ENGINEERS IRELAND
cpd

Practical Steps To Extend the Lives of Bridges

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Probabilistic Fatigue Model using Fracture Mechanics

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Outline of Presentation

- Introduction
- Fatigue design
- Fatigue stresses
- Reliability Level
- Reliability Estimation & Inspection Planning
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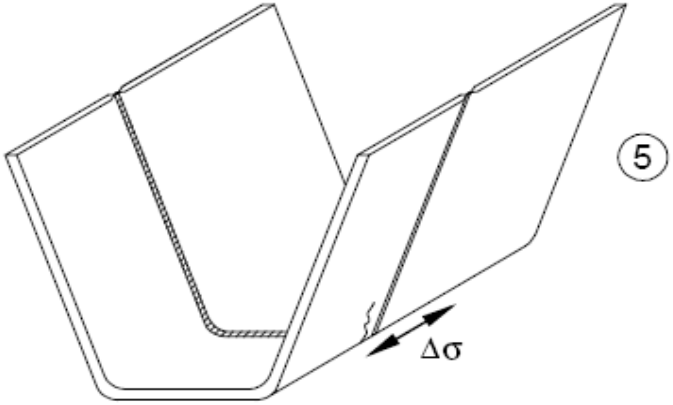
Introduction

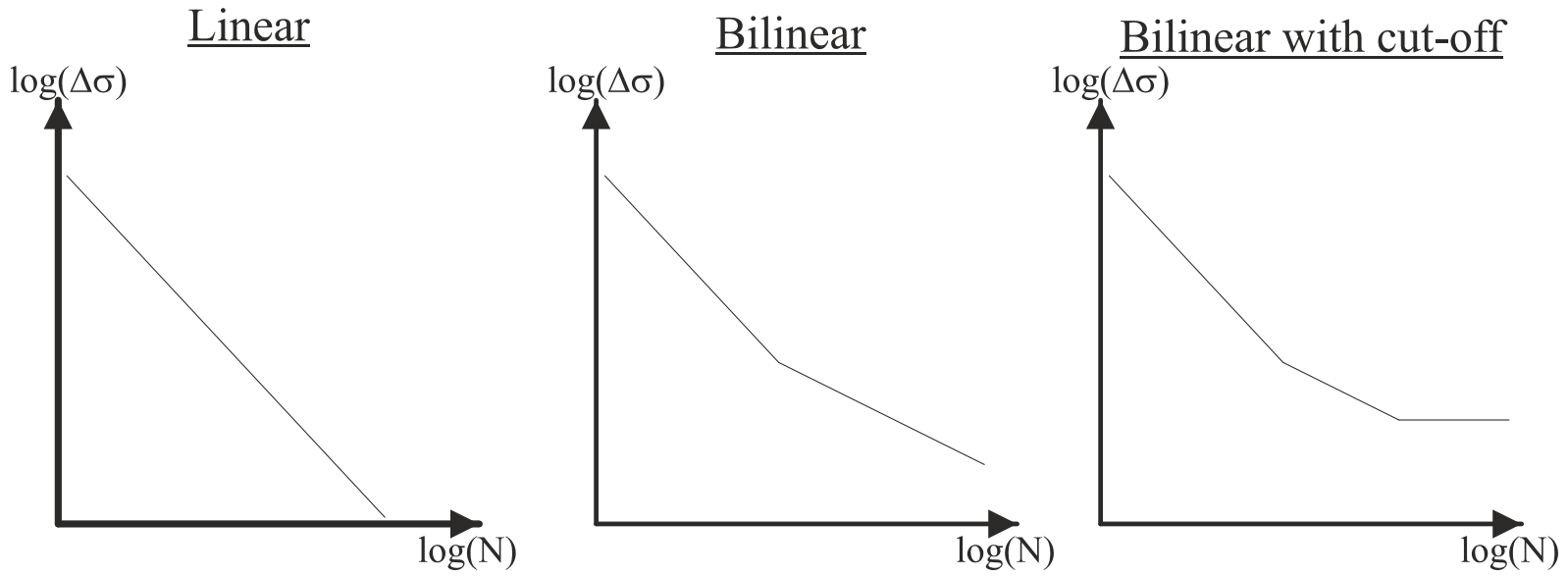


Eurocode 3: Design of steel structures. Part 1-9: Fatigue

Fatigue Design

Deterministic Fatigue Design:

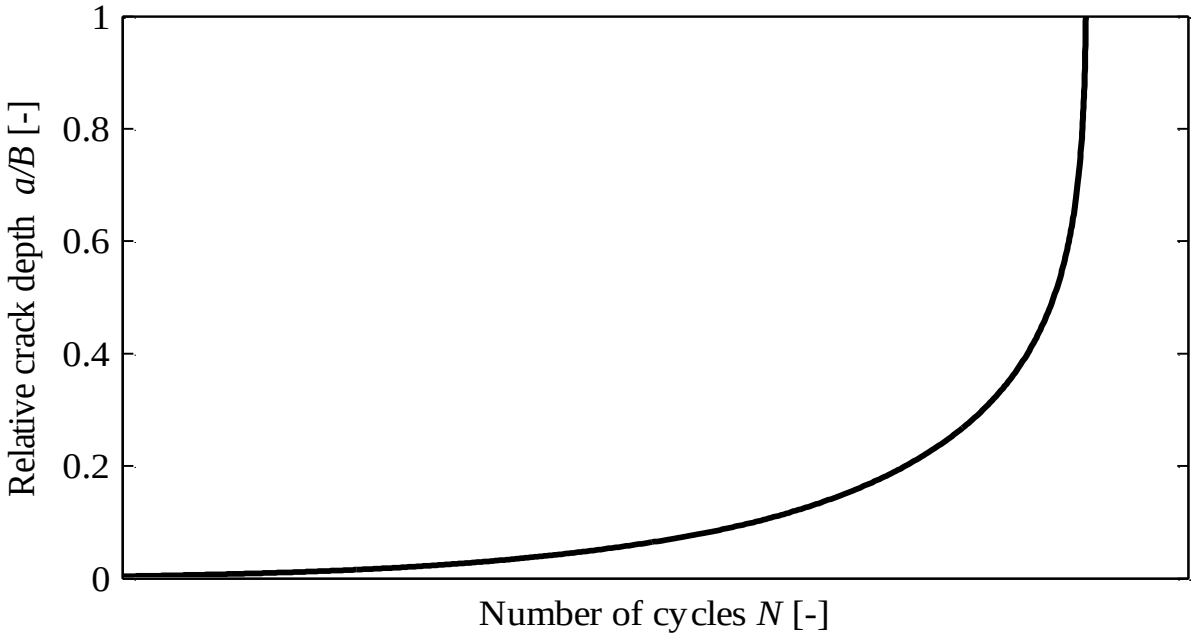
- Rainflow-counting of stress time-series
- SN-curves (linear, bilinear, etc.)
- Miner's rule (linear damage accumulation)



Fatigue Design

Probabilistic Fracture Mechanics:

- Crack size (inspection planning)
- Reliability level (calibration of partial safety factors)



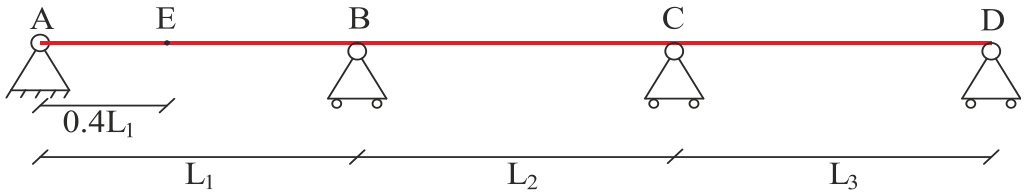
Fatigue Stresses

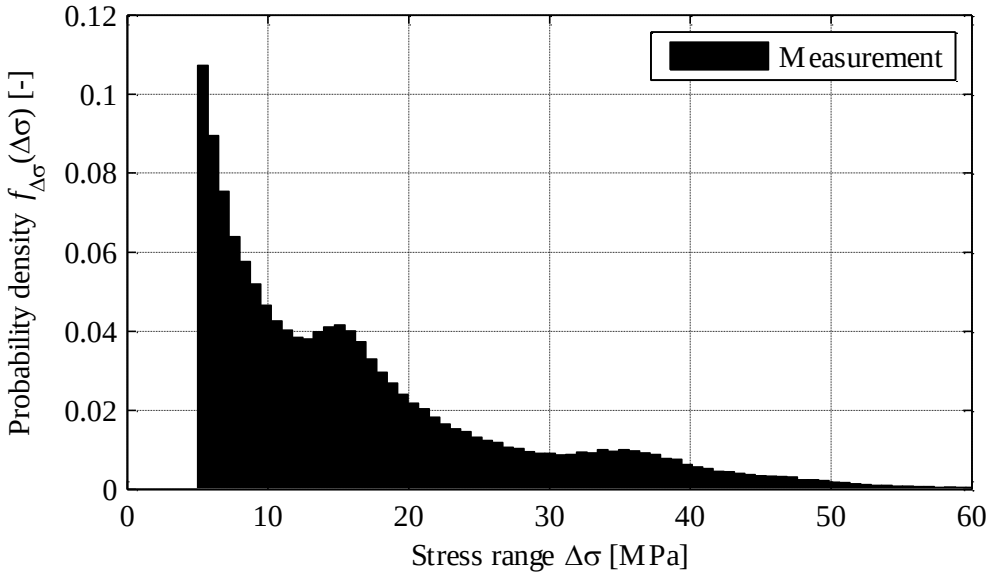
Fatigue stresses due to traffic loading are estimated from 10 weeks of traffic measurements (weigh-in-motion).

Axles	Measurement Woerden	Traffic Types Eurocode		
		Long distance	Medium distance	Local traffic
2 Axles	20.6%	20%	40%	80%
3 Axles	9.3%	5%	10%	5%
4 Axles	24.4%	15%	15%	5%
5 Axles	38.6%	60%	35%	10%
6 Axles	6.1%	0%	0%	0%
Sum	99.1%	100%	100%	100%

Fatigue Stresses

The stress ranges are estimated using the influence function for a generic bridge which is 100m long (1 lane, 1 direction).





Reliability Level

The optimal annual probability of failure is estimated for a typical welded bridge detail using two different approaches:

- Life Quality Index
- Cost Benefit Analysis

The life quality index is defined as the societies requirements to a minimum reliability level.

The cost benefit analysis is based on a balance between the initial construction costs and the failure cost.

Reliability Level

Optimal annual and accumulated probability of failure:

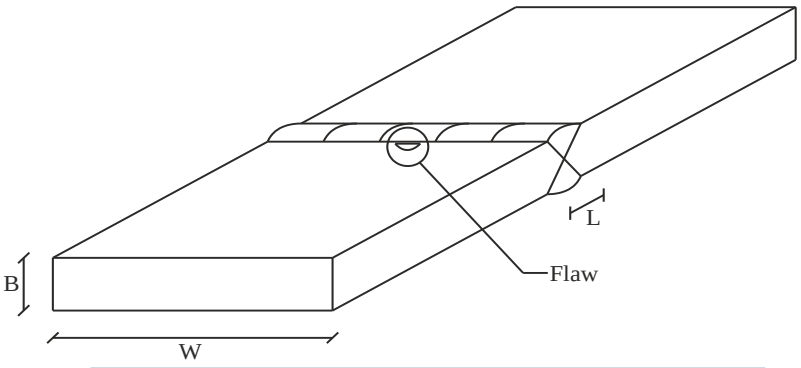
LQI Year 100	Society Cost-benefit	Owner Cost-benefit
$\Delta P_F=3\cdot10^{-4}$ $P_F=1\cdot10^{-2}$	$\Delta P_F=1\cdot10^{-5}$ $P_F=4\cdot10^{-4}$	$\Delta P_F=4\cdot10^{-5}$ $P_F=2\cdot10^{-3}$

- Joint Committee on Structural Safety: $\Delta P_F= 6\cdot10^{-6}$ -$1\cdot10^{-5}$
- ISO 2394: $\Delta P_F= 1\cdot10^{-6}$ -$2\cdot10^{-5}$

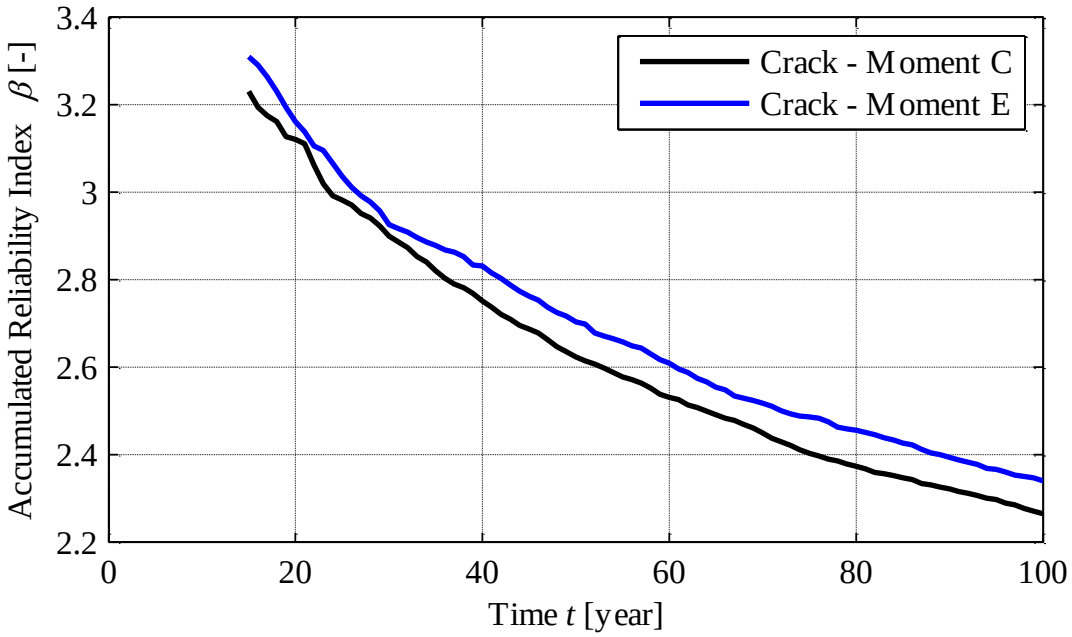
Medium to large consequences of failure and moderate cost of safety measures for a design lifetime of 100 years.

Reliability Estimation & Inspection Planning

The accumulated reliability index for a butt-weld in a steel plate.



W=250mm, B=25mm, L=25mm



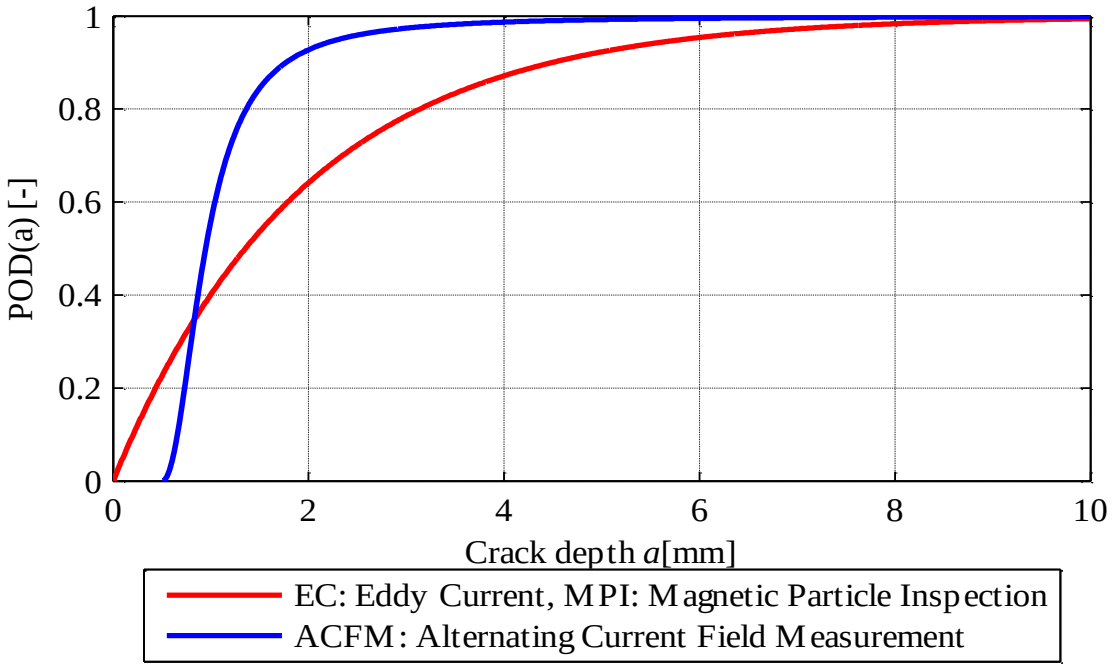
The reliability index is linked to the probability of failure by: $\beta = -\Phi^{-1}(P_F)$

where Φ is the standard normal distribution.

Reliability Estimation & Inspection Planning

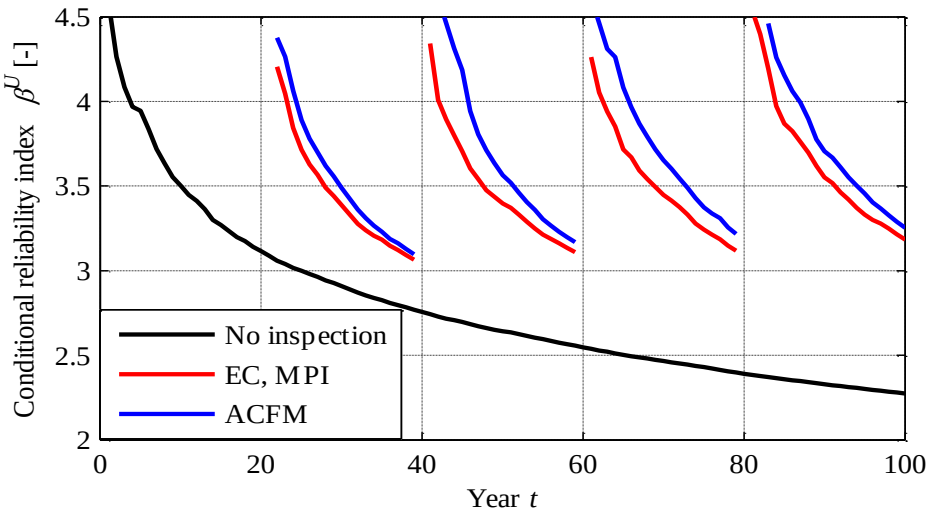
Inspections can be used to update the reliability level during the design lifetime.

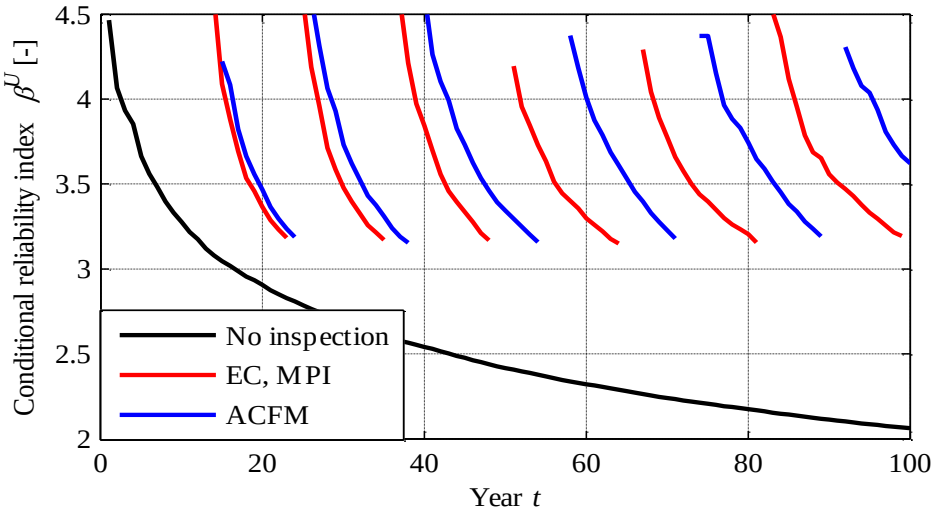
What is the probability for detecting a crack with a given depth in mm. ?



Inspection Planning & Reliability Estimation

The inspections can be planned with equidistant time intervals or in order to obtain a minimum reliability level:





It is assumed that detected crack are perfectly repaired.

Conclusion

- A probabilistic approach to reliability estimation of welded steel details is proposed.
- The distribution of fatigue stress ranges due to traffic loading is multi-modal.
- The optimal reliability level is estimated taking into account the risk of human lives using the life quality index (LQI).
- The influence of planned equidistant inspections and reliability-based inspections on the probability of failure are investigated.

Thank You

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Project Website

www.longlifebridges.com

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