DESTination RAIL – WP 2: Assessment and Modelling

Final Conference
26th April 2018

Lorcan Connolly, ROD-IS

Introduction: WP2 Milestones

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Milestone 2.2: Instrumentation of Boyne Viaduct (**M15**)

Milestone 2.3: Reliability based assessment framework for earthworks (**M12**)

Milestone 2.4: Selection of case study for train track modelling (**M6**)

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Deliverable 2.1: Probabilistic Basis for Multi Criteria Performance Optimisation of Railway infrastructure

DESTination RAIL – Decision Support Tool for Rail Infrastructure Managers
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Guideline for Probability Based Multi Criteria Performance Optimisation of Railway Infrastructure

Authors
* Lorcan Connolly (ROD-IS), Alan O' Connor (ROD-IS), Cormac Reale (GDG)

*Corresponding author: Lorcan Connolly, lorcan.connolly@rod.ie

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- Probabilistic Deterioration
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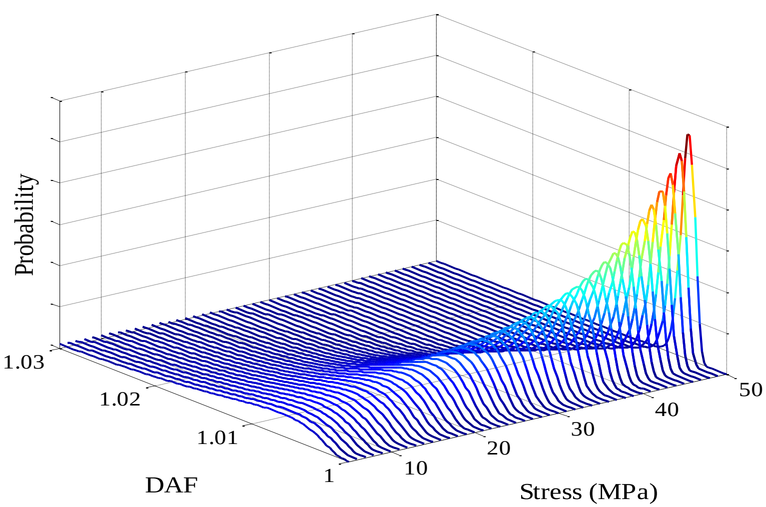
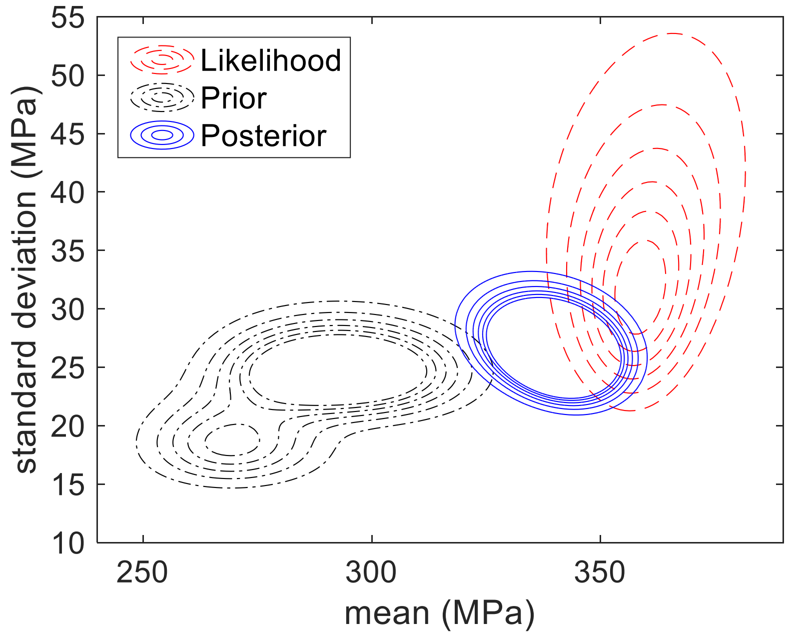




Deliverable 2.2: Assessment of Bridges

- Probabilistic Assessment
- Model Calibration
- Dynamic Allowance
- Fatigue Analysis
- Deterioration
- System Analysis
- Application of Empirical Mode Decomposition & discrete fast Fourier spectral analysis for damage detection
- Soil-Structure Interaction with cyclic loading

Deliverable 2.3: Assessment of Earthworks

- Apply Reliability Theory and Probabilistic approaches to slope stability for railways.
- Account for different failure mechanisms and climatic effects
- Use monitoring data from WP1 to develop appropriate statistical distributions and employ said distributions in analyses.
- Develop fragility curves to describe vulnerability of earthworks to rainfall events

Deliverable 2.4: Assessment of Tracks

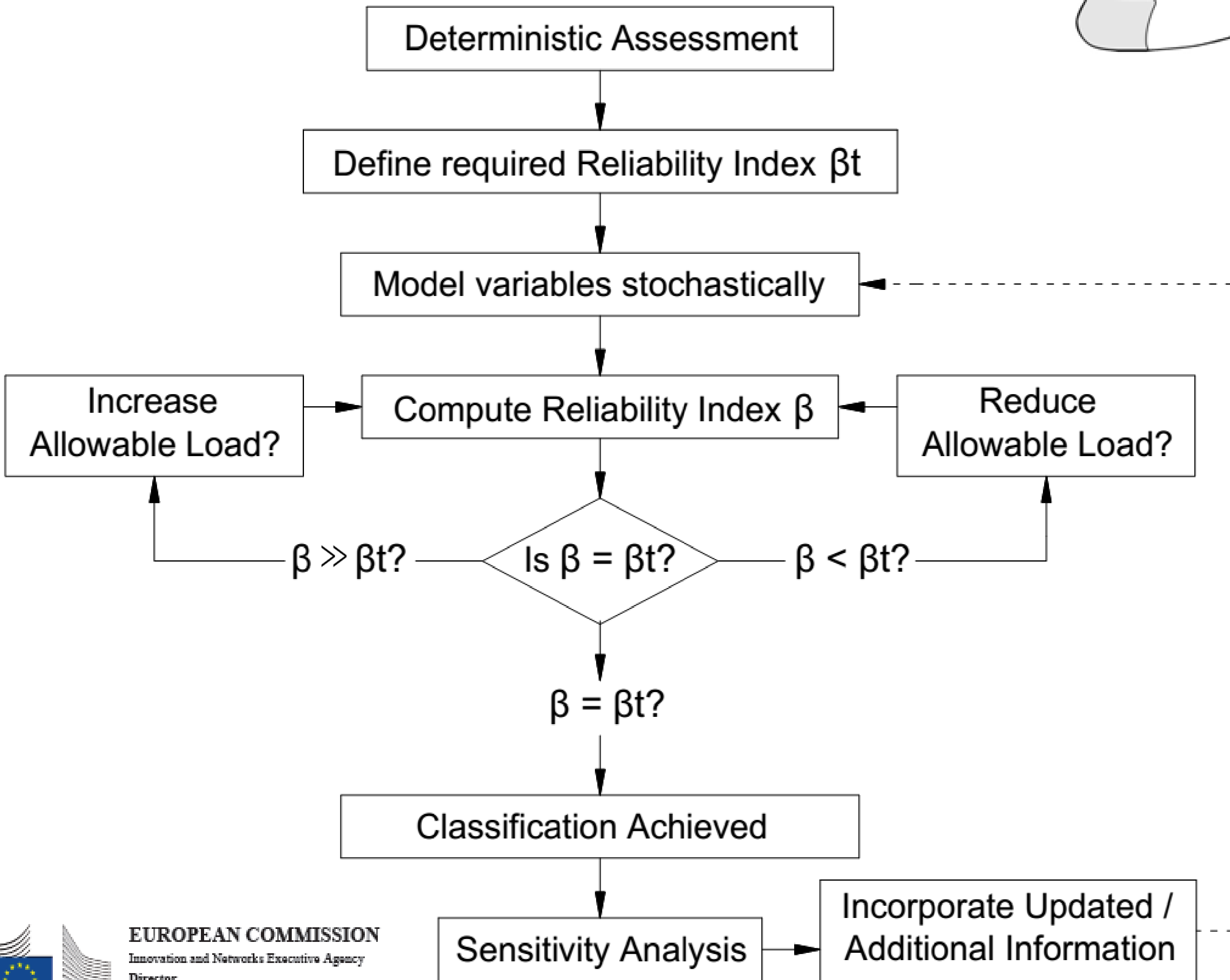
- Investigation of the difference between loaded and unloaded longitudinal level and relation to track supporting layer stiffness variation, (GPR measurement).
- Numerical method to identify track stiffness variation in long section based on the measurement result from strain gauge and other measurement methods.
- Synchronization of the measurement result from track recording car to rail seat.

DESTination RAIL
Reliability Assessment Models for Structures

26th April 2018

Lorcan Connolly, ROD-IS

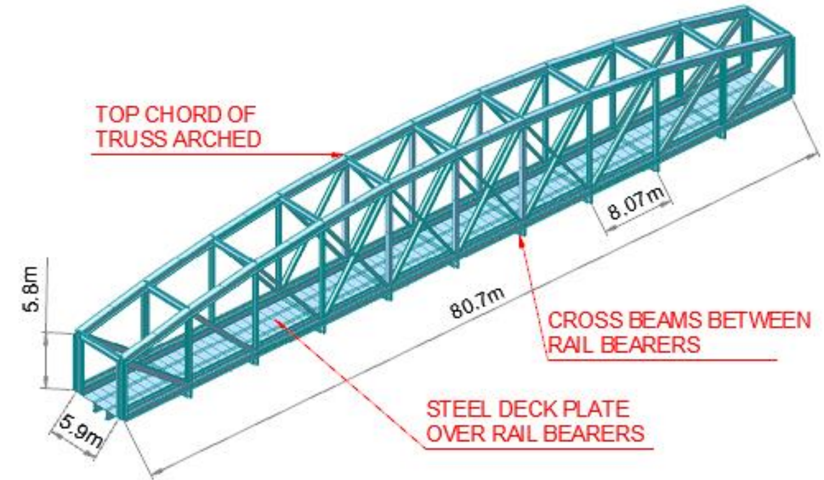
Reliability Analysis

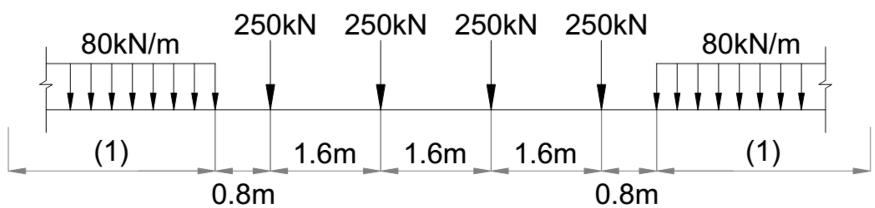


Boyne Viaduct Instrumentation – Deterministic Assessment

- Assessment to BD21/01
- Type RU live loading
- No assessment of joints
- No assessment of deck plate

Member	Effect	Usage
Cross beam	Y	21%
Rail bearer	Y	-6%
Rail bearer	S	18%
Bottom chord	Y	56%
Top chord	CB	19%
Truss diagonal	Y	3%
Truss Vertical	CB	13%



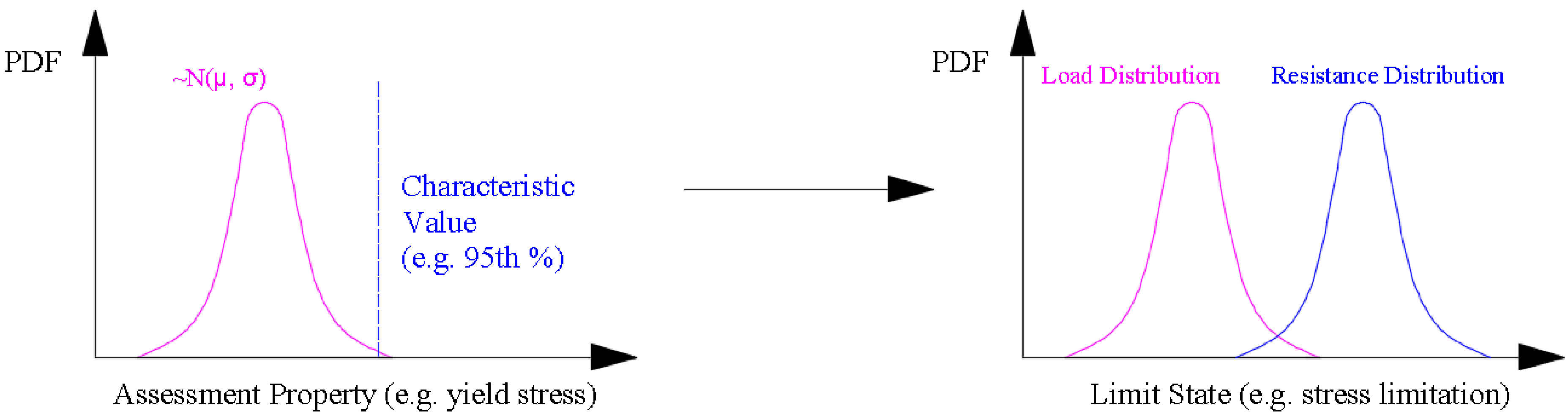


Key
(1): No Limitation

Reliability Assessment

- Consider inputs to assessment as random variables
- Perform assessment 1E6 times, randomly selecting from distributions to calculate final load/resistance distribution

Deterministic Assessment | **Probabilistic Assessment**

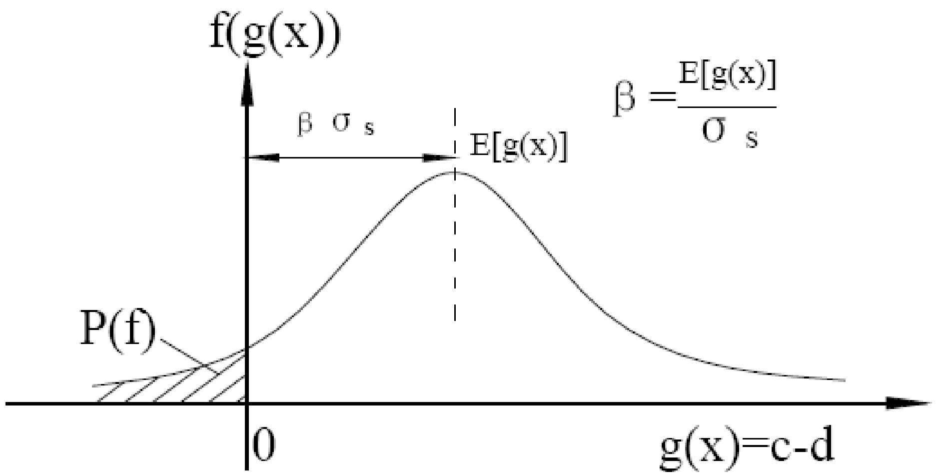


Reliability index

Consider alternative form of performance function g(x):

$$FOS = \frac{Capacity(C)}{Demand(D)}$$

$$g(x) = C - D$$

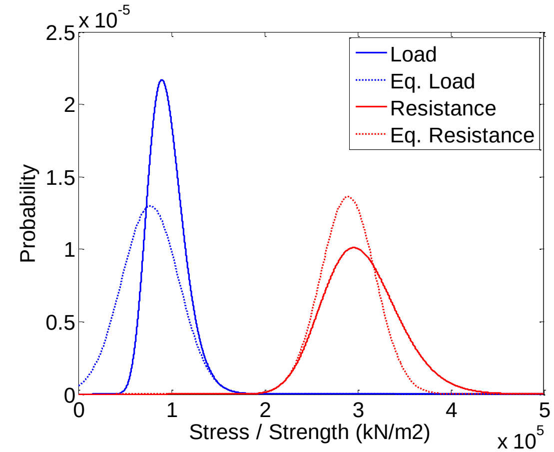


$$If \quad C - D \leq 0 \Rightarrow \text{ limit state failure}$$

The β-index represents the mean of the performance function, divided by the number of standard deviations between the mean and origin.

Boyne Viaduct Instrumentation – Reliability Assessment

- Stochastic distributions (DRD guidelines)
- Simulation & FORM analysis in MATLAB
- β-value of 4.3 calculated for yielding critical rail bearer



Variable	Distribution	μ	CoV
Yield Strength	LogN	297 MPa	0.11
MU. Yield Strength	LogN	1.0	0.10
Dead Load Stress	Norm	17.1 MPa	0.05
MU. Dead Load Stress	Norm	1.0	0.05
SDL Stress	Norm	13 MPa	0.10
MU. SDL stress	Norm	1.0	0.05
Fraction of RU loading	Gumb	0.66	0.20
MU. Live Load	Norm	1.0	0.15
ε Increment	Norm	0.14	1.00

Conservatism

- Live Load
- Uncertainty
- Yield strength
- Dynamics

Boyne Viaduct Instrumentation – Reliability Assessment

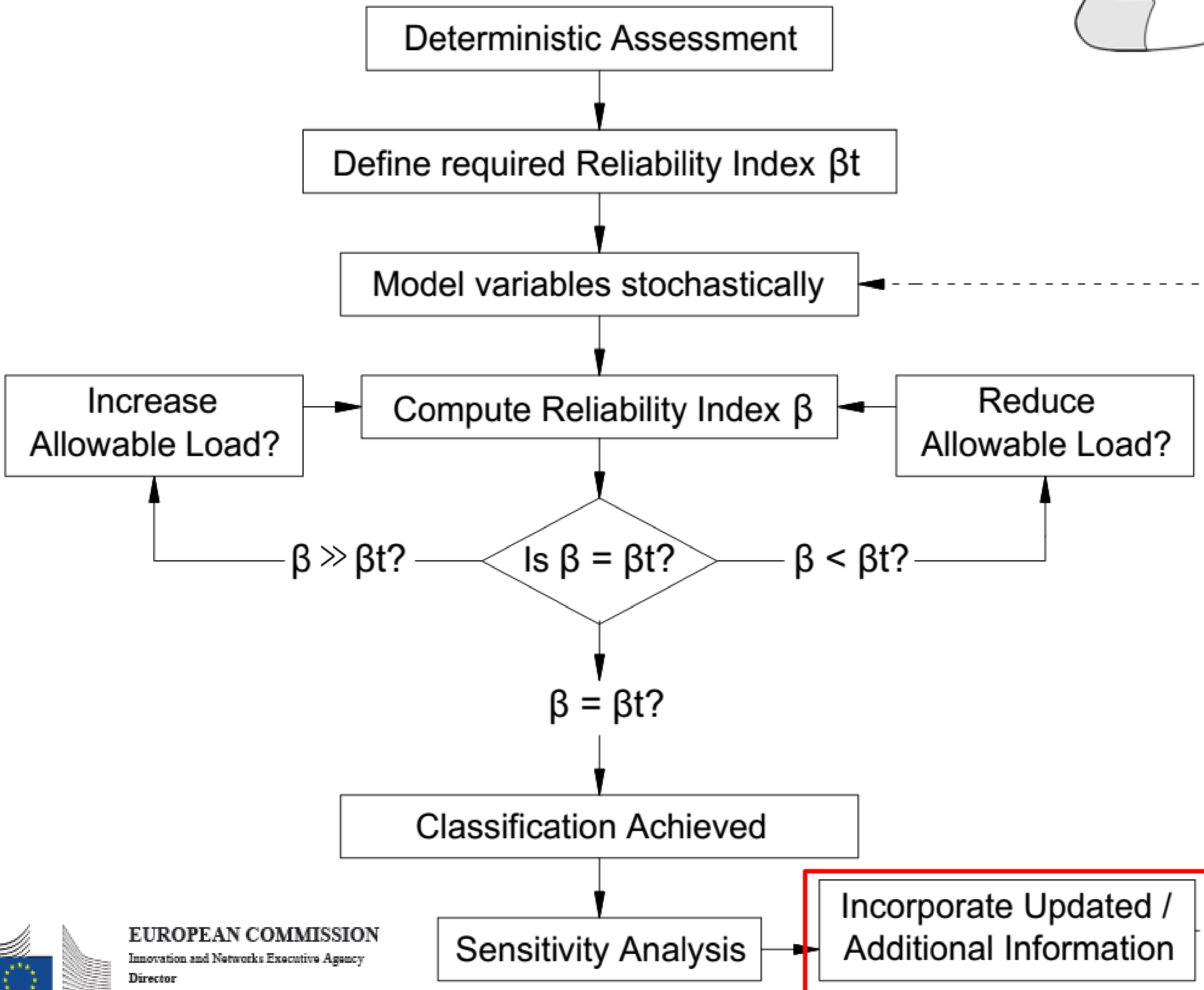
ISO 2394: 2015 - General principles on reliability for structures

Consequences of failure			
Very low	Low	Medium	High
2.3	3.1	3.8	4.3

JCSS, (2001), Probabilistic Assessment of Existing Structures

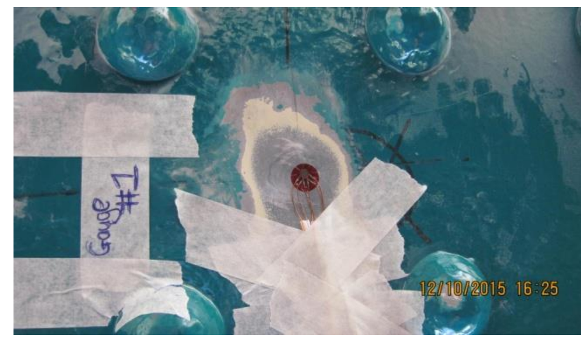
Cost of safety measures	Consequences of failure		
	Minor	Moderate	Large
Large	3.1	3.3	3.7
Normal	3.7	4.2	4.4
Small	4.2	4.4	4.7

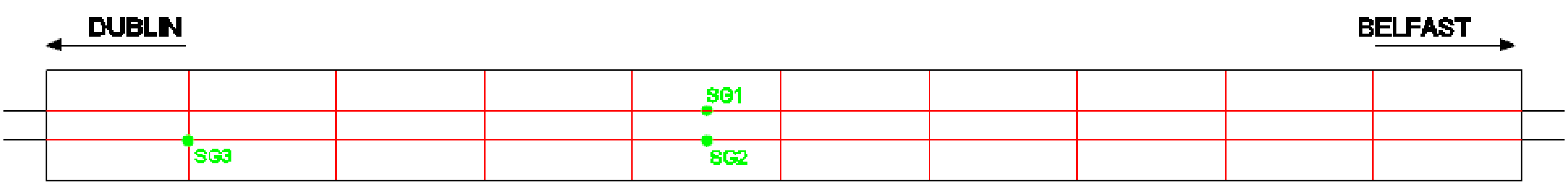
Task 2.1: Reliability Analysis



Boyne Viaduct Instrumentation – Strain Measurement

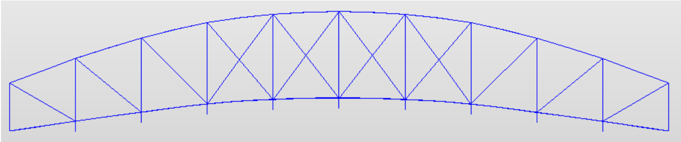
- Critical section of rail bearers (centre span) instrumented with rosettes.
- Corrosion on one side → instrument both sides
- Critical cross beam instrumented for model calibration & fatigue analysis
- Rosettes → principal stress calc

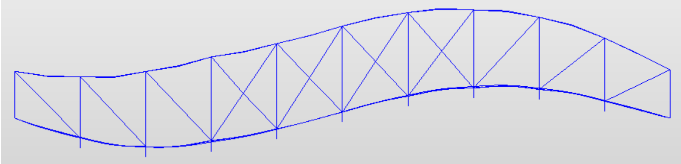


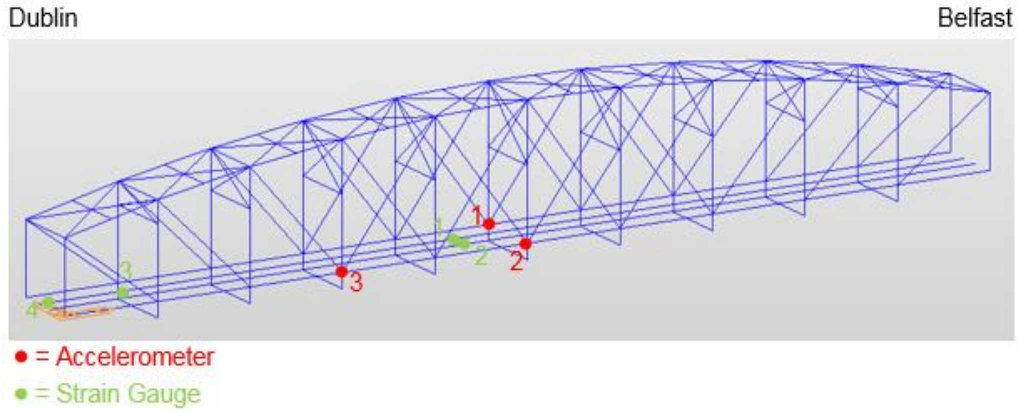


Boyne Viaduct Instrumentation – Acceleration Measurement

- Identification of mode shapes and frequencies from FE model
- Mobile measurement used to specify sensors.
- Triaxial accelerometers used.







Boyne Viaduct Instrumentation - Data Summary

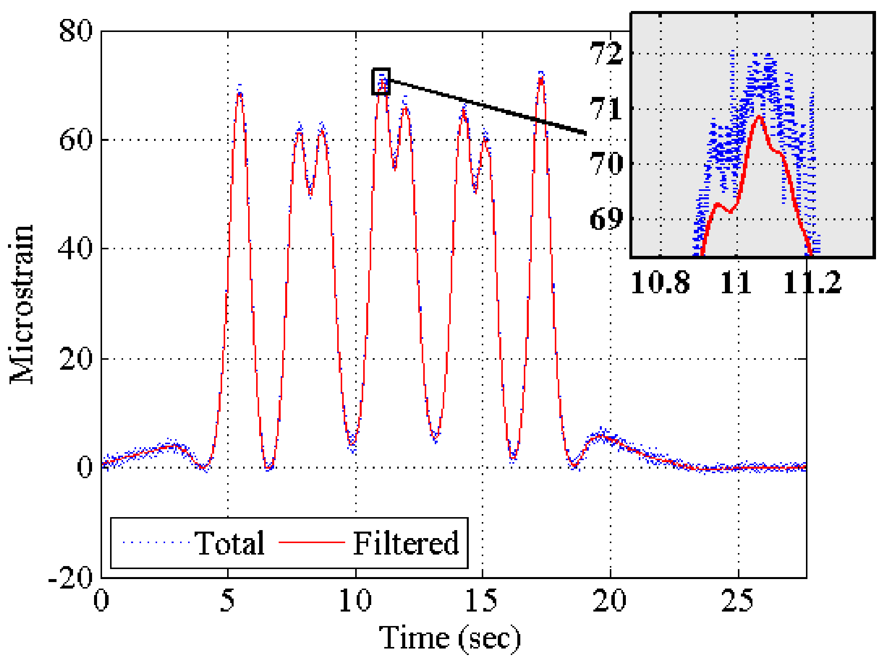
- Final sensor installed on 10/11/2015.
- Data from 22/10/2015 – 18/01/2016.
- 35 days of data measurement
- 843 events with 726 train events
- 30 full days (≥ 8 events) with up to 37 trains per day.
- Data provided in .csv and .mat format
- Current monitoring

Fields	chnum	chname	samples	samplerate	basetime	xtitle	xunits	ytitle	yunits	data
1	16	'BH1@Vbatt...	54532	1000	59.2060	'Time'	'secs'	'BH1@Vbatt...	'Volts'	1x54532 single
2	17	'BH1@R3_0...	54532	1000	59.2060	'Time'	'secs'	'BH1@R3_0...	'uE'	1x54532 single
3	18	'BH1@R3_0...	54532	1000	59.2060	'Time'	'secs'	'BH1@R3_0...	'uE'	1x54532 single
4	19	'BH1@R3_0...	54532	1000	59.2060	'Time'	'secs'	'BH1@R3_0...	'uE'	1x54532 single

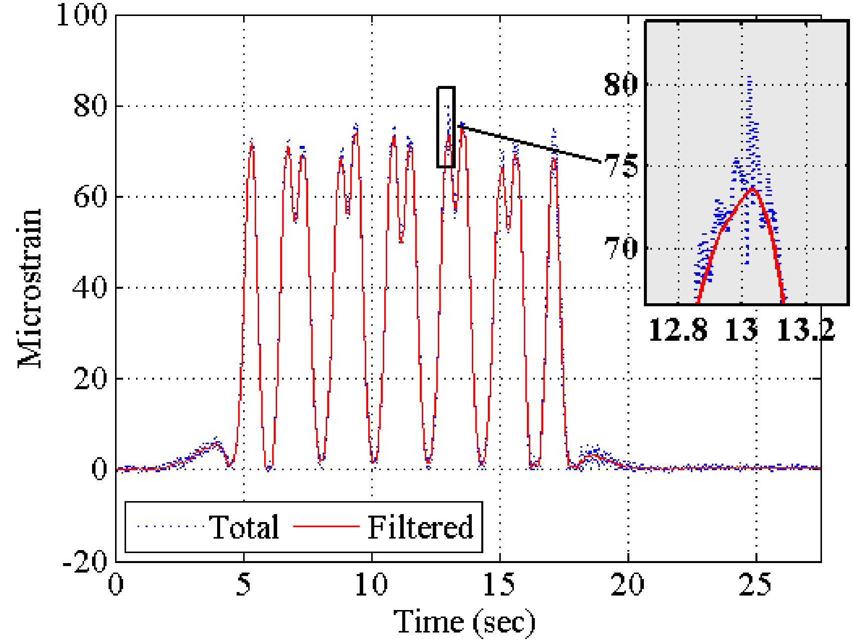
Data usage - Dynamic Analysis

Removal of dynamics – low-pass filtering

<u>DAF = 1.02</u>



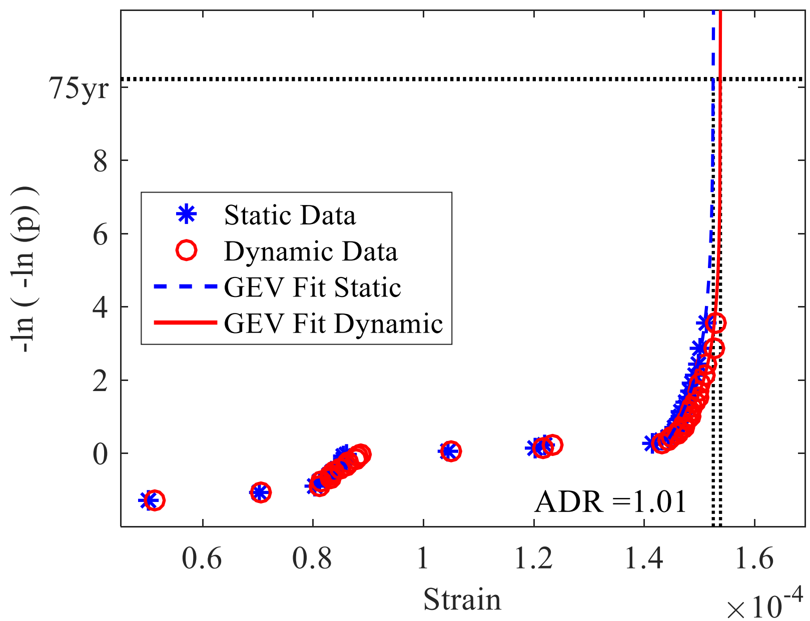
<u>DAF = 1.07</u>



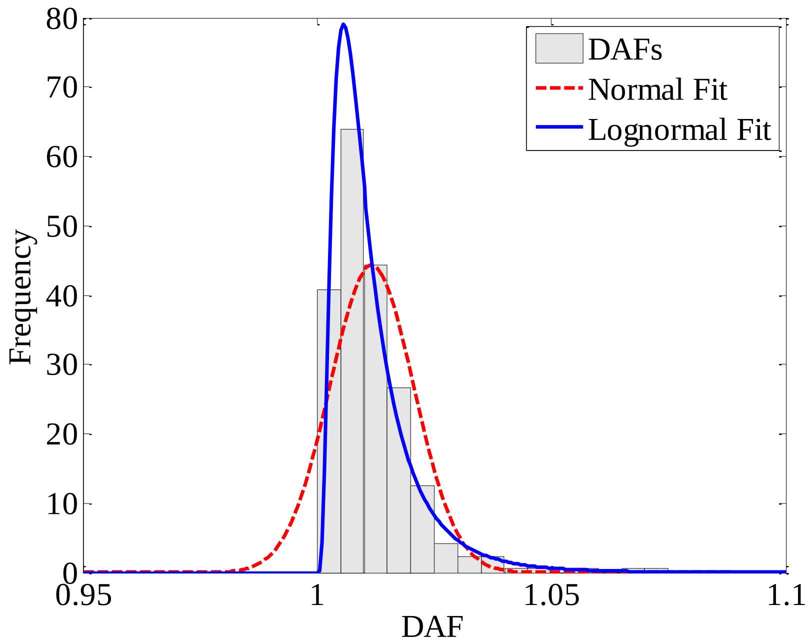
Data usage - Dynamic Analysis

Calculation of ADR & ε - distribution

ADR = 1.01



ε – lognormal (0.12, 0.03)

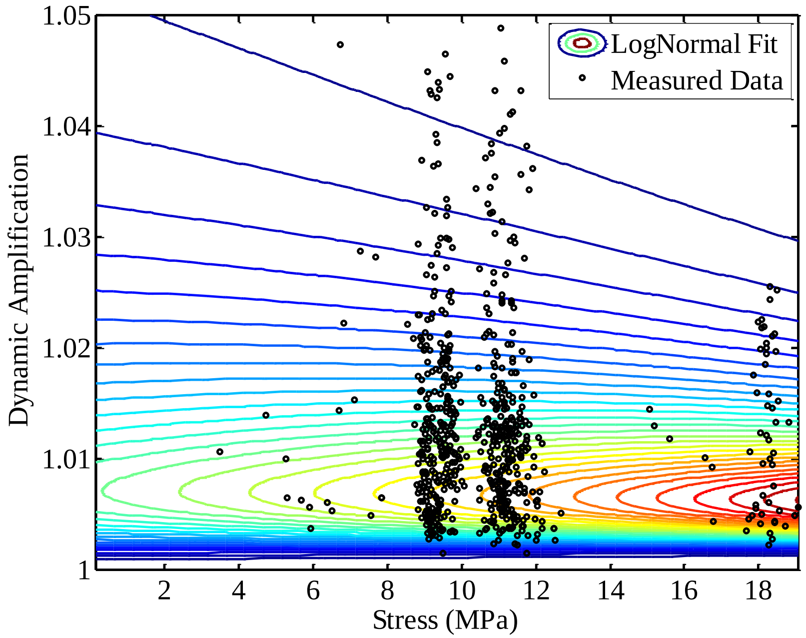


ε – distribution not indicative of load!

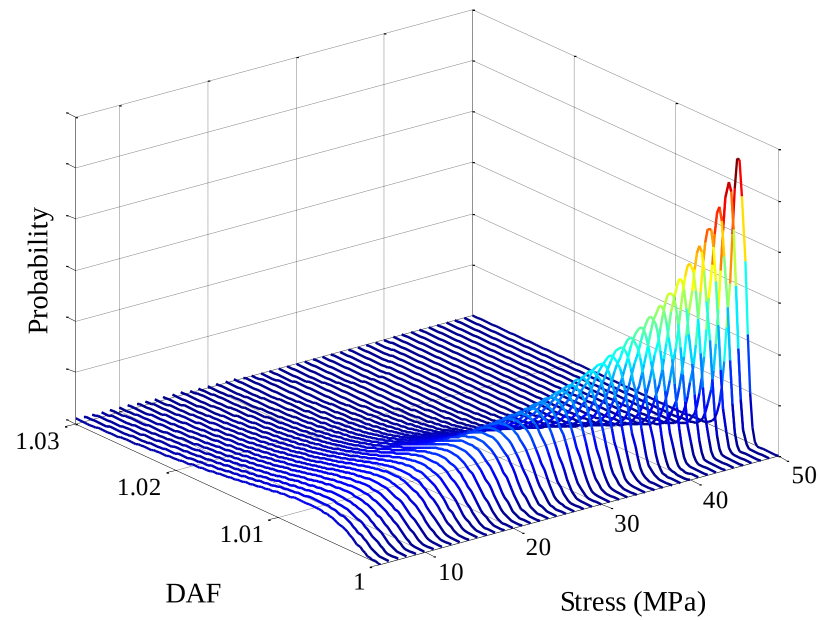
Data usage - Dynamic Analysis

Stress Varying ε - distribution

<u>ADR = 1.01</u>



<u>ε – lognormal (0.12, 0.03)</u>



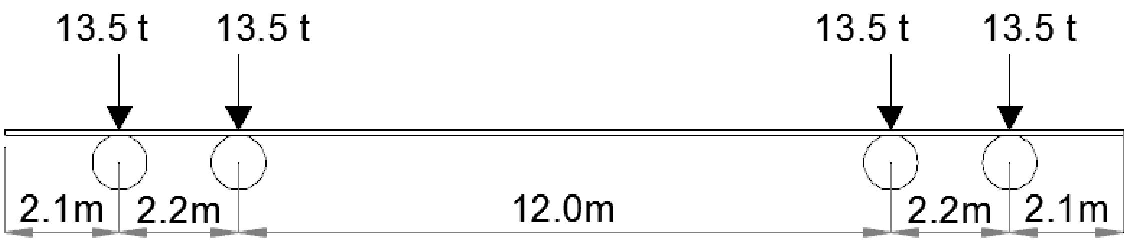
Data usage - Dynamic Analysis

Results – effect on assessment of rail bearer

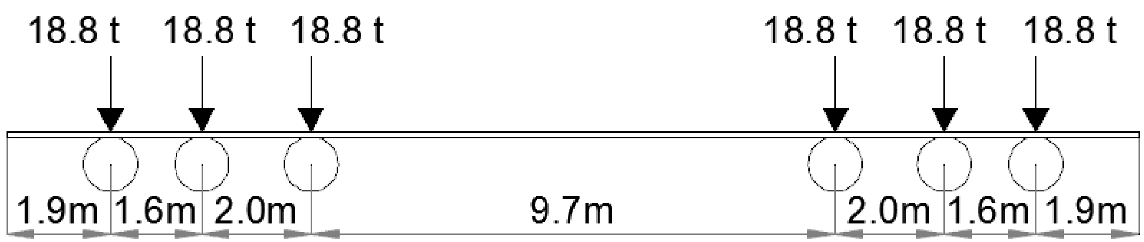
	Deterministic Assessment Utilisation	Probabilistic Assessment reliability index (β)
Original	-6%	4.3
Use of ADR	20%	-
Use of standard logn distribution fit to ε	-	4.7
Use of stress-varying lognormal fit to ε	-	5.1

Data usage – Model Calibration

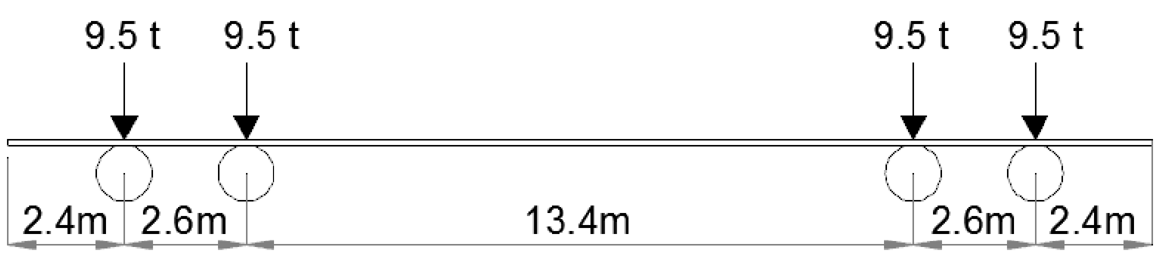
Calibration for two locations and two trains



DMU



Enterprise Loco 201

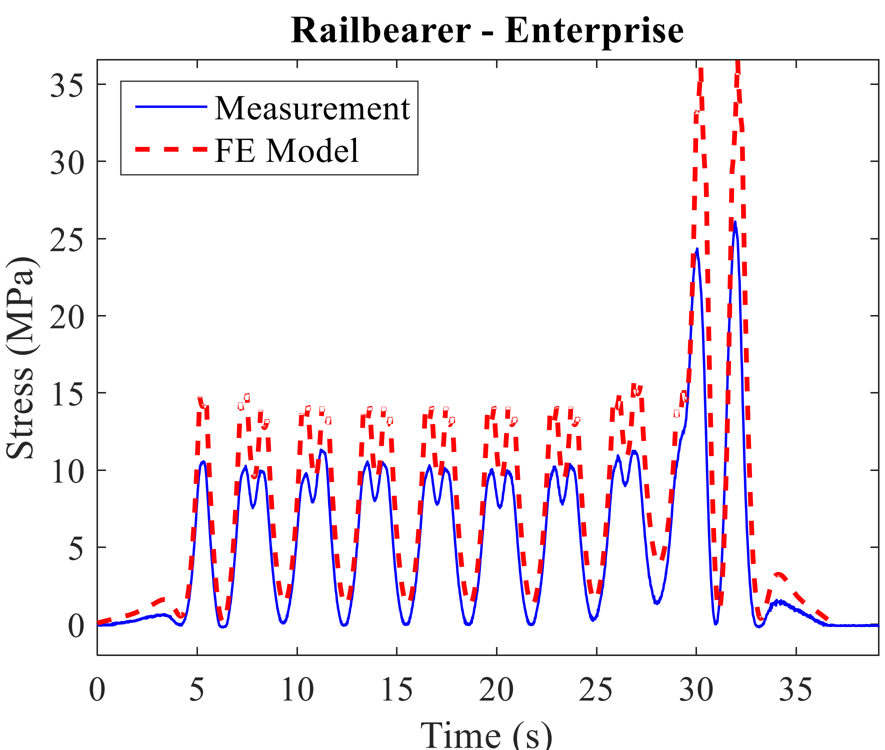


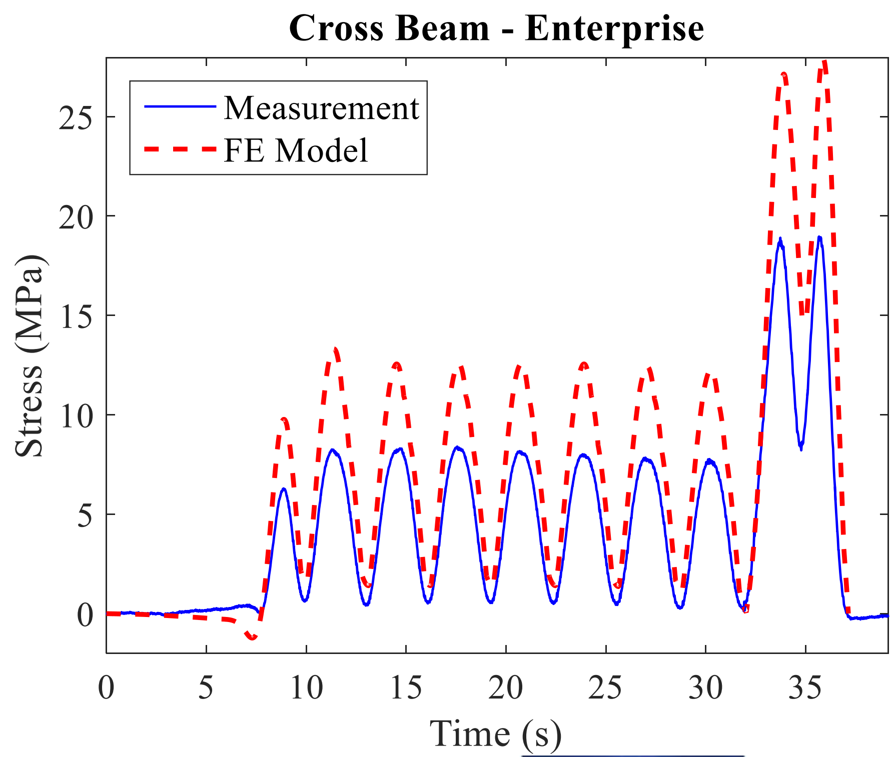
Enterprise Carriage

Data usage – Model Calibration

Calibration for two locations and two trains

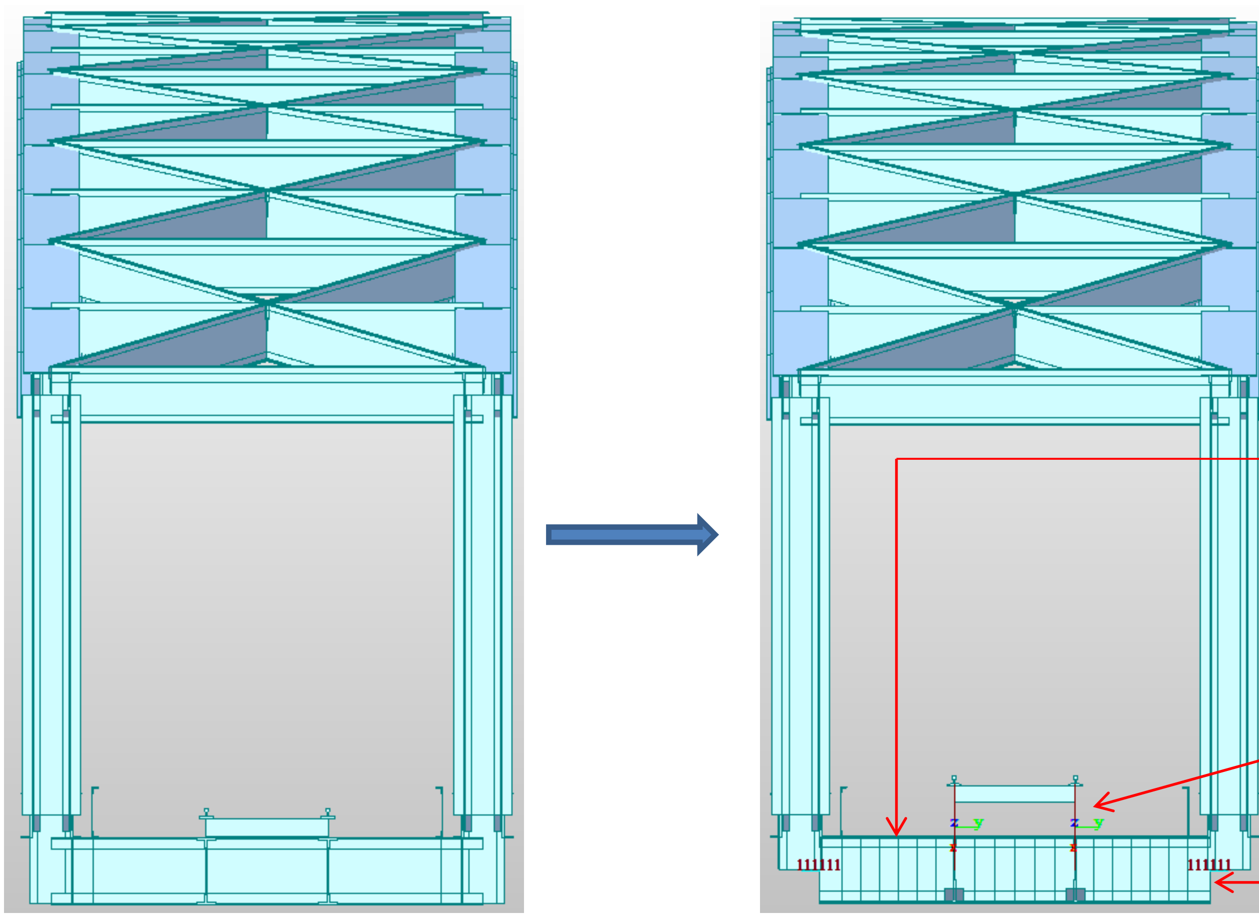
$$principal\_stress = \frac{E}{2}\left(\frac{\varepsilon_1 + \varepsilon_2}{1-\nu} \pm \frac{1}{1+\nu}\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2}\right)$$





Data usage – Model Calibration

Model refinement:



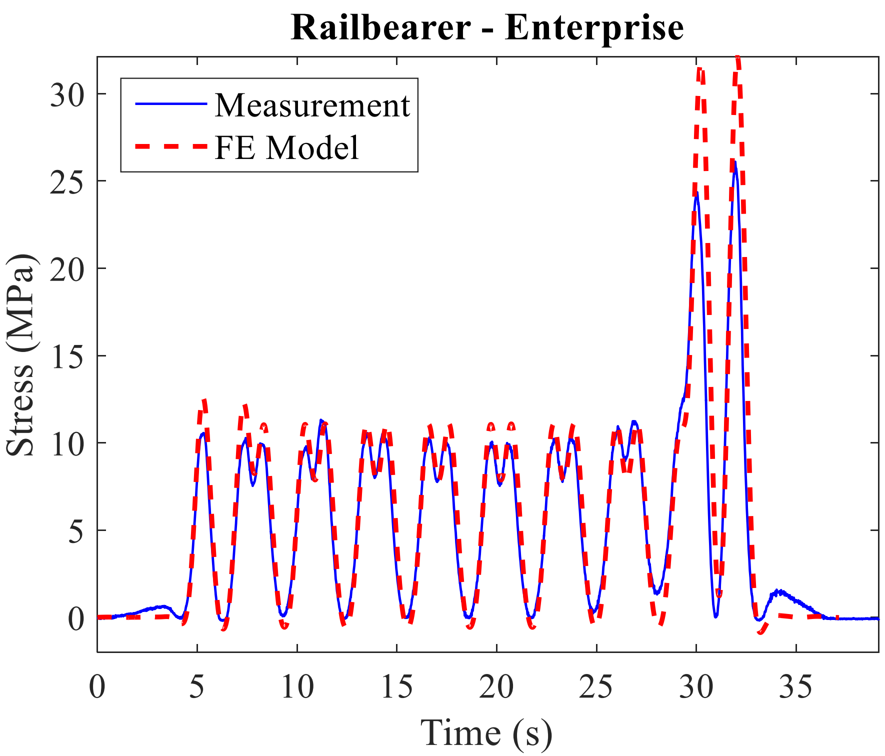
Deck plate mesh refined

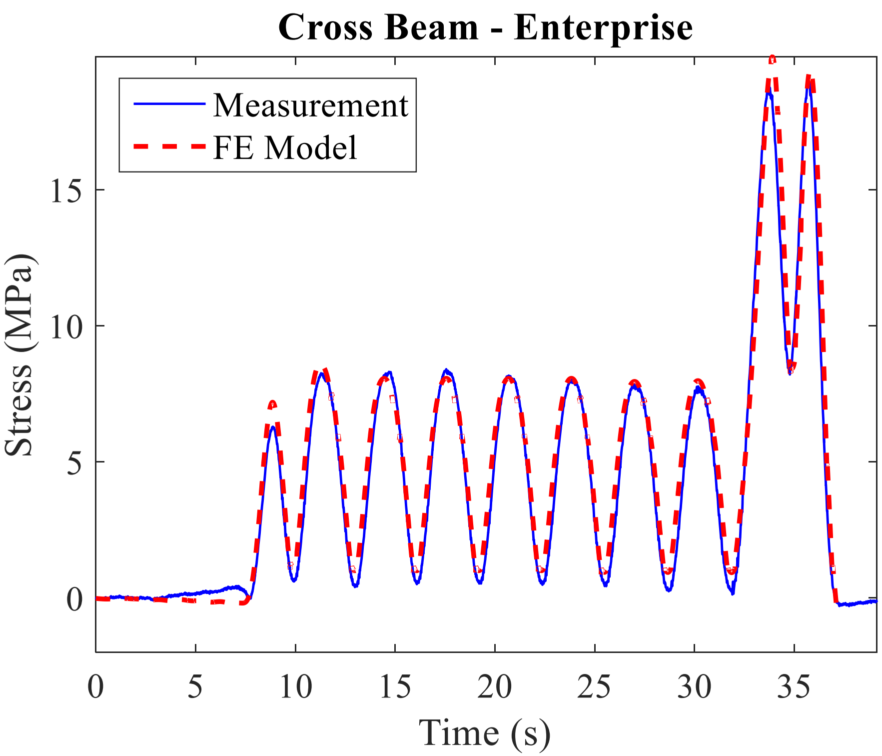
Springs to model ballast

Eccentricities

Data usage – Model Calibration

Comparison of response after refinements





Data usage – Model Calibration

Recalculation of reliability index

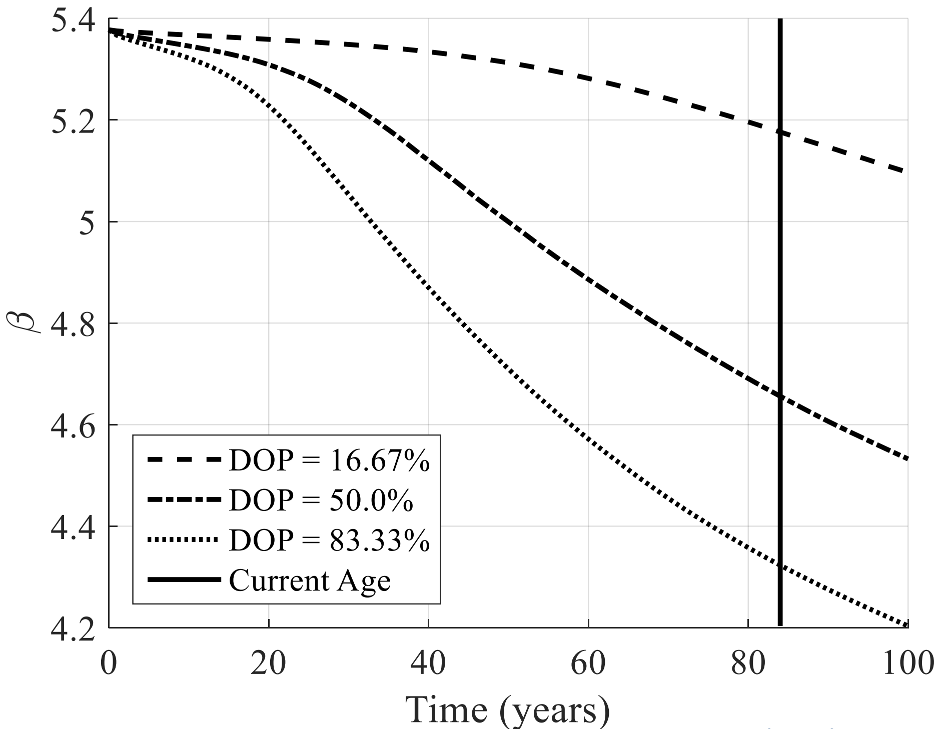
1) Refined FE model
2) Optimised stress-varying DAF modelling
3) Reduction of uncertainty in capacity due to calibration from 10.4% – 6.6%.

- Final reliability index (β) = 7.55

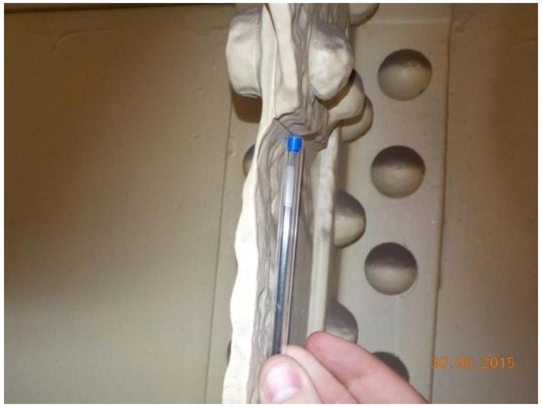
- Note: use of fractile value of LM71 still uncertain!

Probabilistic Corrosion Modelling

- Critical corrosion mechanism: Pitting
- pit diameters of 5, 15 and 25 mm were investigated with a constant pit spacing of 30 mm.

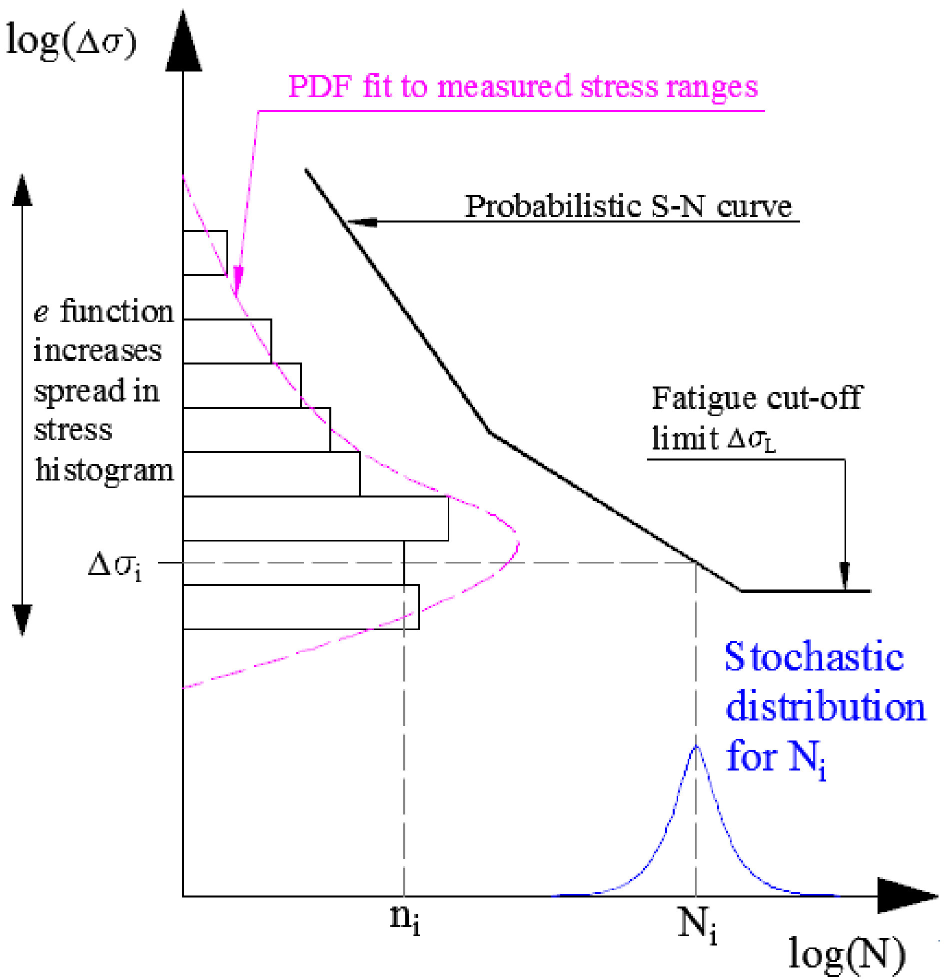


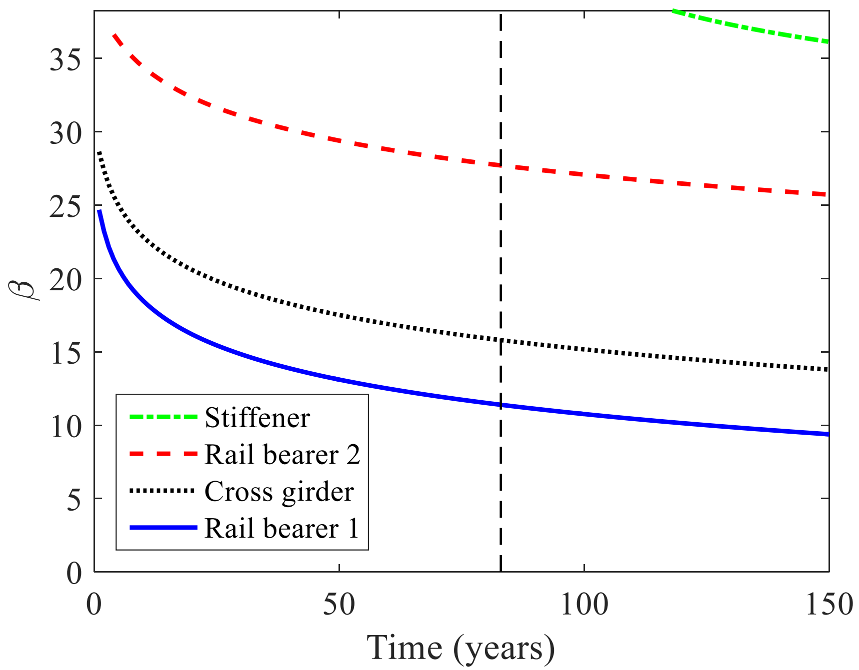
- Corresponding DOP of 16.67%, 50% and 83.33%
- Re-evaluate reliability analysis each year



Probabilistic Fatigue Assessment

Measurement-Based Assessment

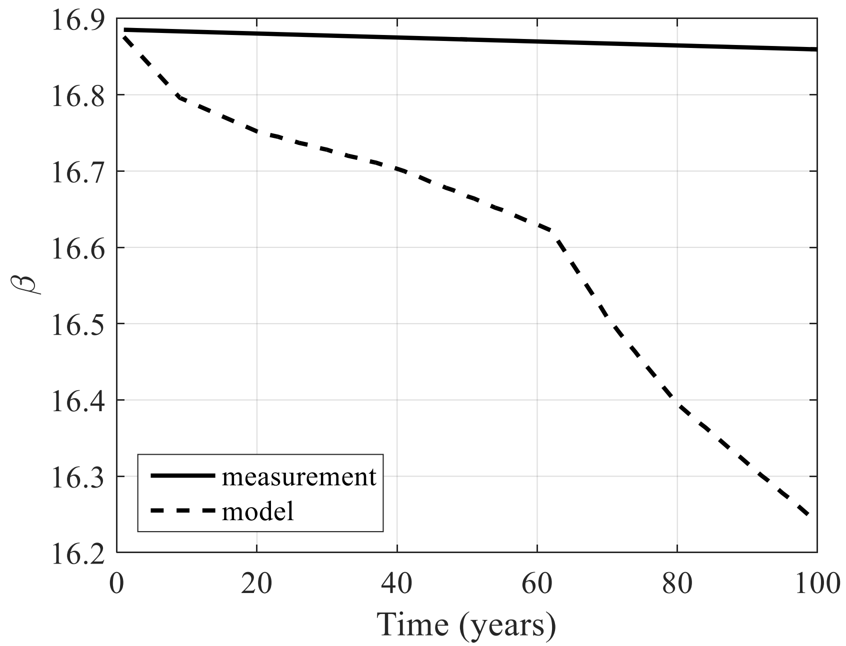


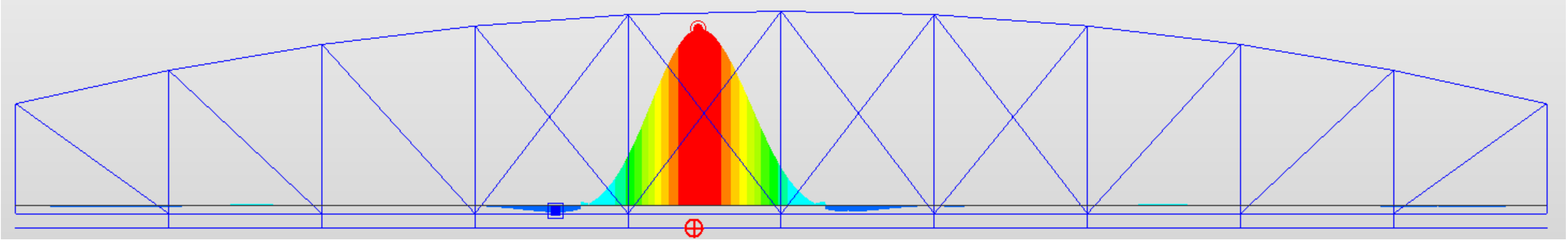


Probabilistic Fatigue Assessment

Model-Based Assessment

- Timetables from IRRS
- Train passages from 1932
- Can be applied throughout calibrated FE model, to every element.
- Also to connections





Conclusions

- Probabilistic approach can show safety even if traditional assessment has shown insufficient capacity at ULS / SLS / FLS.
- Deterioration can be considered with uncertainty
- Use of SHM data:
  - Significant reductions in dynamic allowance
  - Refined FE models for higher accuracy
  - Probabilistic fatigue assessment
- Further input into Risk Calculation

Thank you

lorcan.connolly@rod.ie

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Decision Support Tool for Rail Infrastructure
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