Competitive comparison of load combination models

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1921-2011
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Introduction
Comparison based on previous experience
Numerical example
Concluding remarks

Introduction

- Civil engineering structures often exposed to ***combinations of time-variant loads*** (climatic actions, imposed loads)

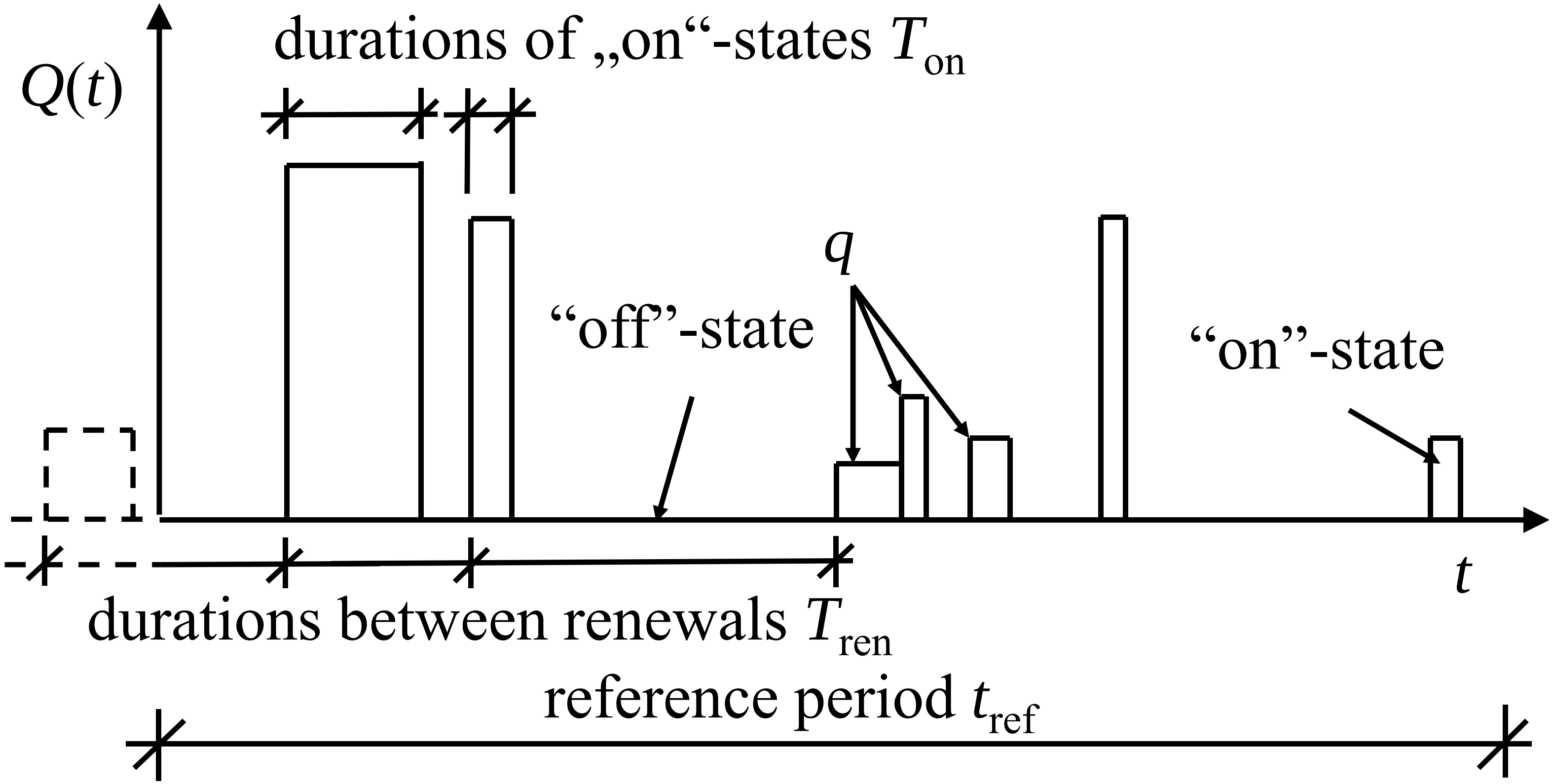
- ***Several*** load combination ***models*** applied in reliability studies

- The present study aimed at comparison of ***three selected approaches***:
  - Rule proposed by ***Turkstra*** (1970)
  - Rectangular wave renewal processes with fixed durations of pulses, Ferry Borges & Castanheta (1971) – ***FBC models***
  - Rectangular wave ***renewal processes*** with random durations between renewals and random durations of load pulses, Rackwitz (1998) and Sykora (2005)

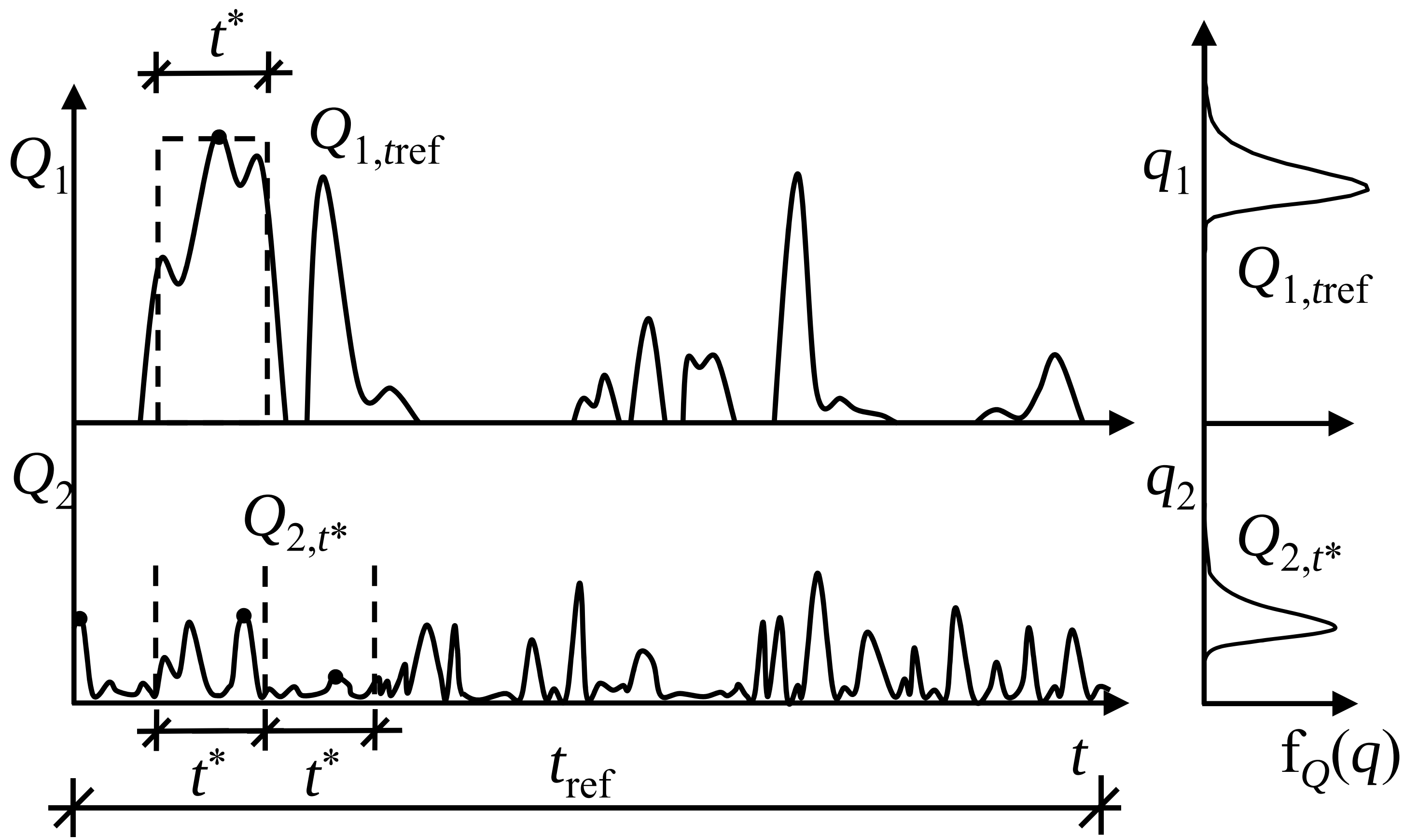
- Comparison based on ***previous experience***, ***numerical study***

Basic assumptions

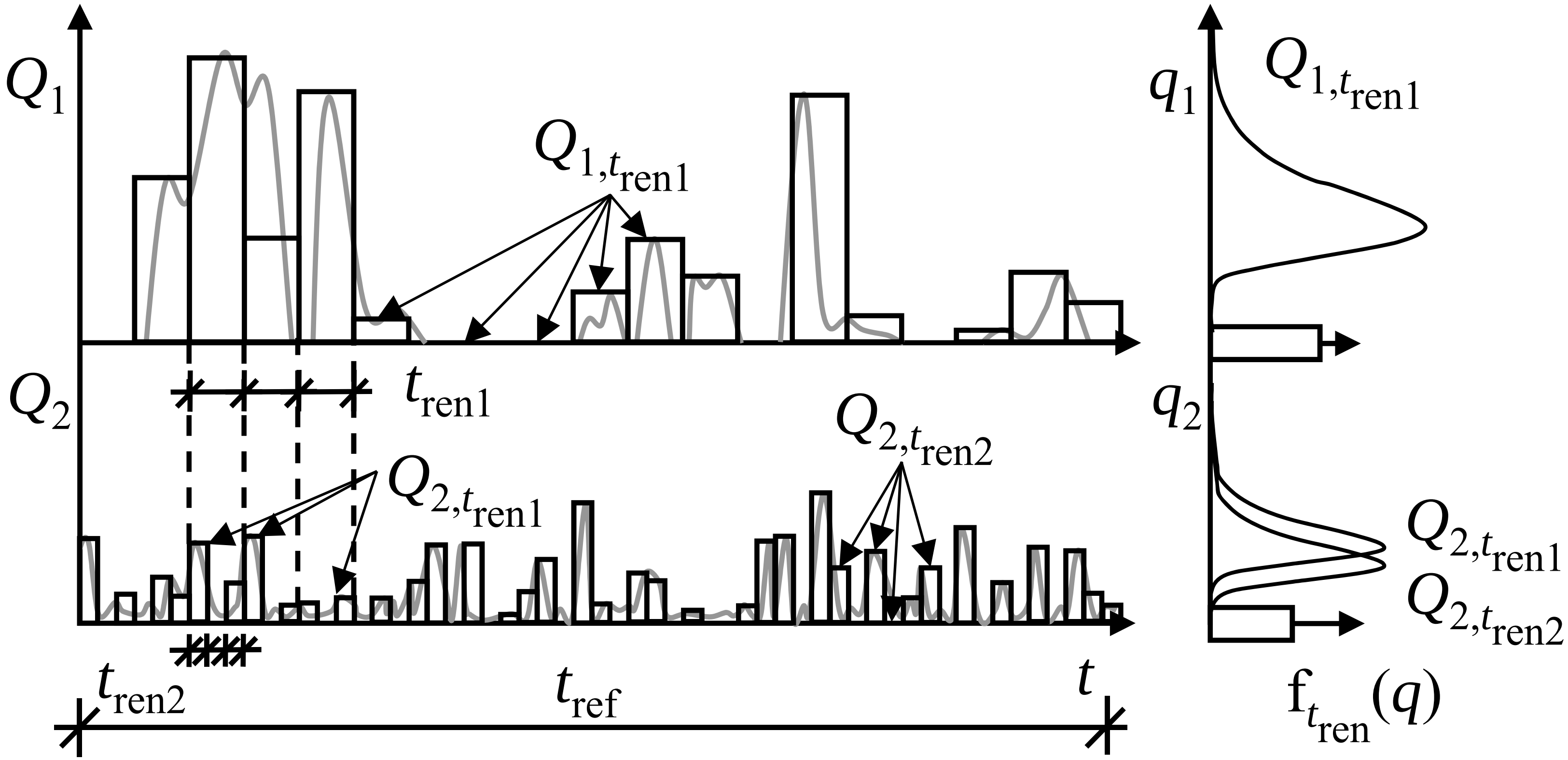
- ***Resistance***, geometry variables, permanent actions and model uncertainties - ***time-invariant***
- ***Time-variant actions*** described by stationary, ergodic and regular ***processes***



Turkstra's rule



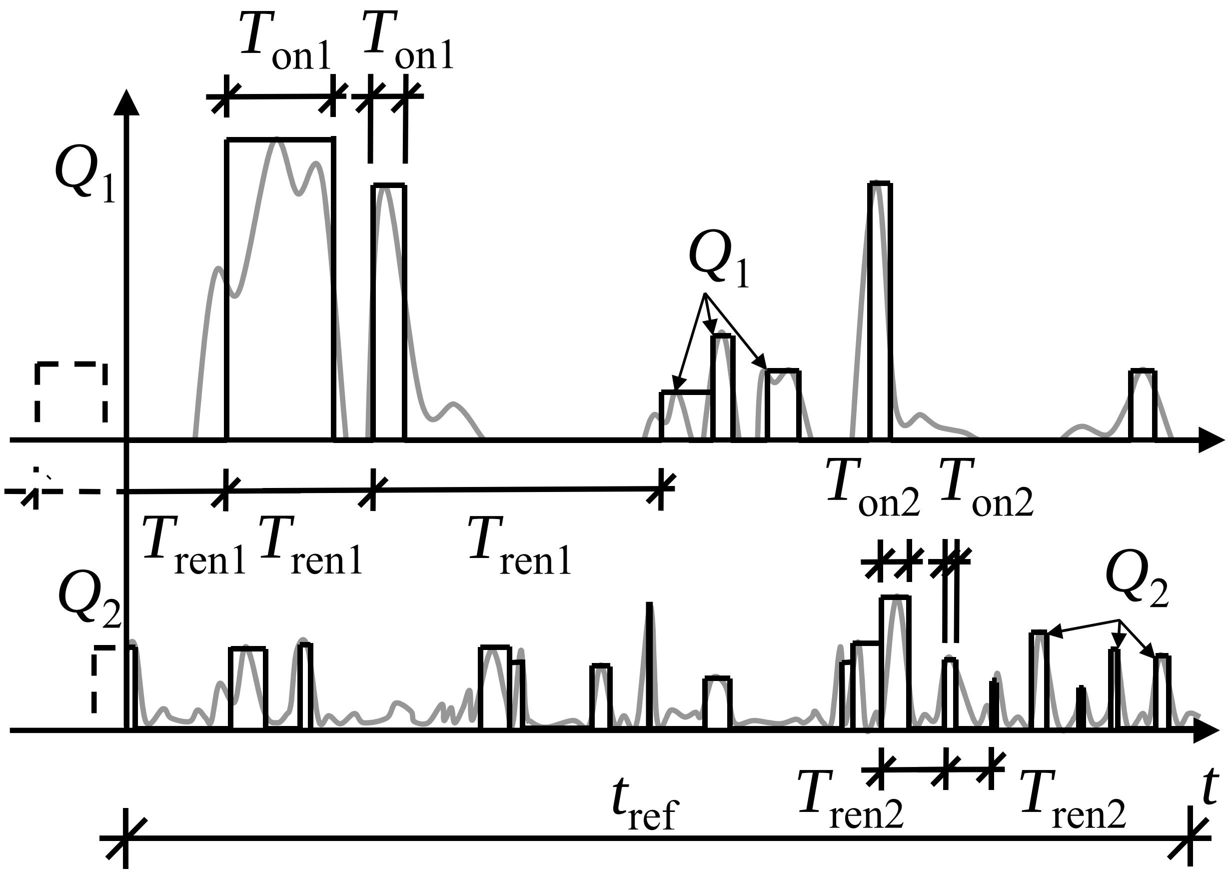
FBC models



Q_1
$Q_{1,t_{ren1}}$
Q_2
t_{ren1}
$Q_{2,t_{ren1}}$
$Q_{2,t_{ren2}}$
t_{ren2}
t_{ref}
t
q_1
$Q_{1,t_{ren1}}$
q_2
$Q_{2,t_{ren1}}$
$Q_{2,t_{ren2}}$
$f_{t_{ren}}(q)$

Renewal processes

- ***Upper bound*** on the failure probability in most applications (initial failure probability + outcrossing rate)



Comparison based on previous experience

- Applicability of reliability methods

  (+) ***Turkstra*** - any of well-established methods for the time-invariant analysis

  (-) ***FBC models*** – Rackwitz-Fiessler algorithm available in few software products

  (-) ***Renewal processes*** – upper bound unavailable in software products

- Accuracy

  (0) ***Turkstra*** – sufficiently accurate in most cases (given the leading action is identified)

  (0) ***FBC models*** – exact solution (applicability to short-term actions like storms and earthquakes disputable)

  (0) ***Renewal processes*** – applicable for many types of actions, crude approximation when time-invariant variables dominant

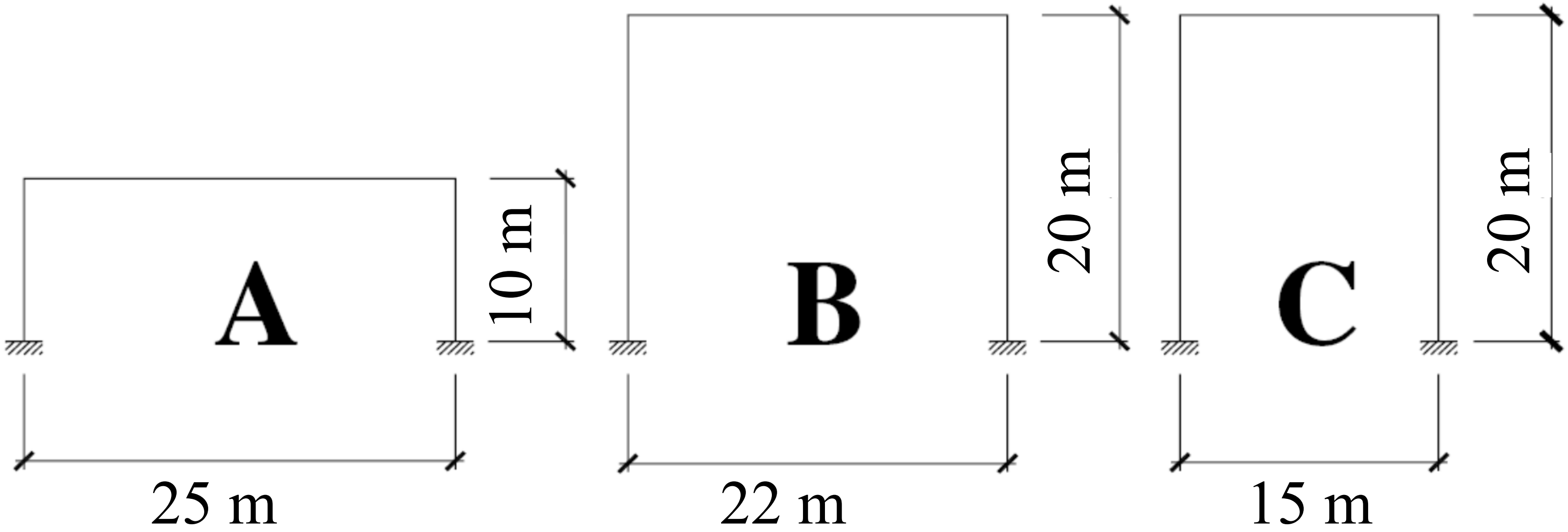
Comparison based on previous experience

- Estimation of partial factors (calibration studies)
  (+) ***Turkstra*** - straightforward
  (-) ***FBC models*** – easy for time-invariant variables, difficulties for time-variant loads
  (0) ***Renewal processes*** – straightforward when a dominant load case can be identified

- Non-stationary cases (out of the scope of the contribution)
  (-) ***Turkstra*** and ***FBC models*** – upper bound (maximum load effect and minimum resistance) may be overly conservative
  (+) ***Renewal processes*** – efficient analysis using the Laplace transform

Numerical example

- Reliability analysis of low-rise frames exposed to ***snow*** and ***wind***, Schleich et al. (2002) and Sadovsky & Pales (2008)
- Design according to Eurocodes
- Models for the ***monthly maxima*** of the climatic loads - meteorological data for six locations in Germany
- ***Snow*** present with the ***probability*** p_{on}; wind always present



Basis of analysis

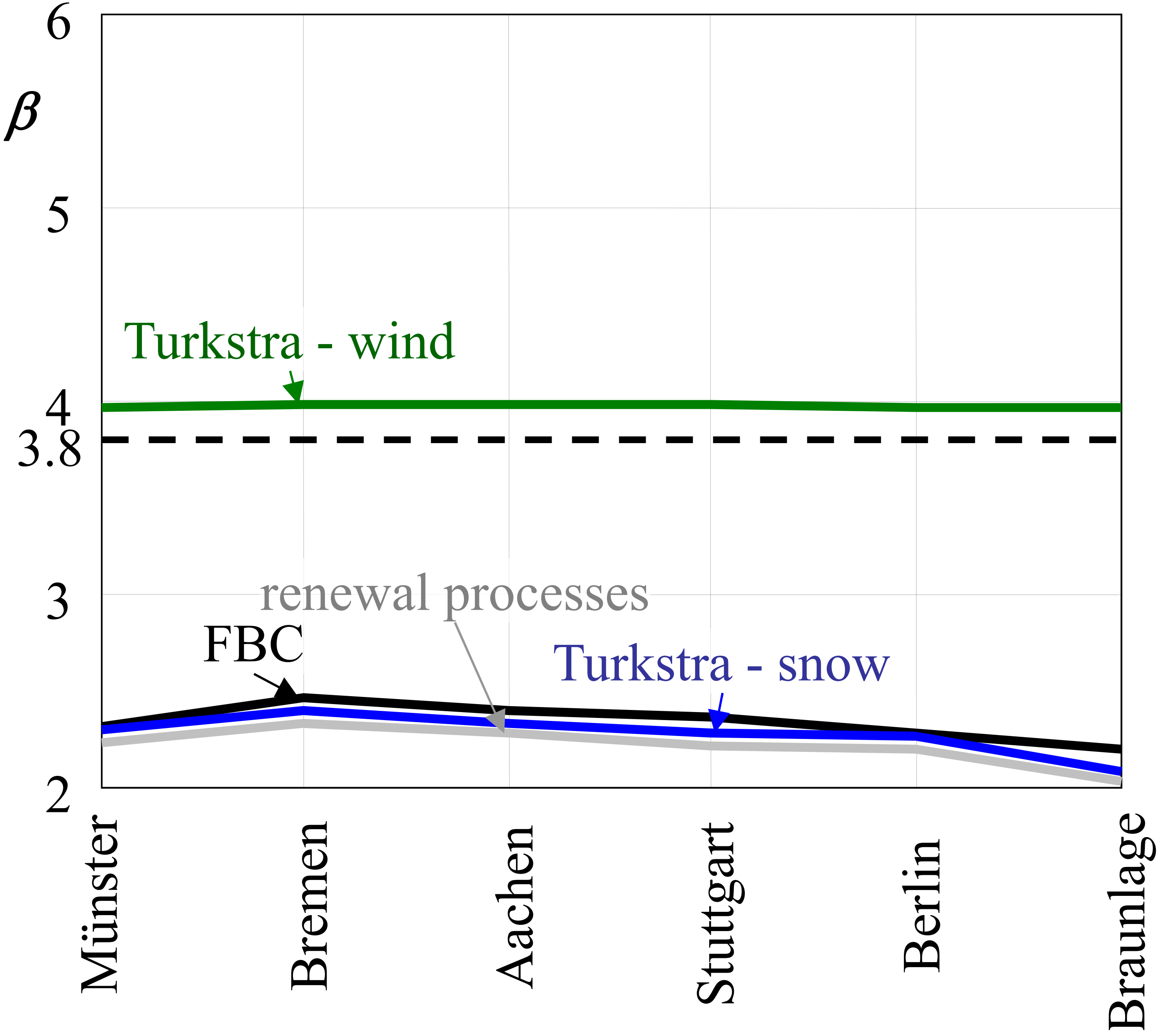
- ***Limit state function***: $g[\mathbf{X}(t)] = K_R R - K_E[G + S(t) + W(t)]$
- Reference period – 50 years

Variable	Dist.	μ_X/x_k	V_X	$p_{on,X}$
Resistance R	LN	1.18	0.08	-
Permanent load G	N	1	0.10	-
Snow on roof S (Münster)	GU	0.26	1.17	0.23
Wind action W (Münster)	GU	0.17	0.67	1
Resistance uncertainty K_R	LN	1.15	0.05	-
Load effect uncertainty K_E	LN	1.0	0.10	-

- Parameter - ***load ratio*** $\chi = (s_k + w_k) / (g_k + s_k + w_k)$

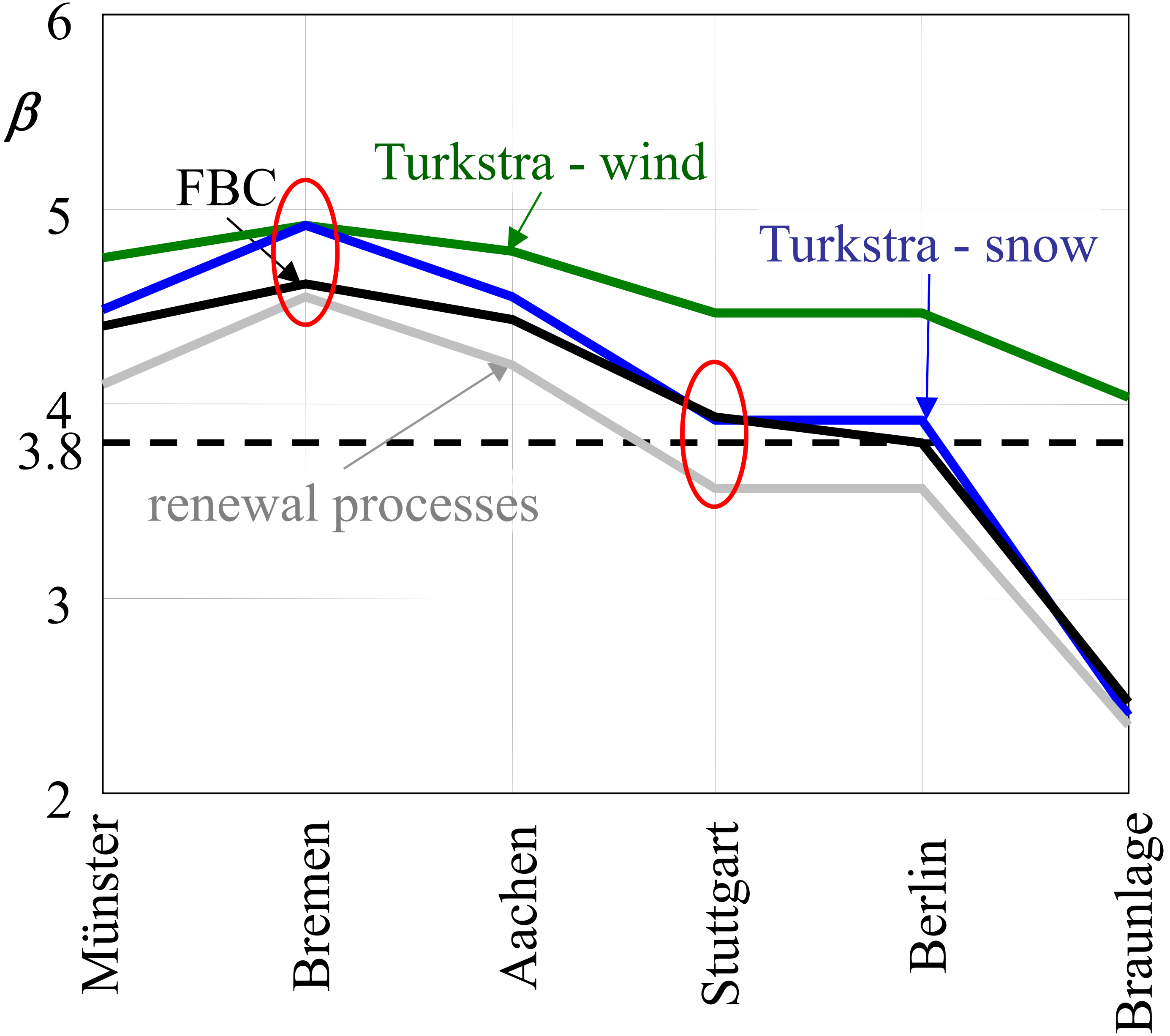
Reliability index – frame A (χ = 0.8)

One dominant action (frame A – snow, frame C - wind)

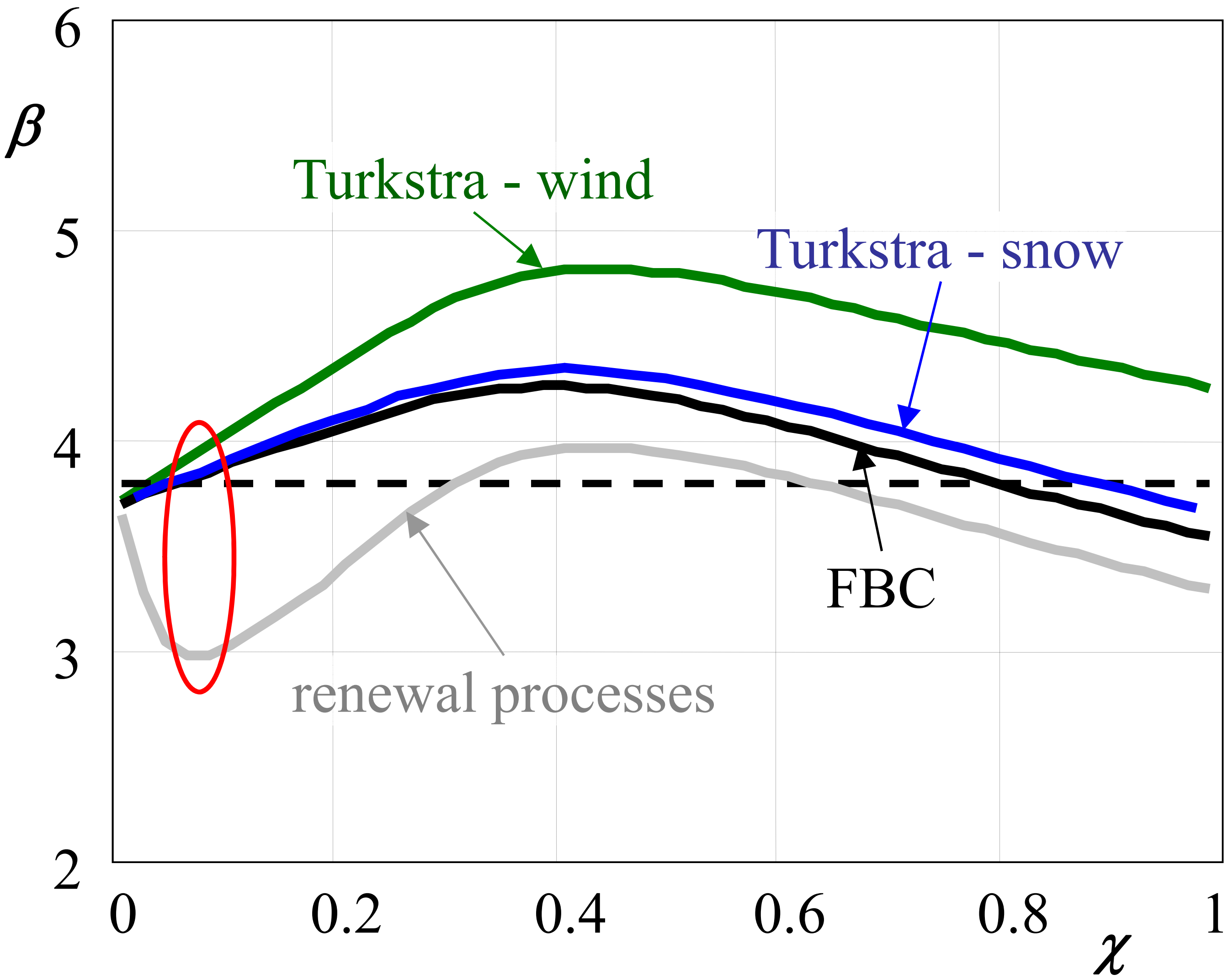


Reliability index – frame B ($\chi = 0.8$)

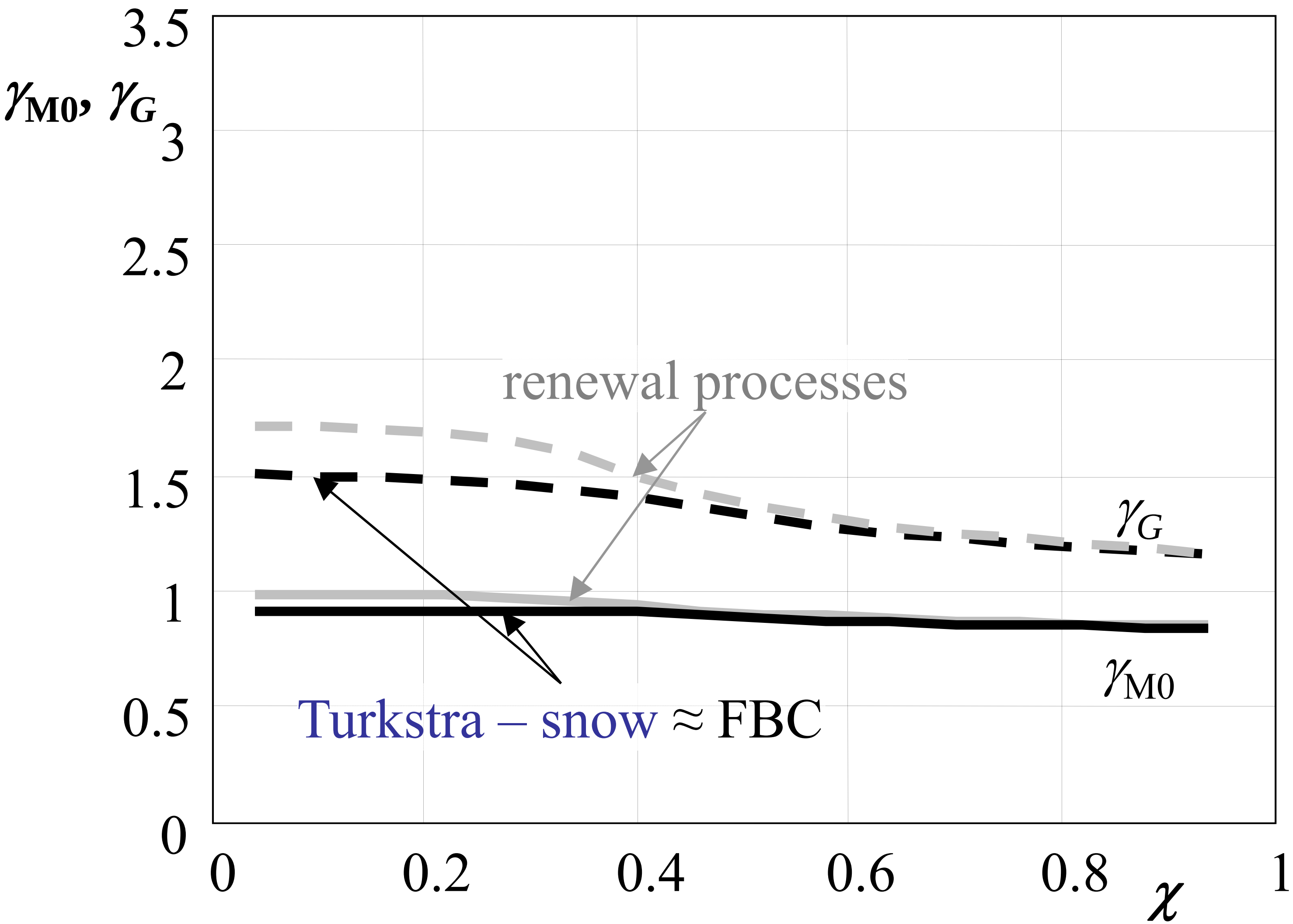
Comparable effects of snow and wind (frame B)



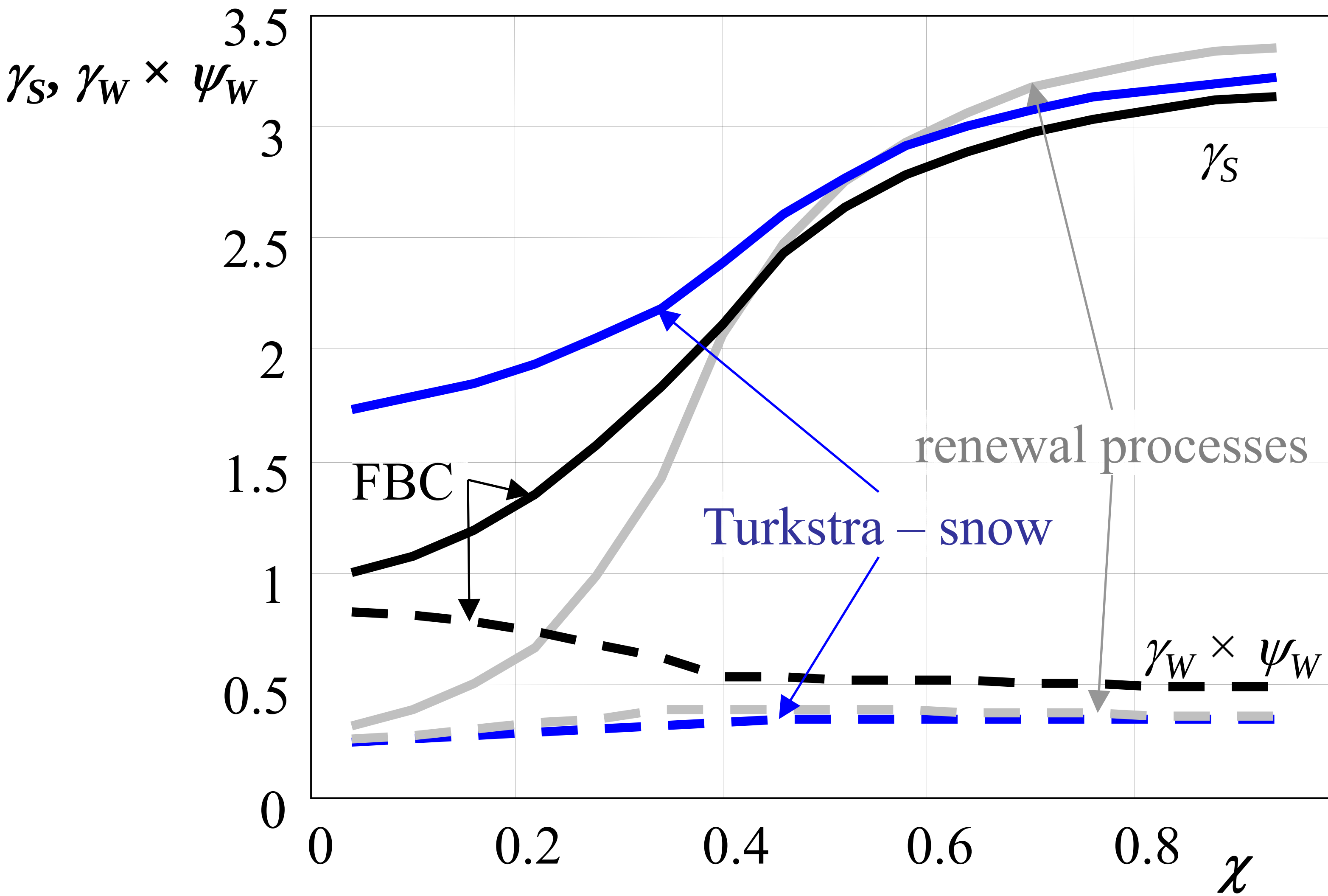
Reliability index vs. χ – frame B, Berlin



Partial factors γ_{M0} and γ_G vs. χ – frame B, Berlin ($\beta_t = 3.8$)



Partial factors γ_S and $\gamma_W \times \psi_W$ vs. χ – frame B, Berlin ($\beta_t = 3.8$)



Conclusions

- Selection of a model for the ***load combination*** may be a ***key issue*** of reliability analysis.

- ***Comparison*** of the three approaches reveals that:

1. ***Turkstra's rule***:
(+) Reliability can be assessed by ***any method*** for the time-invariant analysis.
(+) Estimation of ***partial factors*** is ***straightforward***.
(0) When applied strictly as proposed, ***failure probability*** may be ***underestimated*** (error insignificant).

2. ***Ferry Borges-Castanheta models***:
(+) The ***exact solution*** is found if time-variant loads are well described by FBC models.
(-) ***Rackwitz-Fiessler algorithm*** may be ***unavailable*** in software.
(-) Estimation of ***partial factors*** may be ***complicated***.

Conclusions

3. ***Renewal processes***:
   (0) Estimation of ***partial factors*** is ***straightforward*** if a dominant load case is identified.
   (-) For dominant time-invariant variables, ***conservative results*** are obtained.
   (-) ***Upper bound*** on failure probability is ***not available*** in software products.

- **For common studies, Turkstra's rule is recommended (verification by FBC models).**
- **Renewal processes may be useful for non-stationary conditions.**

More details: Sýkora, M. - Holický, M. Comparison of load combination models for probabilistic calibrations (to be published). In *Proc. ICASP11, 1-4 August, 2011, ETH Zurich*, Switzerland, 2011.

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Thank you for your attention.

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