# The limitations of reliability analysis in geotechnical design

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with contributions from

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# Origins of reliability in manufacturing

- Prototypes tested to obviate danger to the customer
- Proven product design with specified components
- Tolerances established for each component
- Opportunity for sampling and testing of components
- Opportunity for life-testing assembled products
- Opportunity for collecting copious data from customers claiming under guarantee
- It is therefore practical to predict, and then verify, the probability of disappointing performance.

# Contrast with geotechnics

- Variable and ill-defined geological processes
- Typical soil sampling at 10 parts per million
- All soils highly non-linear, anisotropic, rate-sensitive
- Inadequate testing, especially of soil stiffness
- Inadequate models of soil-structure interaction
- Inadequate criteria of structural serviceability
- Huge significance of groundwater to whole-system behaviour, but frequently inadequate investigation data, and unpredictable future variation.

# Probability of failure in geotechnics

- Variability of geology, climate and the social and economic conditions underlying GI, design and construction, make global statistics of failure almost irrelevant to the site and project of interest.
- Case studies of ultimate failure show that gross errors are very often responsible, and best avoided by clear design guidelines, open communications, and independent checking.
- Although data of failure is sparse due to legal and commercial pressures, unserviceability is thought to be much more common than ultimate collapse.

# Reliability-based design (RBD) in geotechnics

- Advocates of RBD emphasise the need for:
  - Excellent GI providing a spread of appropriate data
  - Physically reasonable PDFs of material parameters
  - Liaison with structural designer on loading PDFs
- However, system uncertainties inevitably remain outside the RBD framework:
  - Picking soil models appropriate to the problem
  - Predicting the critical groundwater regime
  - Vagaries of human error
- The estimated probability of failure via RBD will therefore be notional, and much too small.

# Consequences of system uncertainty for RBD

- In the absence of an objective probability of failure $P_f$, RBD outputs are restricted to reliability index $\beta$ calculated only with respect to measured variables.
- But it is $P_f$ that (falsely) attracts some clients.
- Many practitioners feel that $\beta$ alone would not be sufficiently attractive to owners to warrant re-skilling the design office, and re-interpreting codes (EC7).
- And by emphasising parametric data, RBD may draw attention and resources away from system and modelling uncertainties and so cause $P_f$ to increase.

# Reliability-based assessment of parameter values

- Notwithstanding the dangers of system uncertainty, it seems attractive to use probabilistic methods to choose design values of parameters if data exists.
- However, it is difficult rationally to calibrate against partial factors fixed in codes, such EC7.
  - Although EC7 distinguishes collapse limit states (ULS) from serviceability (SLS), the partial factors on ULS parameters are said partly to limit displacements, and no partial factors are applied on (more uncertain) SLS parameters.
  - If reliability was used properly to derive SLS parameters, ULS factors should therefore logically reduce.

# Reliability analysis for ULS?

- The most uncertain action is groundwater pressure but data relevant to future variability is not available:
  - a “worst case” estimation must be made.
- The most uncertain material parameter is soil strength:
  - due to the variable dilatant component, but the frictional (critical state / residual) component is a reliable “worst case”.
  - EC7 compounds the problem by ignoring this distinction and simply factoring tangent strength parameters c and $\phi$.
  - current practice lags scientific understanding by 30 years, and this must be remedied to achieve rational design principles based on worst case scenarios.

# Reliability analysis for SLS: an opportunity

- Since SLS failures usually precede ULS in geotechnics, and because they are usually driven by differential settlements, this is a proper application of RBD.
- A single “expected settlement” is valueless, it is the variability, moderated by structure-soil relative stiffness, that creates the possibility of damage.
- The link between differential settlement and structural damage, is also statistical.
- Current calculations are very crude and conservative, so this opportunity for RBD remains to be seized.

# Other avenues for probabilistic analysis?

- Use subjective probabilities in the absence of data?
  - Based on an expert’s self-declared degree of confidence.
  - Bayes’ theorem used to refine confidence given new data.
  - Without guidance, experts would likely disagree
- Guided judgements
  - Code drafters may agree on a set of weighted factors that should guide the initial assessment by the engineer.
  - The result may be equivalent to setting partial factors, but varying according to the engineer’s judgement.
  - Followed by Netherlands in assessing dyke safety, and Australia in designing piles: is it an alternative for EC7?

# Limitations of RBD in geotechnics - conclusions

- Geotechnical design is uniquely challenging due to inevitable system (modelling) uncertainties, and this generally makes full RBD impossible.
- Where enough data exists, statistical reasoning may be helpful in choosing a design value for a parameter.
- But ULS checks often require “worst credible values” selected from a different population of data.
- Reliability concepts could be useful in SLS checks of expected damage caused by differential settlements.
- Bayesian decision-making is an alternative to RBD.