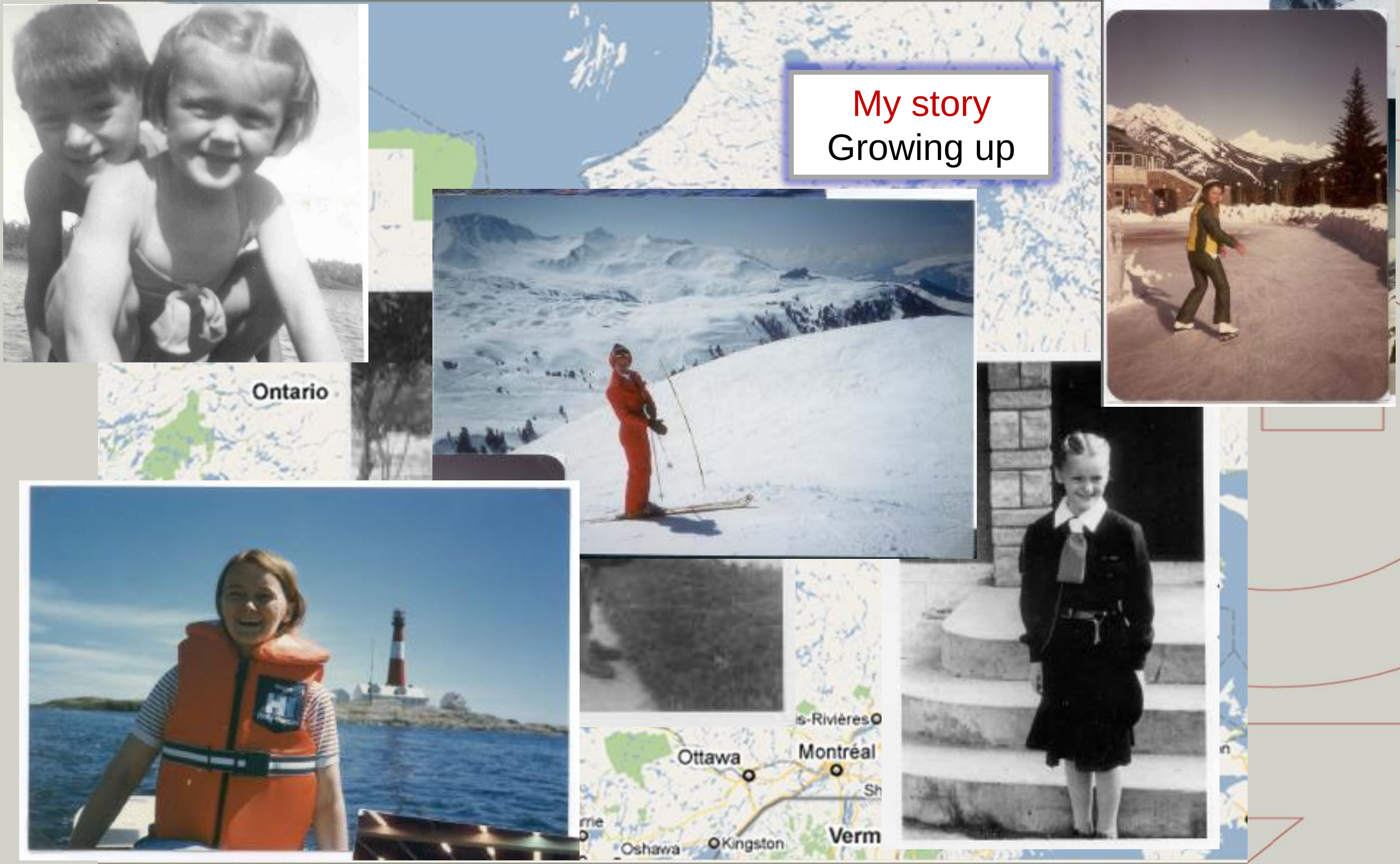
NGI

Reflection

- I have never liked to talk about myself. I like talking about Canada, Québec, Norway, grammar, NGI, art, autochtones, clothes, books, films, knitting, embroidery, picking berries, cats, bears, wolves, skiing, soccer, rugby etc ….
- I never thought about my career path! I did not really plan it.
  - I did not plan to continue with graduate work after my BSc (late 60s)
  - I did not plan to become a faculty member at MIT
  - I never planned staying at NGI for so long….
  - And I certainly did not plan becoming director of NGI, and certainly not staying on for over 20 years
  - And I did not plan on getting married for the first time at age 63!
- Lesson learned: do not overplan (?). Opportunities will pop up in one's career


Barrie

My story
Growing up



My career path

- Family environment had a strong influence.
- Studies at good schools (Polytechnique and MIT)
  - Exposure to different environments help a lot. Started to attend conferences as a student. Being a woman helped.
- Academia and consulting for 12 years while on MIT faculty (seconded to Ardaman & Assoc. in Florida USA and GeoDelft in Holland).
- Early on, active in learned societies (EIC, CGS, ASCE and ISSMGE)
- Post-doc at NG for one year (that was the plan).
- Started at NGI in 1982 (seconded to Exxon in Houston (1½ yr) and Elf/Total (5 yr) in France) – consulting work and research, much networking.
- Managing Director NGI 1991-2012.
- Solely technical work since,

What did I work on

What I THOUGHT?

I would continue as
an academic, as a … h
and in situ test…
specialist, be… s
more lear… his
field, wi… sional
cons… or
fou… ns on soft
c…

I w… uld move back to
a university in Canada

That lasted until i left MIT

What HAPPENED (technically)?

NGI: On a dam as controller, tests of core, rockfiill and compaction
Cyclic behaviour of sand
Design of offshore installations
Offshore site investigations

3D FEM, Offshore installations and dams
Slope stability
Risk and reliability
Automatisation in lab

Today Risk assessment and management, all geo-aspects
Expert committees: Slopes, Dams, TSFs

My story – being a woman early on

I never thought that being a woman made a difference! (too many brothers, I guess).

Since starting at Ecole Polytechnique, I have never felt discriminated against:

- Teased, challenged to be one of the gang, flirted with, yes, but not put down.
- I liked the presence of men and I liked (when young) being flirted with!
- I was fortunate enough to work with people who did not think that being a woman made a difference. If one door was closed because I was a woman (in the early days no women down in mines or in factories…), there were other opportunities.

I was not a “fighter on the barricades for women’s rights”. In all circles, I was better remembered than my fellow male students. Maybe I became a “curiosity”, but no one made me feel like one. It was perhaps reverse discrimination (?).

A good career

Is a successful career a good career?

A «good» career:

- ✓When you feel you are achieving something
- ✓When you are motivated to go about your tasks
- ✓When you look forward to going to work every morning

You simply have to enjoy your work!

Trends for today's professionals

Today's geotechnical engineer/geoscientist must be ready for the challenges of rapidly changing environments. Engineers and scientists need to be able to function at many levels, in many positions. Compared to before, we work

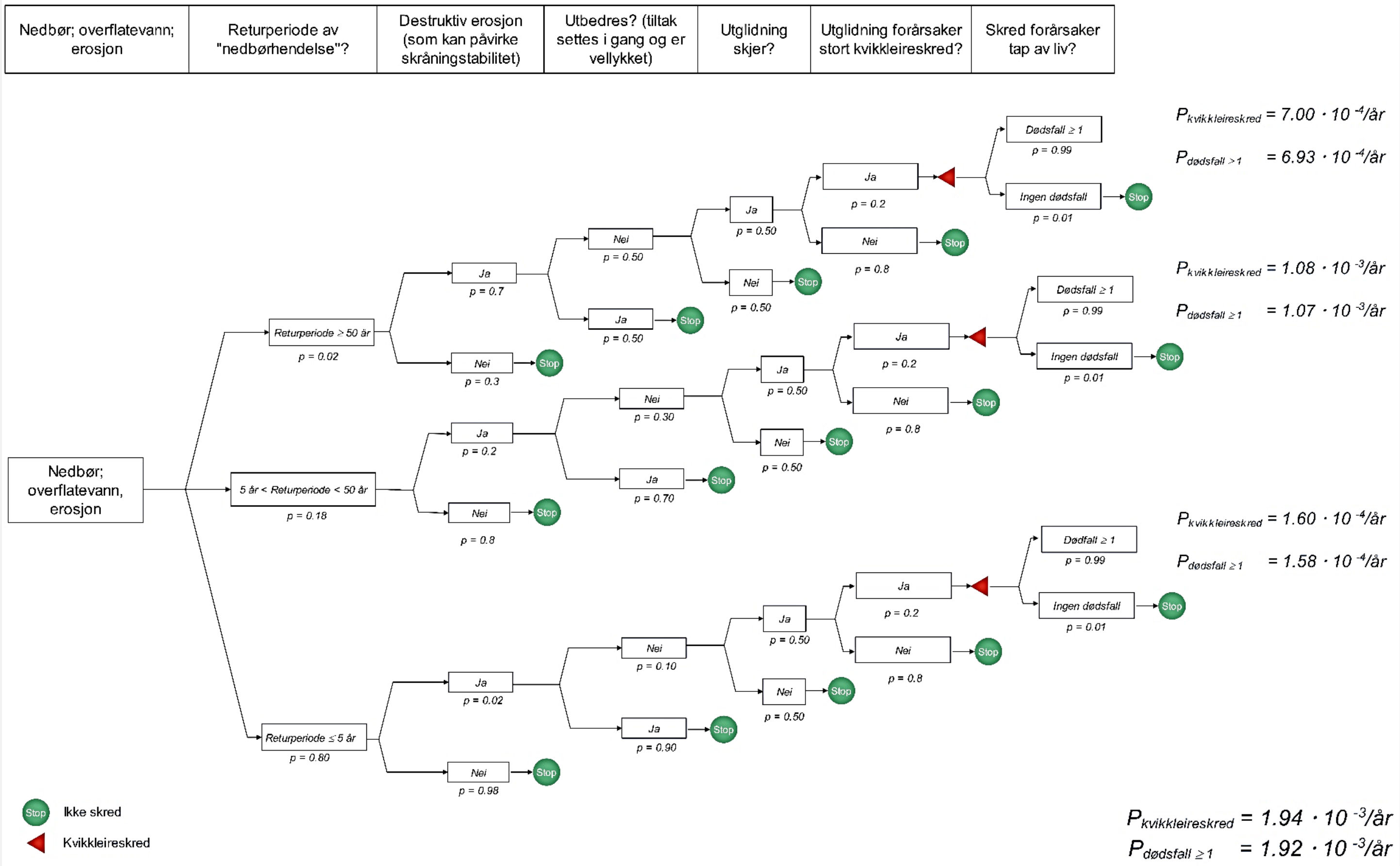
- across disciplinary boundaries and geographical boundaries
- need to solve a wider range of problems
- adapt to play a more demanding role in society.

How our profession has changed:

- from hand notes to Big data projects
- from correlations (on paper) to Machine Learning and AI

Tips for your own career story

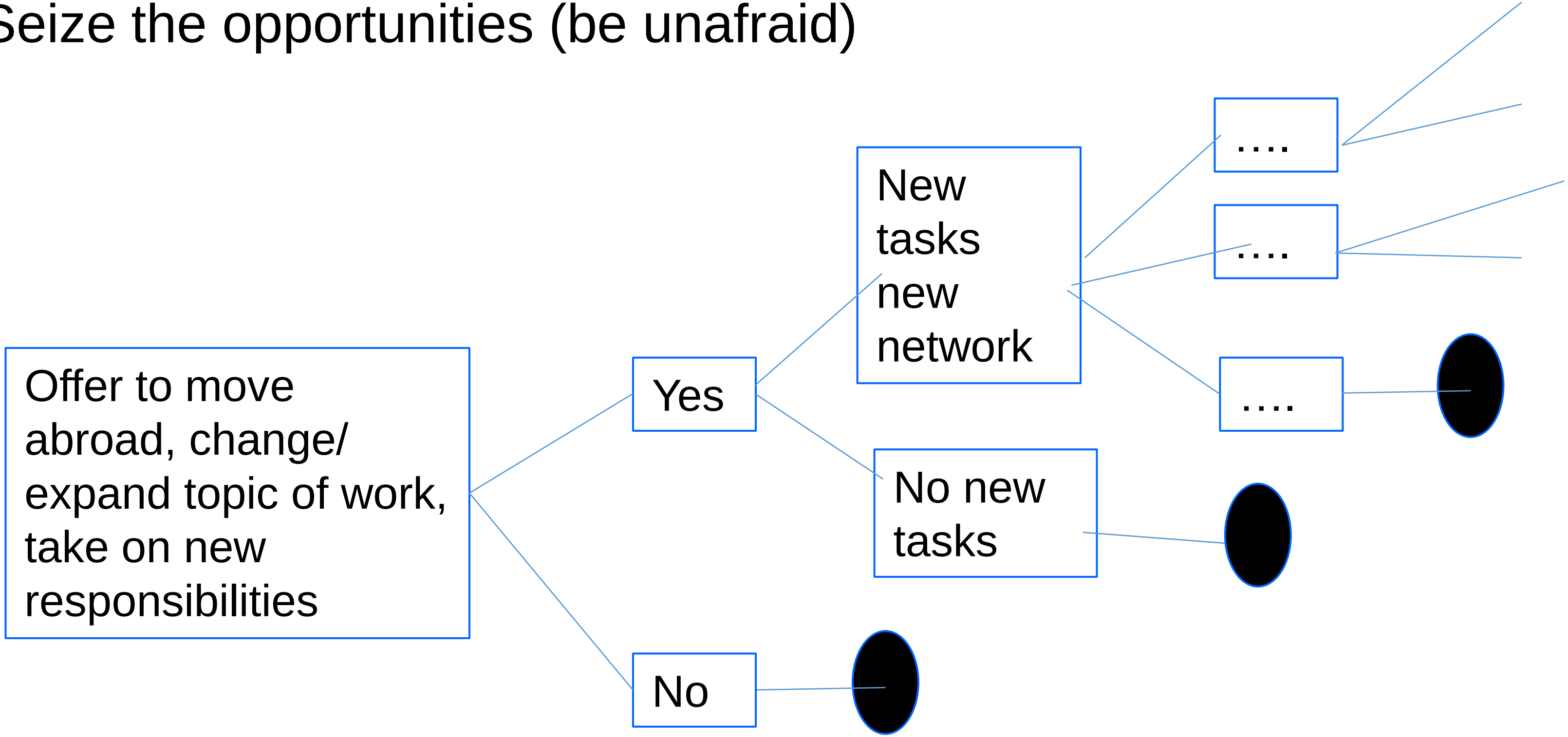
Event tree analysis approach
Sub-area 1, initial conditions, rainfall → surface water and erosion



NGI

Tips for your own story

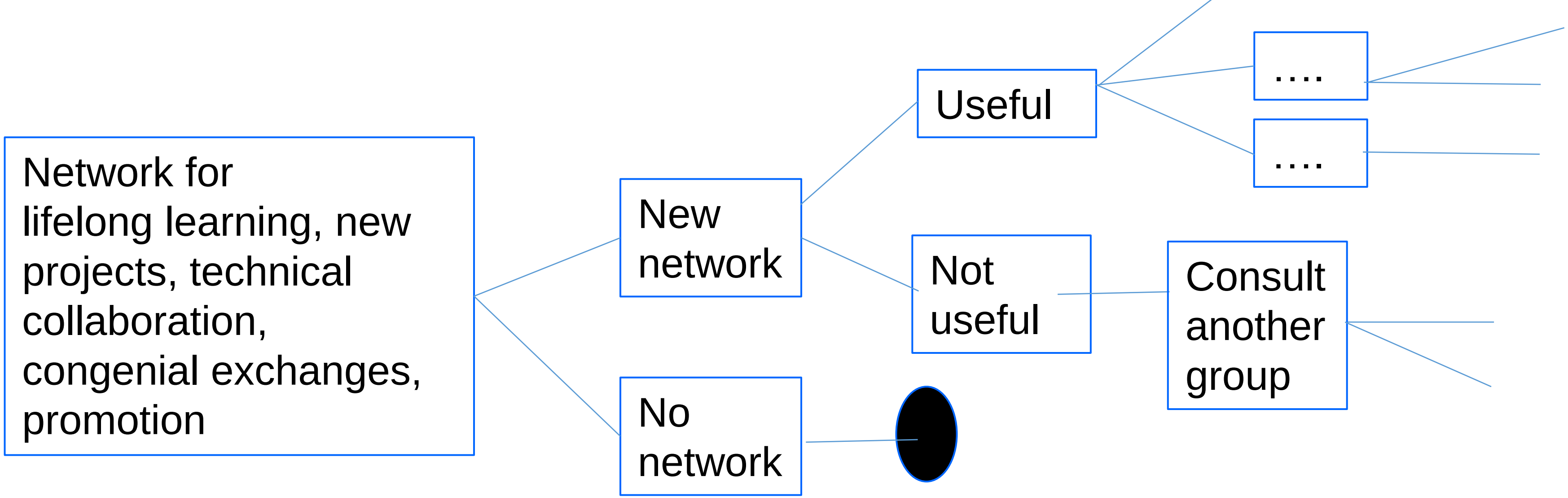
Seize the opportunities (be unafraid)



Tips for your own story

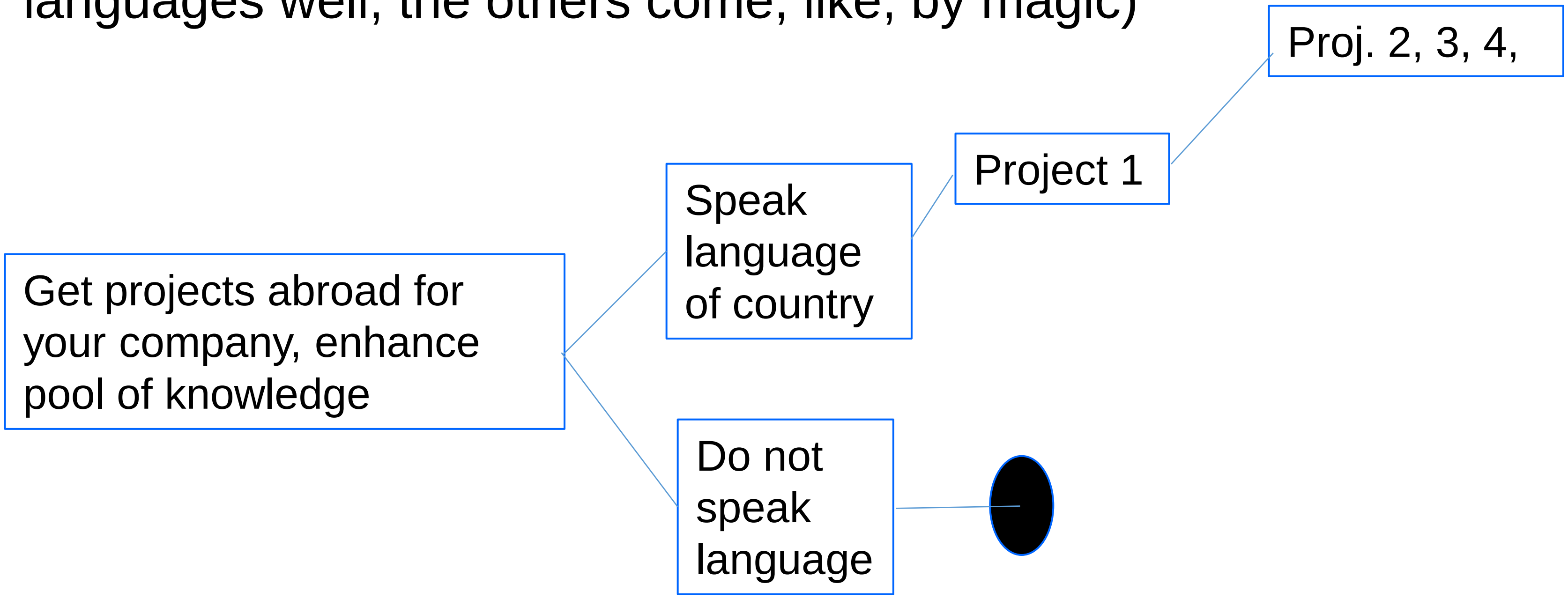
Be active in learned societies (CGS, ASCE, EIC, ISSMGE, ISRM, IAEG, University Alumni Assoc., take on some role)

- Build and maintain a network



Tips for your own story

Learn new languages (once you know two or three languages well, the others come, like, by magic)



Tips for your own story

- Combine basic technical skills, inventiveness for new solutions or knowing where to find ideas for new solutions; nurture engineering judgment.
- Work in good teams, and make your team look good.
- Know yourself, what you are best at.
- Do not try too hard, the good opportunities will come.
- People skills: - Effective communication and interpersonal skills

  - Commitment to lifelong learning (20 years experience vs 20 times 1-yr experience);

  - Awareness of societal changes.

Tips for your own story

- Show a passion for what you do!
- Maintain a curiosity to learn more. Learn from your errors and the errors of others
- Understand the basic assumptions in the software you use
- In critical design situations, ensure redundancy and do checks with supplementary analyses
- Publish the results of your work
- Presentations: think about what the audience is interested in, not what you are interested in!

Tips for your story

- Do not «overplan» your career. Rather, seize the opportunities when they arise.
- Faced with two good career alternatives, there is no bad choice. You will make the success as you go.
- A good health is indispensable – take good care of yourself

I perceive the younger generation as much more capable and having a much wider background than my generation.

So, the future is all yours!

Reflexion: What about when you have become an older geo-professional?

- First, you never realise that you are 75 years old, you think that you are still the same young person, able to do the same as before
- What do I enjoy most:
  - Working with the young geo-professionals (male and female, all countries)
  - Not having to do much administrative work anymore

Only regret: not having been an academic for a longer time. Throughout the years, I missed the teaching and contact with the younger generation (and perhaps the freedom of academics).

NGI

Concluding thoughts

Looking back, I don't think I could have been happier in any other profession. The engineering/geo-profession is really very special, friendly, proud, devoted to continuing improvement and continuously renewing itself. It is the interaction with colleagues and clients (and more recently with the public, related to risk assessment) that is the most rewarding.

Nothing replaces enthusiasm when trying to convince a client!

Success is not synonym with higher salary, a fancy title or higher international recognition. Success is gaining the respect of your peers.

Enjoy your career, seize the opportunities,
and you will achieve amazing results!