11th INTERNATIONAL SYMPOSIUM ON STEEL BRIDGES 2024

Reliability-based Allowances of Corrosion Losses for Weathering Steel Bridges

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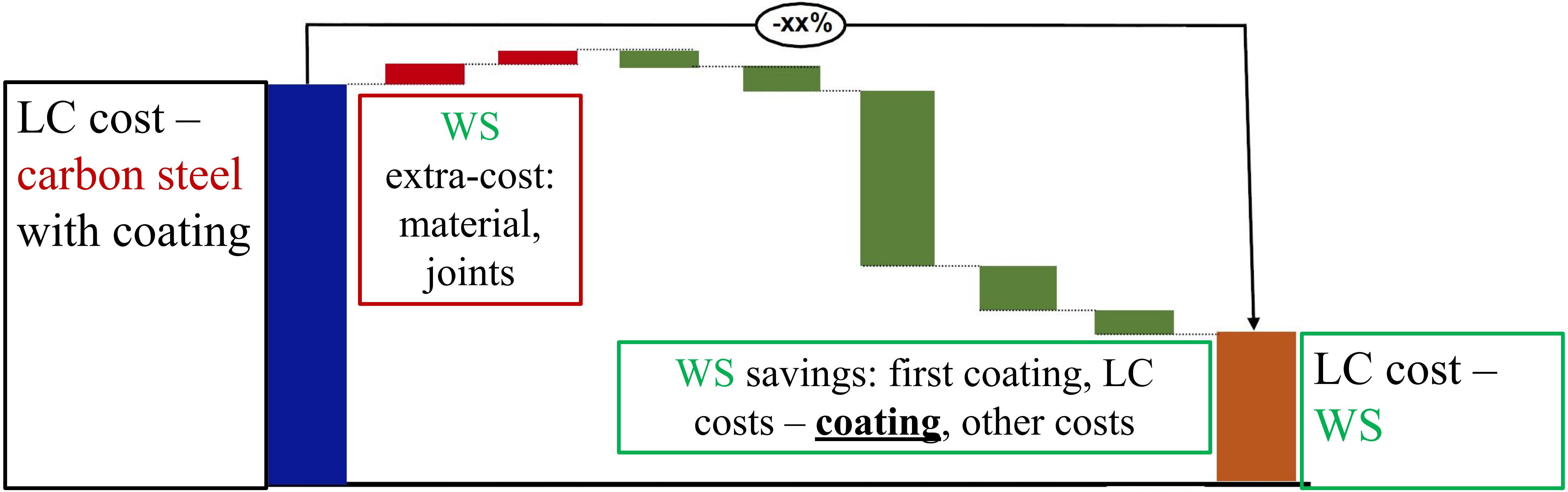
Introduction

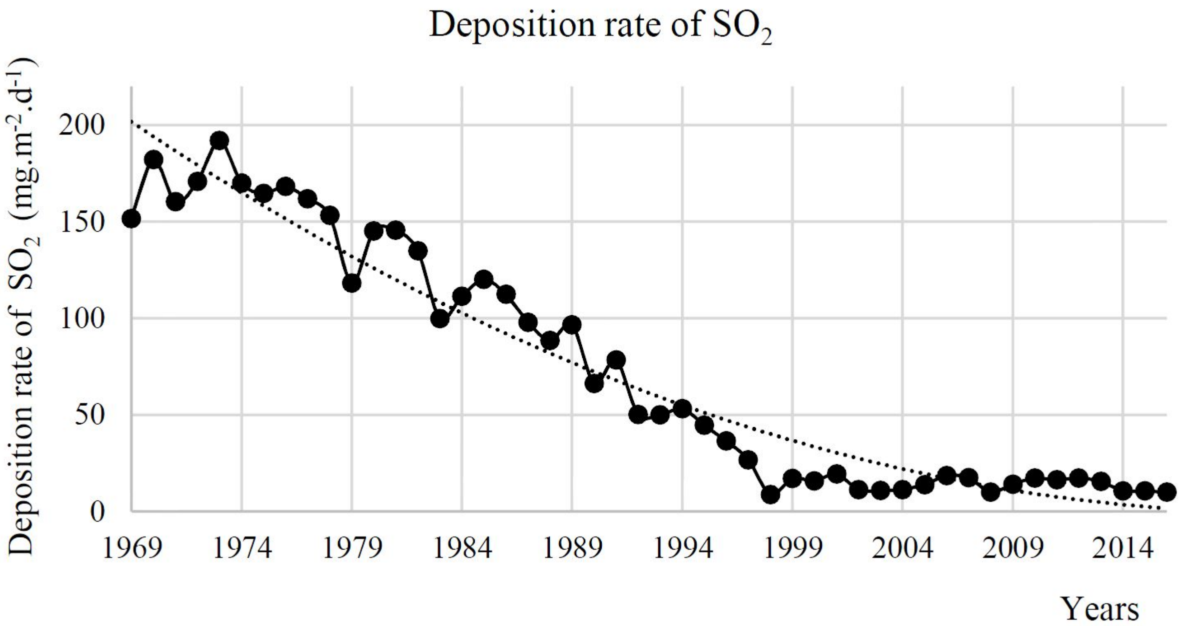
- Road, railway and several footbridges made of ***weathering steel*** in Czechia
  - developing protective layer (“patina”)
- No protective coating, low maintenance costs and 100% recyclability



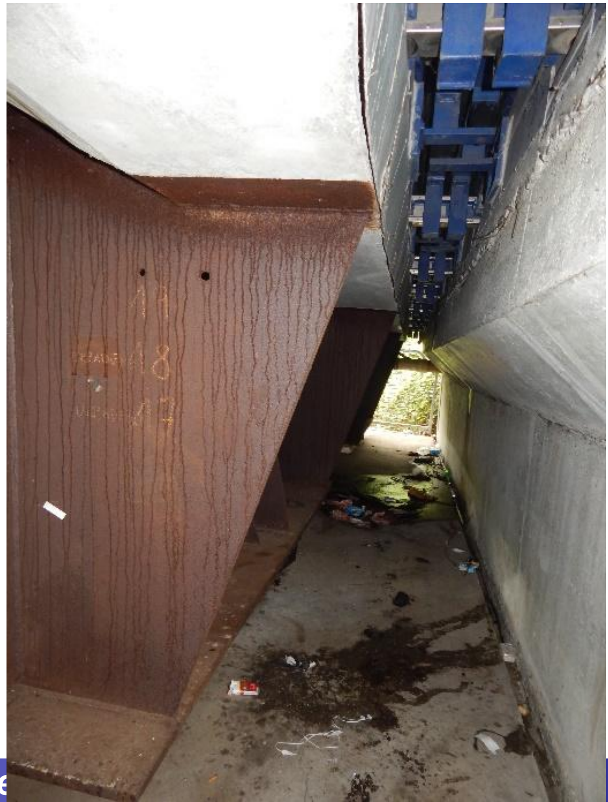
Weathering steel – ***ideal choice***? For all conditions?

Introduction

Measured corrosion losses (15y.):
good design + execution 100 µm
poor 250 µm
leakage **500 µm**



Development of patina in changing ***conditions***?
Wrong ***details***?



- ***Monitoring*** of patina development key for predicting service life

√ statistical analysis of ***measurements*** in literature along with new measurements

→ ***generic probabilistic models*** verified for current conditions

√ ***probabilistic reliability analysis*** of representative cross-sections

→ ***reliability-based allowances*** for a range of situations (uniform corrosion)

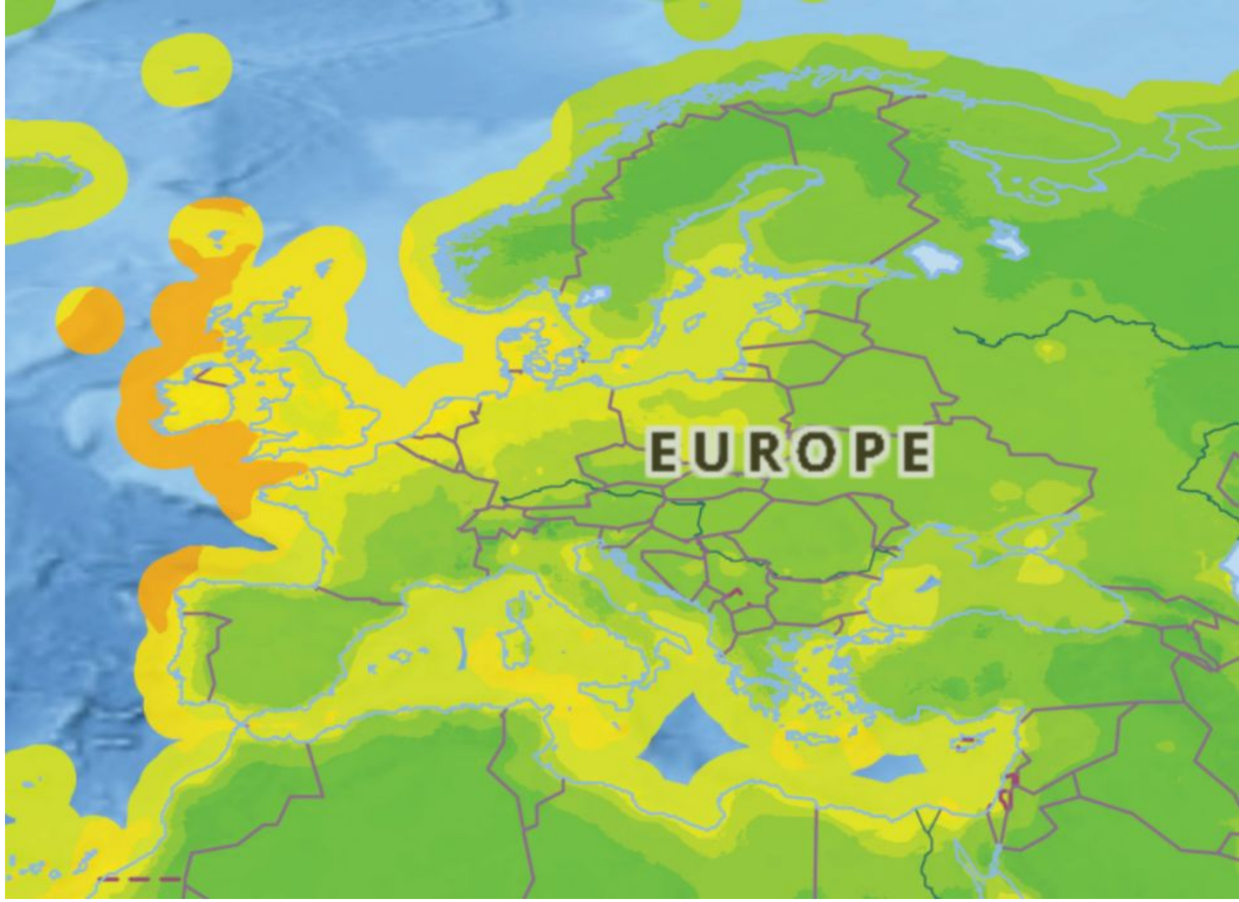
International database

- C2 through C5 corrosivity categories

ISO 9223

Value

- C1 <= 1.3 um/year
- C2 <= 12.5 um/year
- C2.5 <= 25 um/year
- C3 <= 32.5 um/year
- C3.5 <= 50 um/year
- C4 <= 65 um/year
- C4.5 <= 80 um/year
- C5 <= 140 um/year
- C5.5 <= 200 um/year
- CX (everything else)



- C2 for ~80% of Czechia
- C3 for most bridges over roads where de-icing salts are applied
  - C4 exceptionally for unvented locations with increased chloride concentrations

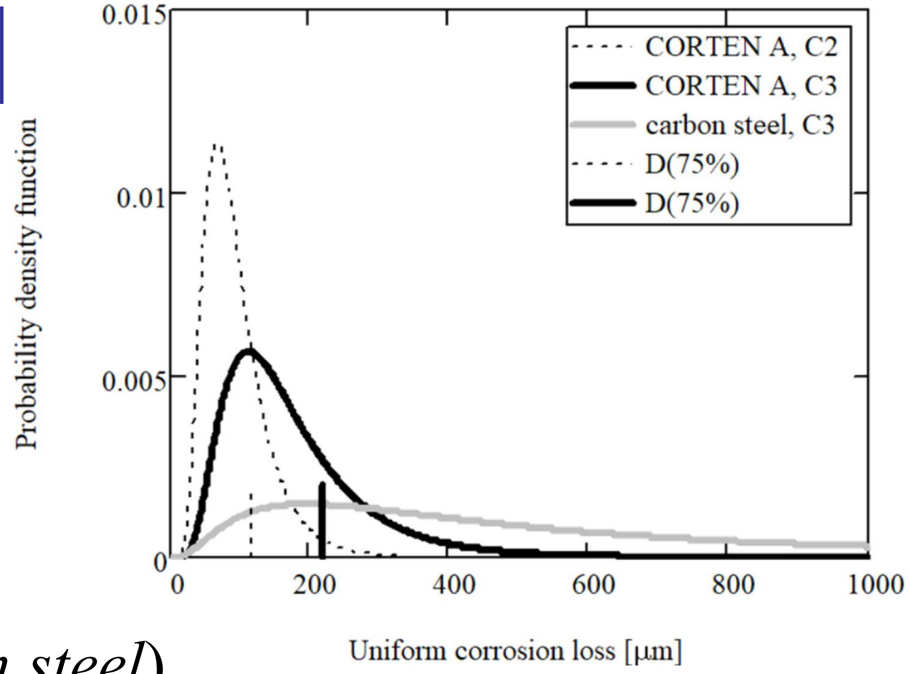
Probabilistic model for uniform corrosion loss

$$D = \theta \, r_{\mathrm{corr}} \, t_{\mathrm{exp}}^{\,b}$$

Model uncertainty $\theta \approx D_{\mathrm{real}} / D_{\mathrm{model}}$

Initial corrosion rate (atmospheric corrosivity)

Exponent (time-dependent behaviour) material and corrosivity



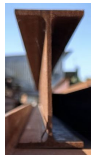
CORTEN A (*carbon steel*)

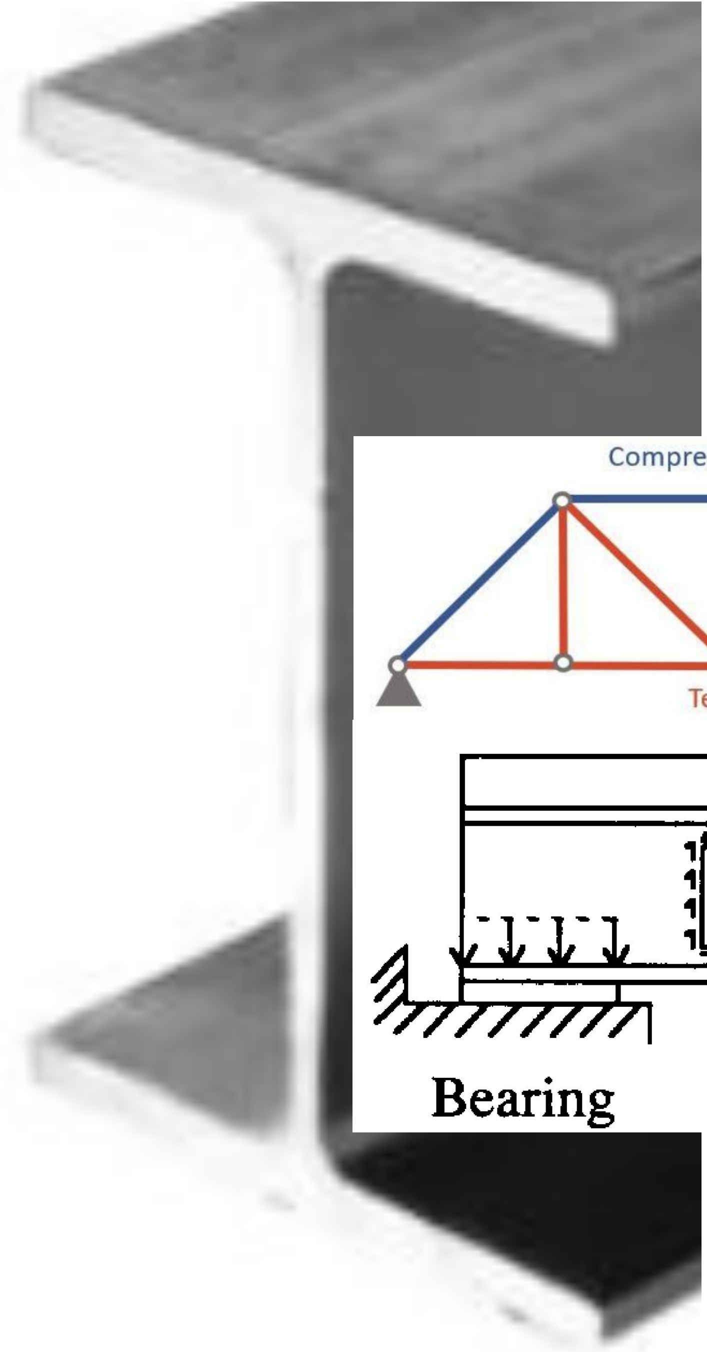
Corrosivity category	Model uncertainty θ		Corrosion rate r_{corr}		Exponent b	
	μ	***V***	***μ* (μm/year)**	***V***	***μ***	***V***
C2	1	10 % (*12.5 %*)	20	27.5 %	0.32 (*0.56*)	25 %
C3	1	10 % (*12.5 %*)	35	15 %	0.32 (*0.56*)	35 %

- **<u>But</u>** adequate design of details (horizontal surfaces, leakages) is needed

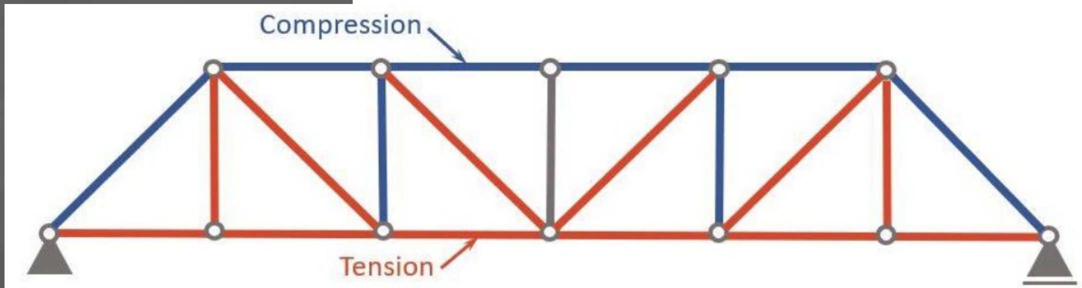
REF Sykora et al. Probabilistic Analysis of Corrosion Rates and Degradation of Weathering Steel Bridges. ***EUROSTRUCT 2023***

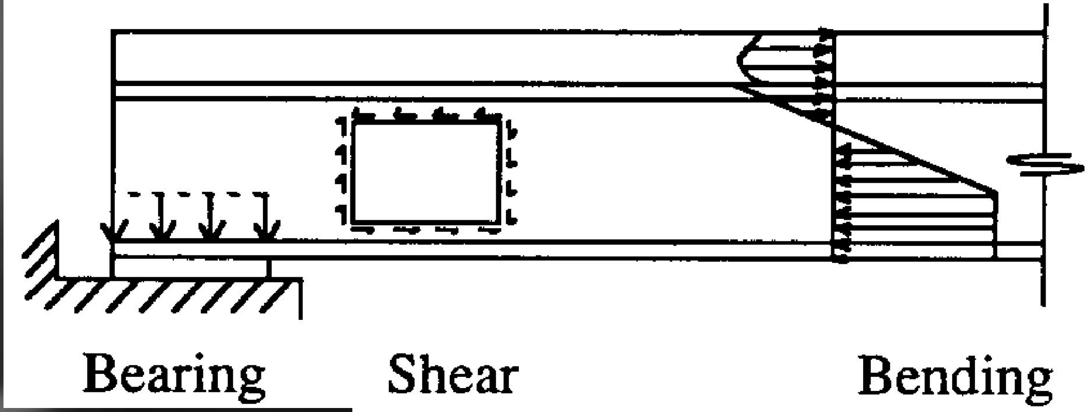
Reliability analysis





- IPE 100
  - secondary load-bearing members, members in truss structures

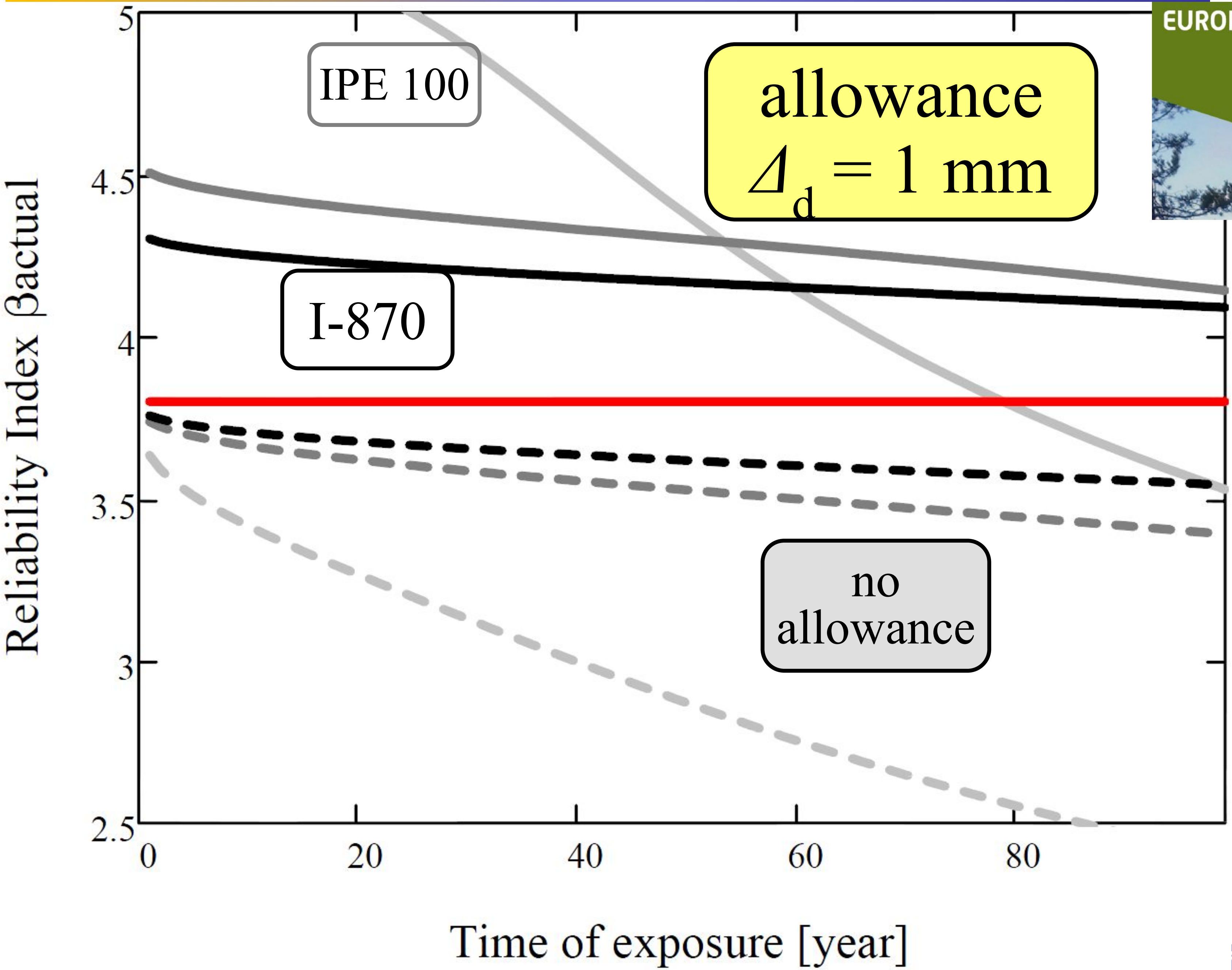




- IPE 500
- welded I-870
  - main bridge girders, secondary members of larger bridges

Reliability analysis of corroding cross-sections

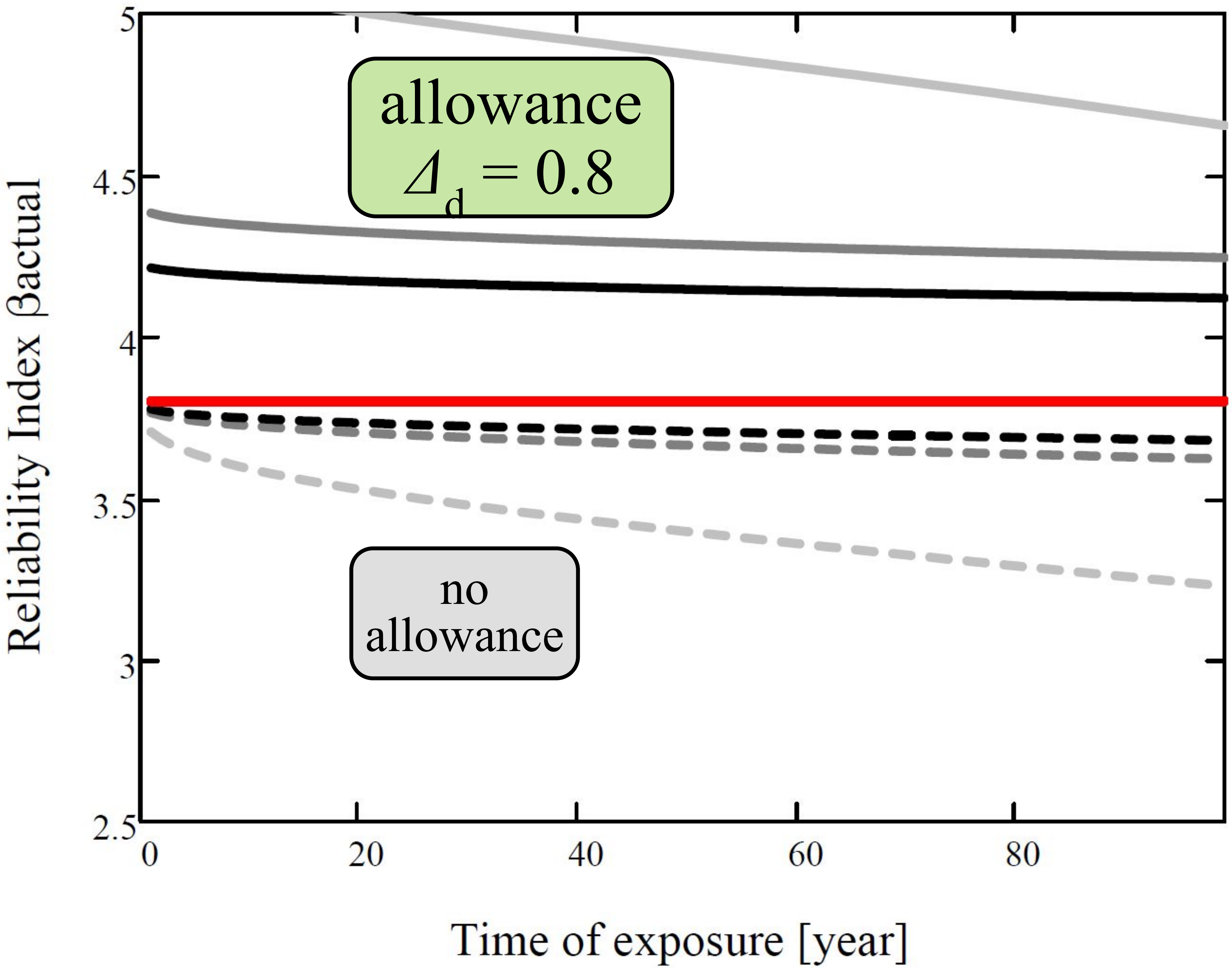
C3



- Substantial design allowance, $\Delta_d > 1$ mm, for small sections
- Small allowance for larger sections
- Small differences between failure modes

Reliability analysis of corroding cross-sections

C2



- Allowance conservative for all sections
- For IPE500 and I870, effect of corrosion on reliability is small → 'no allowance' strategy?
- For IPE100, $\Delta_d << 0.8$ mm is sufficient

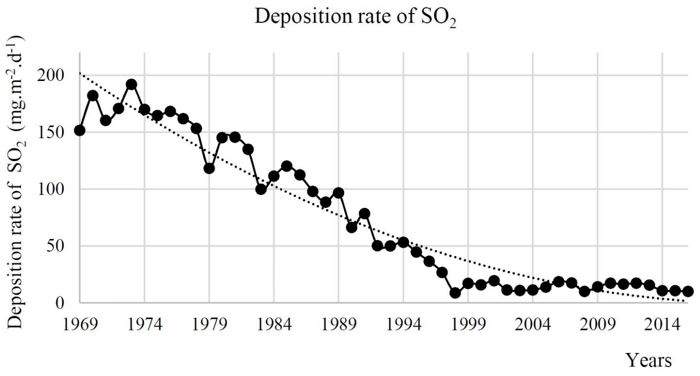
Reliability-based allowances (in mm)

Corr. Cat.	C2			C3		
Reference period	100y		50y	100y		50y
Target reliability β	4.3	3.8		4.3	3.8	
IPE100	0.35	0.3	0.2	1.85	1.35	0.6
IPE500	0.2	0.2	0.15	0.65	0.55	0.35
I870	0.2	0.2	0.15	0.55	0.50	0.3

- averaged over three failure modes
- grey values – unlikely to have small key beams in CC3

Discussion

- For C3+ categories scattered measurements in database
  → ***new measurements*** suggest large potential for improvements
- Corrosion rates depend on orientation of surface - ***within-section variability*** contribute to observed scatter
  - doubled corrosion losses observed for upper surfaces of lower flanges of I-sections
  - unfavourable E- and N-orientation
  - if separated, significant reduction in overall variability may be reached
- For existing bridges, ***changes in exposure*** since their execution to be considered
  - in general corrosivity reducing in Europe since 1990s
  - new US guidelines do not consider industrial pollution in design



Conclusions

- In C3 ***design allowance*** could be about 0.5-0.6 mm.
  - For C2 exposure, a “no allowance” strategy might be considered.
  - Allowances in ECCS guideline seem to be generally conservative.
- Exposure conditions need to be critically considered in ***design*** and carefully controlled during ***operation*** to utilize potential of material.
- ***Poorly developing patina***:
  - identification visually in early phases?
  - non-destructive tests (Electrochemical Impedance Spectroscopy)?
- For ***sustainability in construction***, important is to support decisions regarding use of weathering or carbon steels :
  - for various types of bridges in different environments
  - considering economic, societal, and ecological aspects including predicted climate changes

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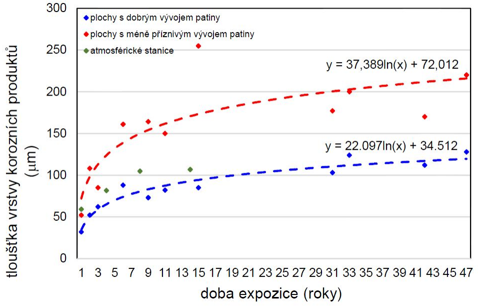

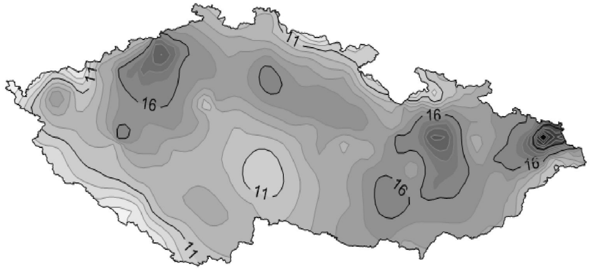

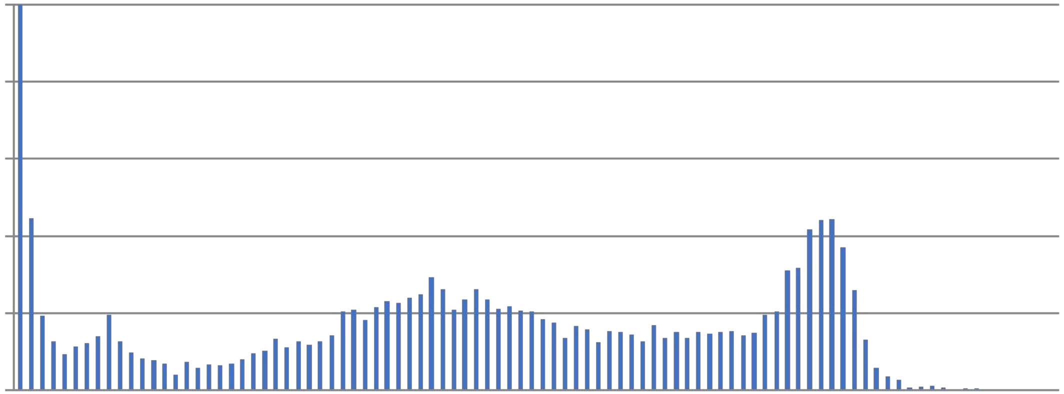

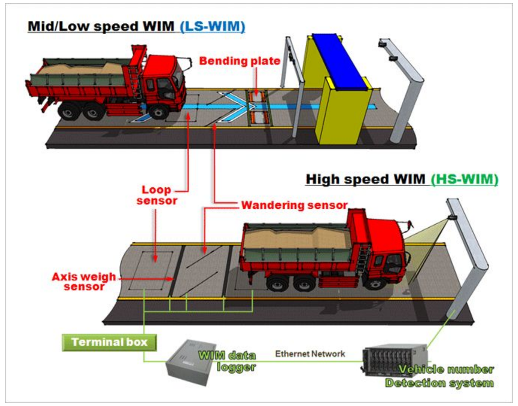

Thank you for your attention.

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