Time-dependent reliability of highway bridges

The sense and nonsense of standardised probabilistic influence factors

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TUM-JCSS Workshop
Time-variant Reliability Analysis:
Old challenges and new solutions

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Disclaimer

- This presentation is not about the use of the standardized probabilistic influence coefficients itself, but about the effect of time-dependence.

- We know that standardized α-factors can lead to oversimplified, suboptimal designs:
  - Hingorani, Ramon and Jochen Köhler. 2023. Towards optimised decisions for resource and carbon-efficient structural design, Civil Engineering and Environmental Systems, DOI: 10.1080/10286608.2023.2198767
  - Hingorani, R., Köhler, J., Sustainability potential of risk-informed decisions in structural design, 14th International Conference on Applications of Statistics and Probability in Civil Engineering (ICASP14), Dublin, Ireland, 2023
  - N.E. Meinen, R.D.J.M. Steenbergen, Reliability levels obtained by Eurocode partial factor design - A discussion on current and future reliability levels, Heron, Vol. 63 (2018) No. 3, pp. 243-301.

Introduction

Introduction

. Hosser, D.: Tragfähigkeit und Zuverlässigkeit von Stahlbetondruckgliedern. Mitt. Inst. Massivbau TH Darmstadt, Heft 28. Berlin, Düsseldorf, München: Ernst & Sohn 1978

In den „Grundlagen" wurden nach [5] die globalen Wichtungsfaktoren α_R und α_S wie folgt festgelegt:

$$\tilde{\alpha}_R = 0{,}8$$
$$\tilde{\alpha}_S = -0{,}7 \qquad (20)$$

- Does this make sense if we look to an existing structure?
- Which influence factors to use when assessing the last year of the design life? Which factors to use for the lifetime extension?

- We studied some cases in which we chose the design at t=0 to be close to these 'standarized' alpha-values to study the influence of time in the conditional failure rate. Typical for road traffic load.

Typical heavy bridge (element)

Typical heavy (concrete) bridge

- Assuming RC2: $\beta = 3.8$ over 50 years
- Limit state function:
  $Z = R - (m_G G + m_T T)$
- Large contribution of self-weight to total load effect (70%)
- Parameters expressed as equivalent uniformly distributed load, per lane

Symbol	Description	Distribution	Mean [kN/m]	Coeff. of variation [-]
R	Resistance (capacity)	Lognormal	304	0.10
m_G	Model uncertainty G	Normal	1.0	0.07
G	Self-weight	Normal	120 (70%)	0.07
m_T	Model uncertainty T	Normal	1.04	0.17
T_1	Traffic load, max. 1 year	Gumbel	51.5 (30%)	0.067
T_{50}	Traffic load, max. 50 years	Gumbel	62.0	0.056

Typical heavy bridge

- Assuming RC2: $\beta = 3.8$ over 50 years
- Limit state function:
  $Z = R - (m_G G + m_T T)$
- Large contribution of self-weight to total load effect (70%)
- Parameters expressed as equivalent uniformly distributed load, per lane
- FORM analysis result using T_{50} (reference period = 50 year):
  - $\beta = 3.82$
  - $\alpha_R = 0.78, \alpha_E = -0.62$

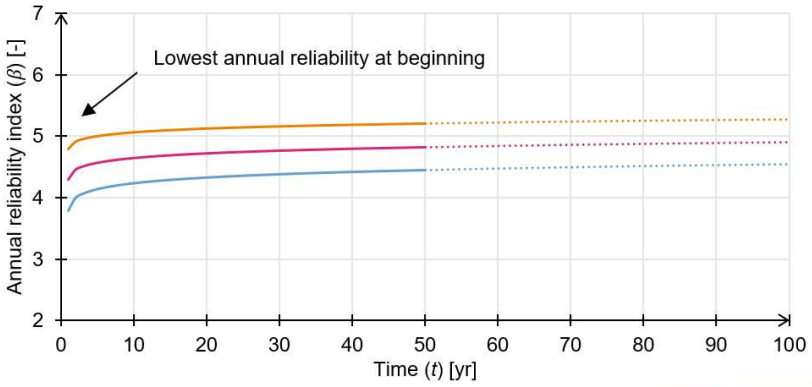
  } As desired, btw not always true!
- FORM analysis result using T_1 (reference period = 1 year) (i.e. *the first year*):
  - $\beta = 4.31$
  - $\alpha_R = 0.78, \alpha_E = -0.62$

Practically the same, since the influence of the time variant part of the traffic load is very small

Typical heavy bridge

Probability of failure in year x given survival in the years before, failure rate

- Consider the *conditional annual* reliability over time without degradation and traffic trend
- Conditional annual increases
- If the conditions remain the same, no need to replace the structure after 50 years



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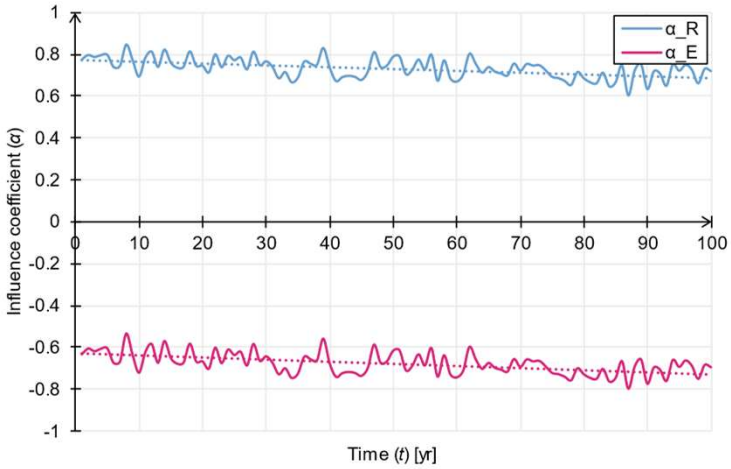
Typical heavy bridge

- What happens to the influence coefficients?
- Monte Carlo simulation, new realization of R, m_G, G and m_Q for every sample and Q for every year of that sample
- Store point that is the closest to origin in U-space for each year, then $\boldsymbol{\alpha} = -\mathbf{u}_\mathrm{d}/|\mathbf{u}_\mathrm{d}|$



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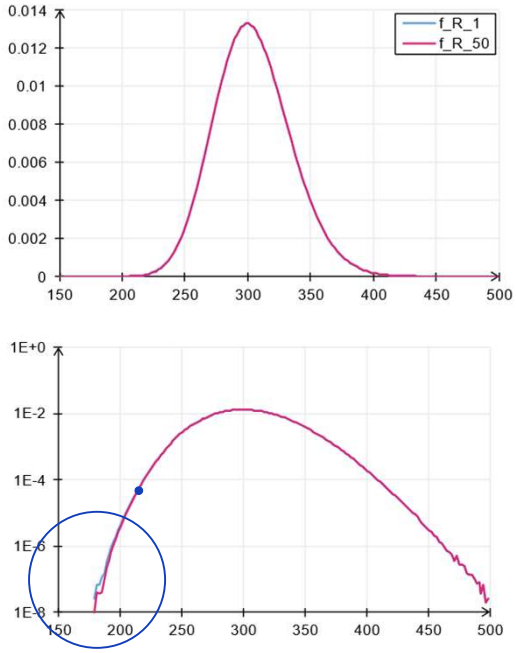
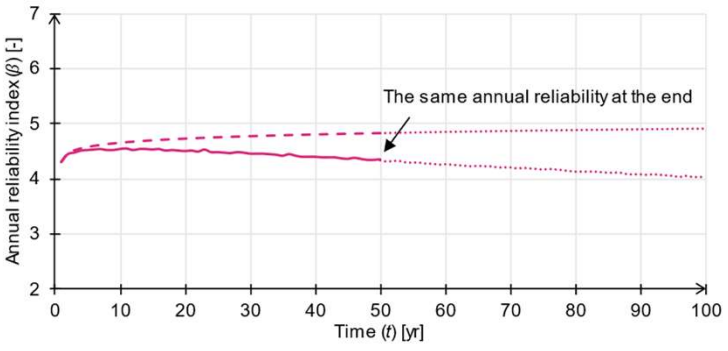
Typical concrete bridge

- The distributions of all auto-correlated random variables are updated with time (R, m_G, G, m_T)
- E.g.: the left tail of the resistance is updated; the right hand tails of m_G, G, m_T are updated.
- Design value R_d changes to slightly higher values



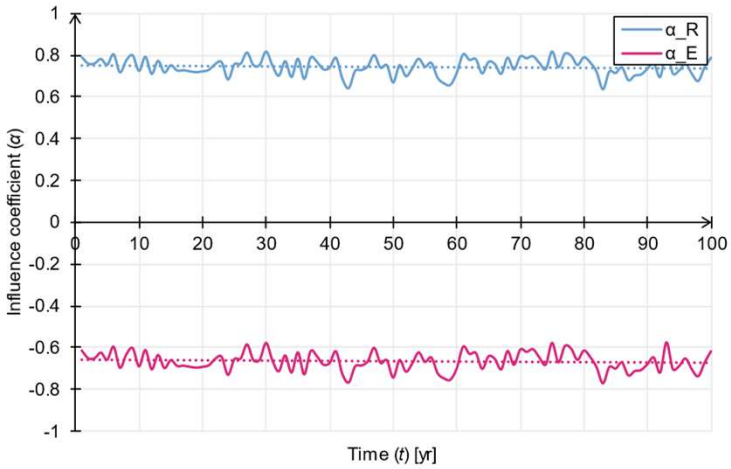
Typical heavy bridge with traffic trend

- What if there is a trend in the traffic load effect?
- Assume an increase of 16% in 50 years
- Annual reliability decreases with time; $\beta = 4.3$ at $t = 50$



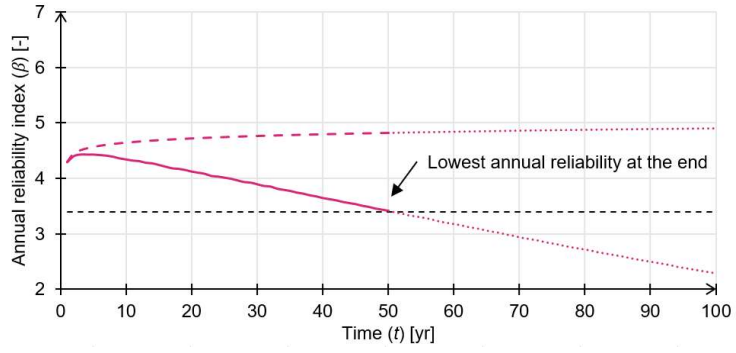
Typical heavy bridge with traffic trend

- What happens to the influence coefficients?
- Smaller change



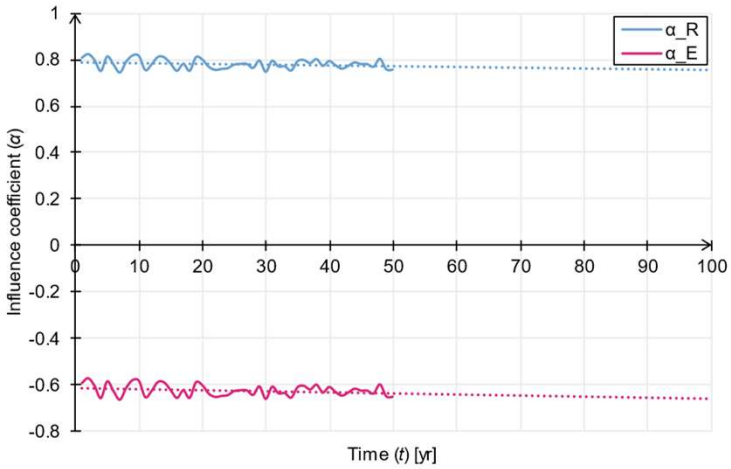
Typical heavy bridge with traffic trend and degradation

- What if considerable degradation takes place?
- Assuming linear decrease of R
- The last year becomes critical
- NEN 8700 requires a minimum annual reliability of 3.4 for RC2 based on life safety



Typical heavy bridge with traffic trend and degradation

- What happens to the influence coefficients?
- Change in influence coefficients less pronounced



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Typical lightweight bridge (element)

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Typical lightweight bridge

- Assuming RC2: $\beta = 3.8$ over 50 years
- Limit state function:
  $Z = R - (m_G G + m_T T)$
- *Small* contribution of self-weight to total load effect (30%)
- Parameters expressed as equivalent uniformly distributed load, per lane

Symbol	Description	Distribution	Mean [kN/m]	Coeff. of variation [-]
R	Resistance (capacity)	Lognormal	177	0.14
m_G	Model uncertainty G	Normal	1.0	0.07
G	Self-weight	Normal	22.0 (30%)	0.07
m_T	Model uncertainty T	Normal	1.04	0.17
T_1	Traffic load, max. 1 year	Gumbel	51.5 (70%)	0.067
T_{50}	Traffic load, max. 50 years	Gumbel	62.0	0.056

Typical lightweight bridge

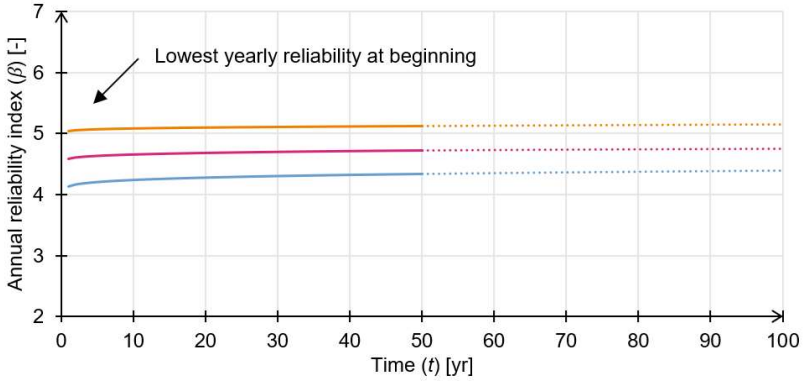
- Assuming RC2: $\beta = 3.8$ over 50 years
- Limit state function:
  $Z = R - (m_G G + m_T T)$
- *Small* contribution of self-weight to total load effect (30%)
- Parameters expressed as equivalent uniformly distributed load, per lane
- FORM analysis result using T_{50}:
  - $\beta = 3.81$
  - $\alpha_R = 0.762, \alpha_E = -0.647$

  } As desired
- FORM analysis result using T_1 (i.e. *the first year*):
  - $\beta = 4.52$
  - $\alpha_R = 0.730, \alpha_E = -0.684$

  Small change

Typical lightweight bridge

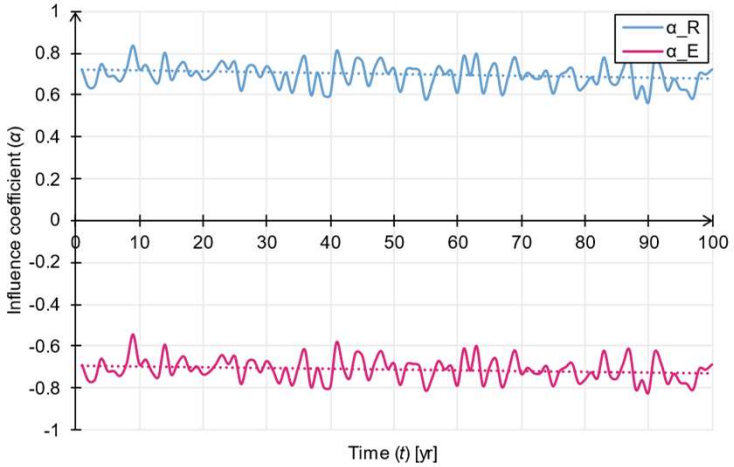
- Observe a more constant annual reliability level
- Follows from a more significant variable load contribution



Typical lightweight bridge

- Development of the influence factors
- Result for the last year:
  - $\beta = 4.73$
  - $\alpha_R = 0.66, \alpha_E = -0.75$

Switched! Closer to $\alpha_R = 0.7, \alpha_E = 0.8$



Conclusions

Conclusions

- **Sense:**
  - Working with standardized alpha-values is easy, allows for calibration of material Eurocodes based on a fixed probability of non-exceedance: $P(R<R_d)=\Phi(-0.8x3.8)$.

- **Nonsense:**
  - α-values are dependent on reference period and on time!
  - α-values are updated based on the ratio between self weight and variable actions, etc
  - For the assessment of existing structures that have some performance over the life-time, the α-value is not necessarily that of new structures.
  - An update of order $\Delta\alpha=0.1$ has been observed for typical bridge elements under road traffic. This means order of magnitude a probability change with a factor of 5.
  - The assumption of a perfect lognormal distribution for R is not valid anymore with time.

- Need for full probabilistic calibration of factors!


Thank you for
your attention
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