MAIN LINE

Extended Use of Existing Rail Infrastructure

Lennart Elfgren
Luleå University of Technology
Final Workshop
Paris, September 30, 2014

SEVENTH FRAMEWORK PROGRAMME

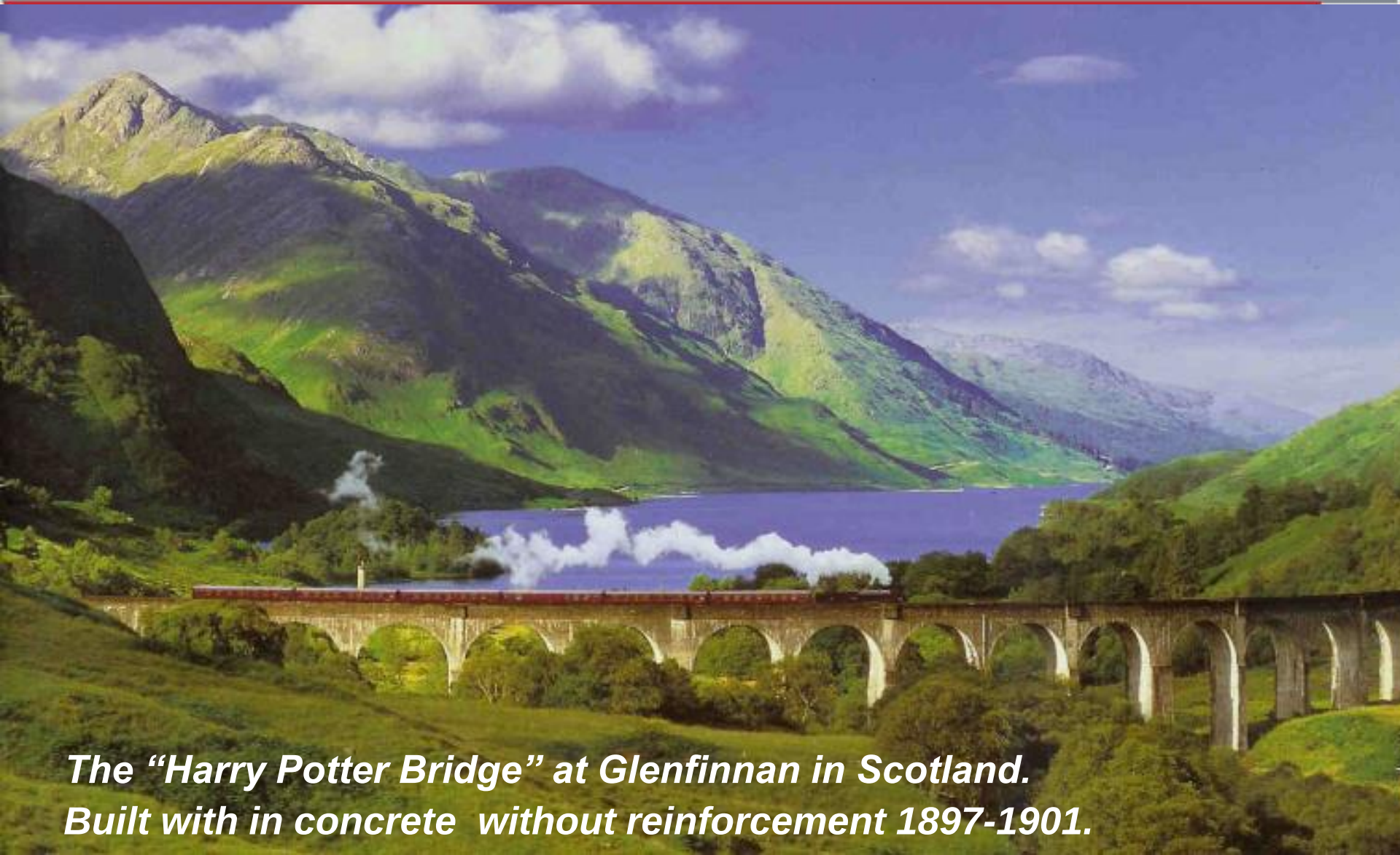
This project is co-funded by the European Commission with the FP7

Outline – Extend Life

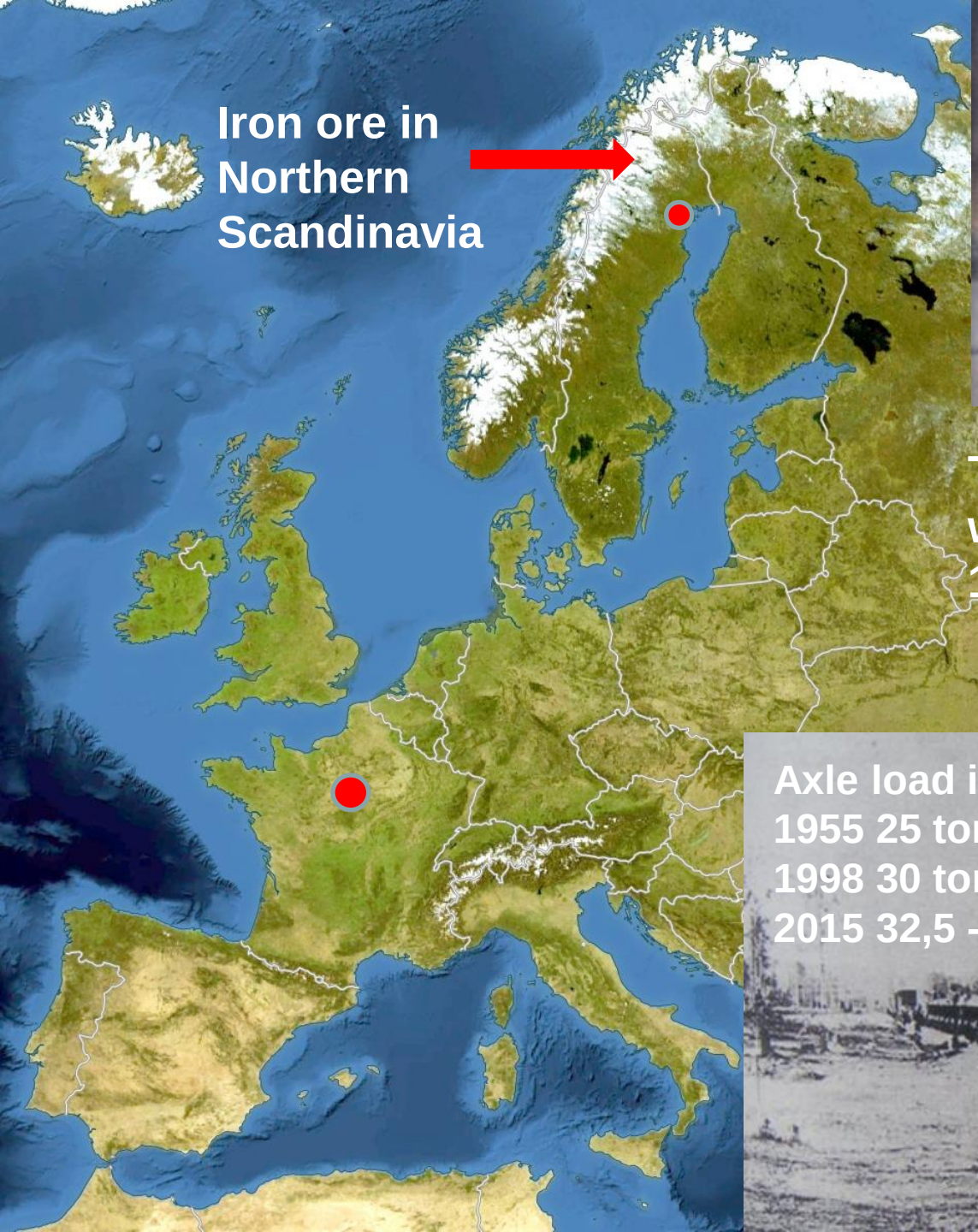
- **Background**
- **Assessment - Examples**
- **Strengthening - Examples**
- **Conclusions – Open questions**

The better you understand a structure – the longer service life can be achieved

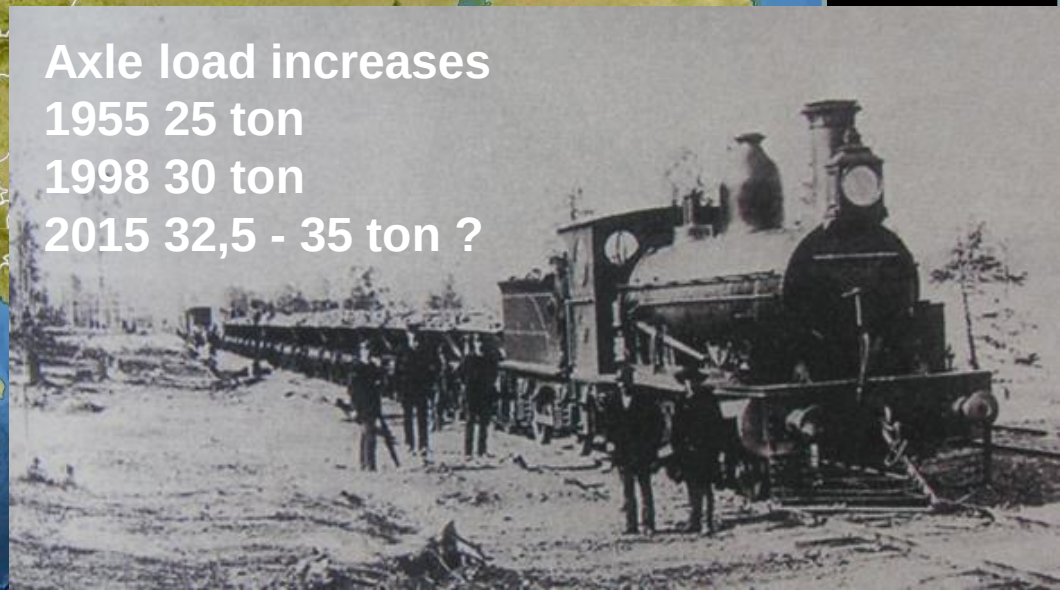
MAINLINE Objective:
Increase service life and capacity of existing railway infrastructure



The "Harry Potter Bridge" at Glenfinnan in Scotland.
Built with in concrete without reinforcement 1897-1901.

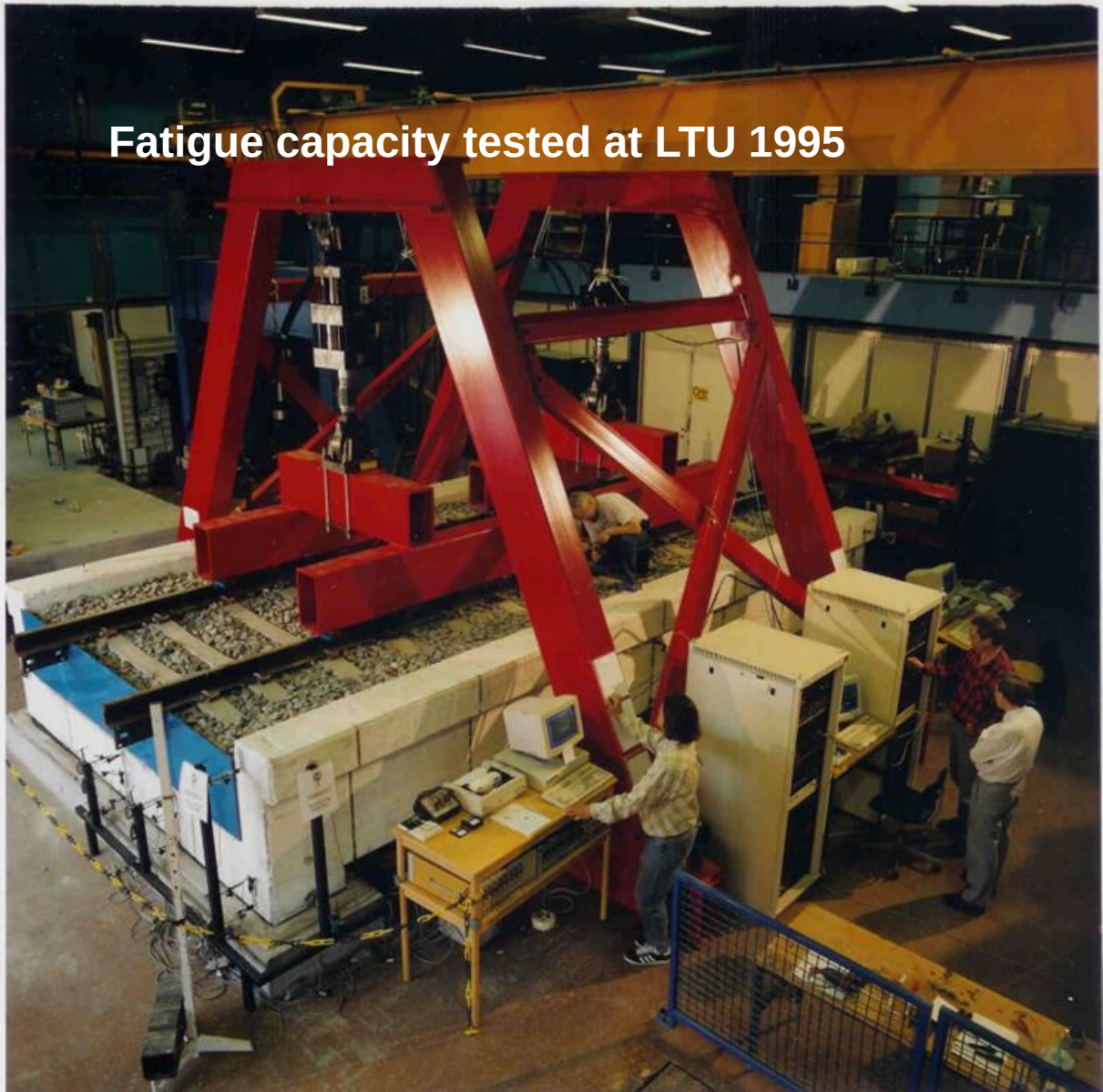


The ore was first transported with reindeers.
1888 Railway line, 14 ton



Axle load increases
1955 25 ton
1998 30 ton
2015 32,5 - 35 ton ?

114 bridges built 1900 - 2014



A train has 68 wagons
each with ca 100 ton ore
12 trains/day transport about
25 Mton/year (increase to 40)
Maintenance cost
~ 45 k€/km, year

Has inspired three EC projects:

Sustainable Bridges

INNOTRACK
Innovative Track Systems

MAIN LINE

Four Reports o

Benchmark, D1.1

Assessment Methods, D1.2

Development, Case Studies, D1.3

Guideline, D1.4

MAIN LINE

SEVENTH FRAMEWORK PROGRAMME

MAINLINE

MAINtenance, renewal and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts

Collaborative project (Small or medium-scale focused research project)

Theme SST.2011.5.2-6.: Cost-effective improvement of rail transport infrastructure

Assessment

Strengthening

Deliverable 1.4:
Guideline for application of new technologies to extend life of elderly rail infrastructure

Grant Agreement number: 285121	SST.2011.5.2-6.
Start date of project: 1 October 2011	Duration: 36 months
Lead beneficiary of this deliverable:	LTU
Due date of deliverable: 30 June 2014	Actual submission date: xxx
Release:	Draft version 0.1, 2014-05-08

Project co-funded by the European Commission within the 7th Framework Programme		
Dissemination Level		
PU	Public	

Participants

- UIC, Paris
- NR, London
- Uminho, Guimarães
- LTU, Luleå
- UPC, Barcelona
- Skanska, Prague
- Jacobs/SKM, London

Outline – Extend Life

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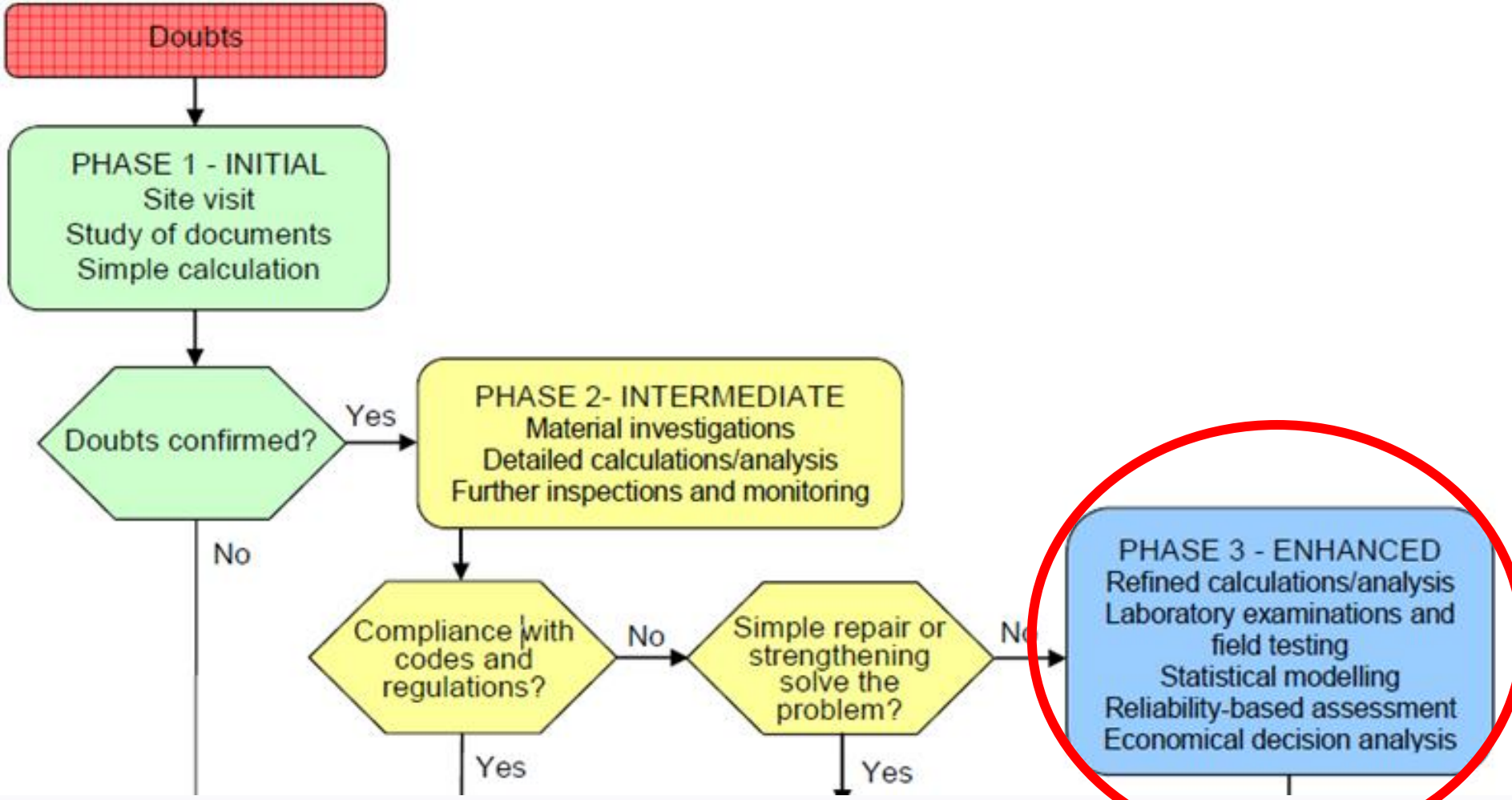
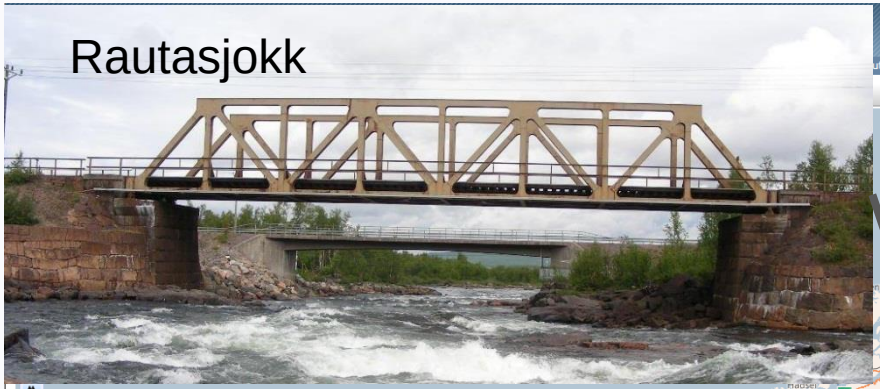
- **Strengthening**
- **Conclusions – Open questions**

Assessment – Three Phases



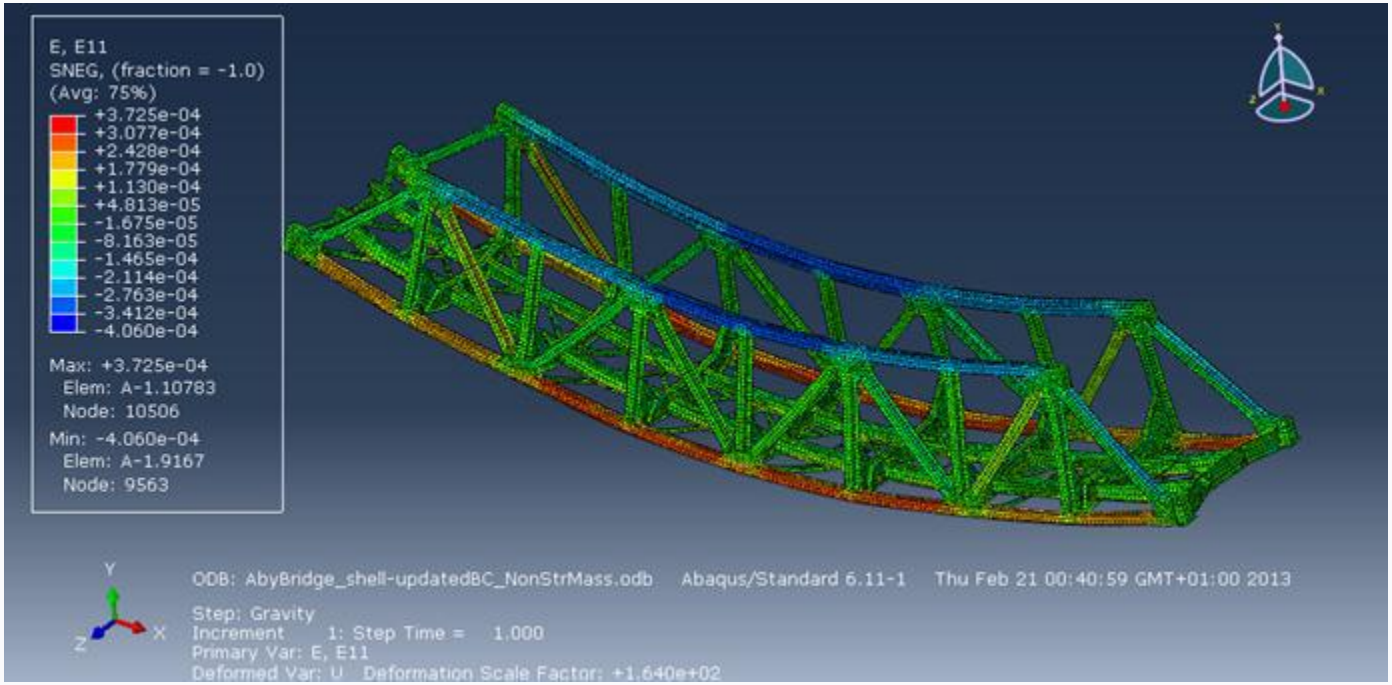
Four case studies



Haparanda

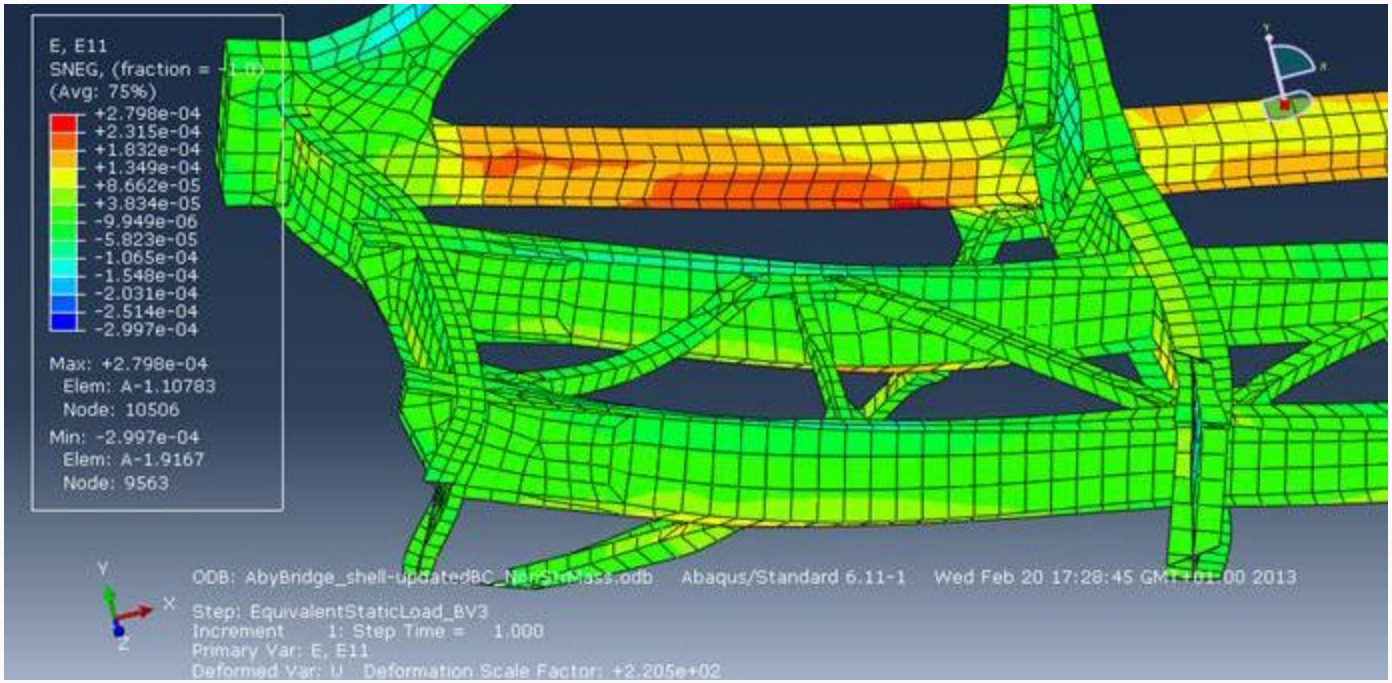
Åby Älv
50 km W Piteå
1894, truss 1957

Södra Rautas
20 km NW Kiruna
1902, truss 1962

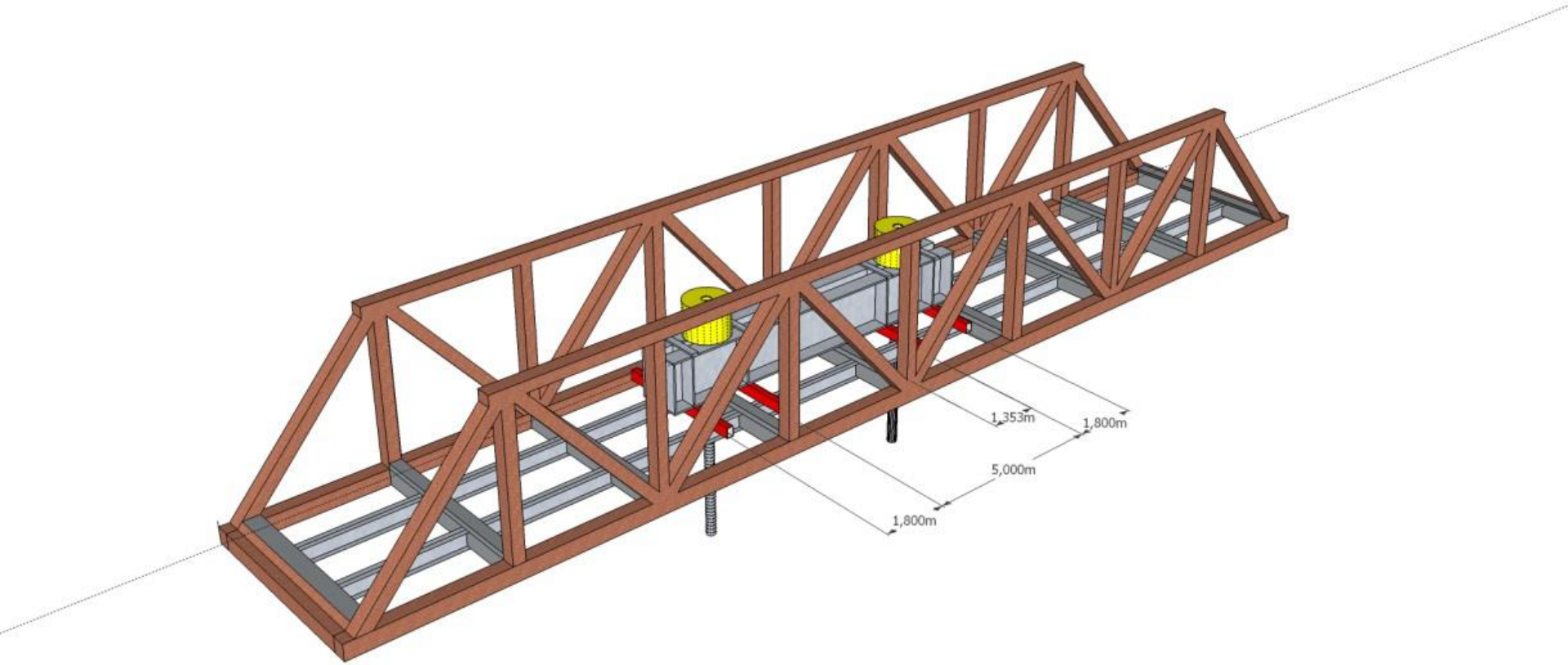


Global view of the E11 strain of deformed Åby Bridge under 250 kN axle load (including self-weight)

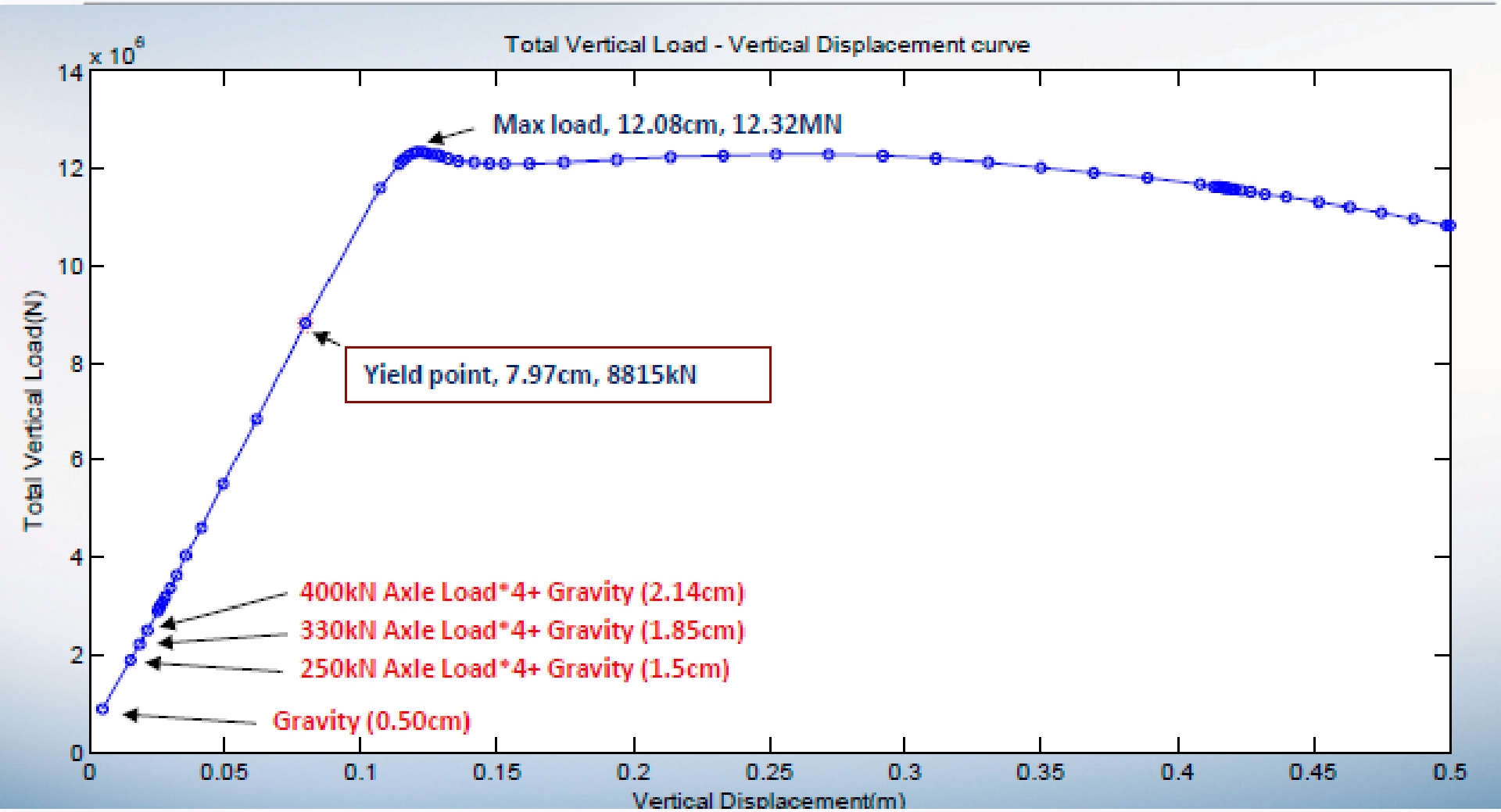
Support strain – Abacus model



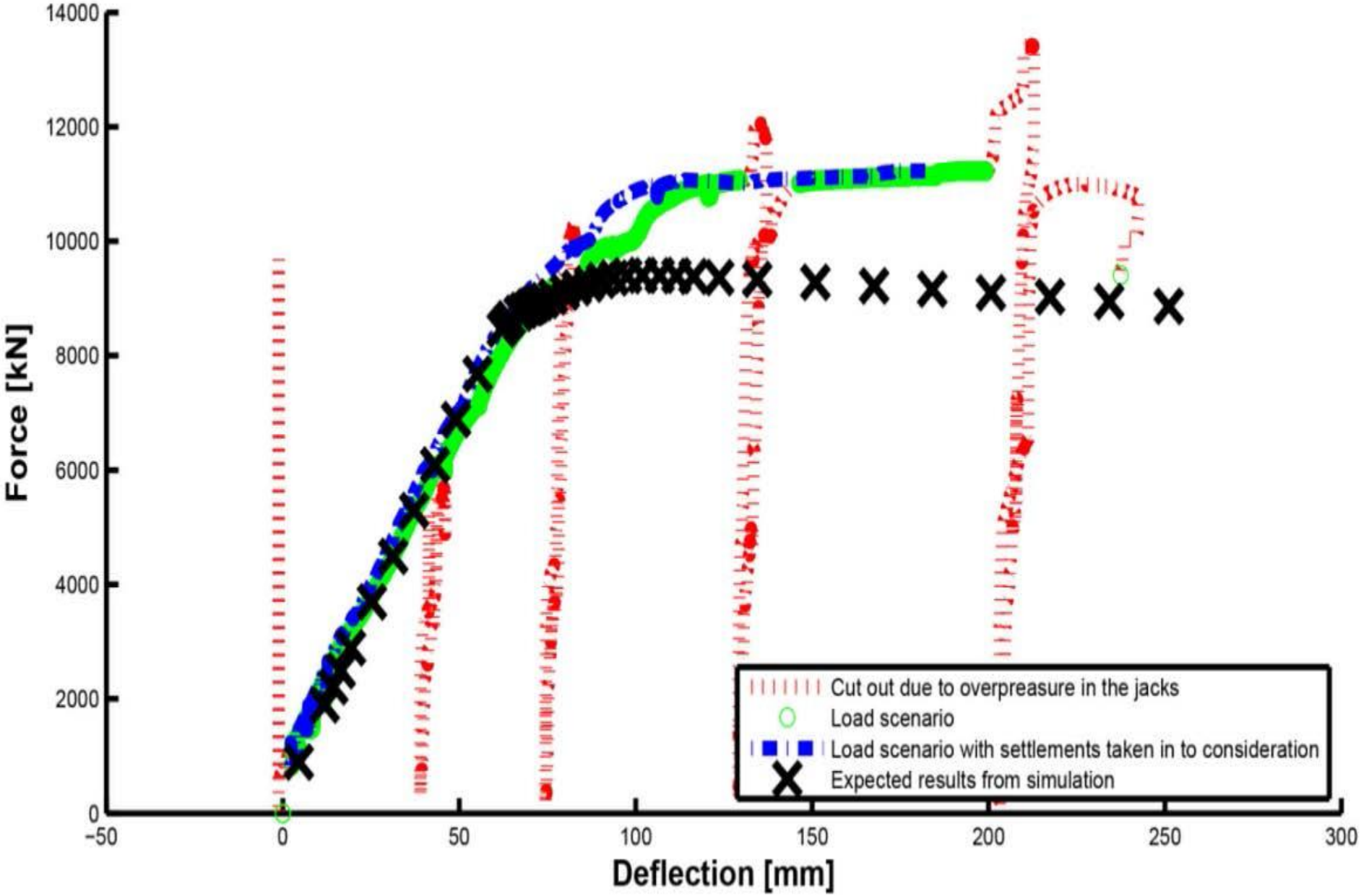
Loading to failure



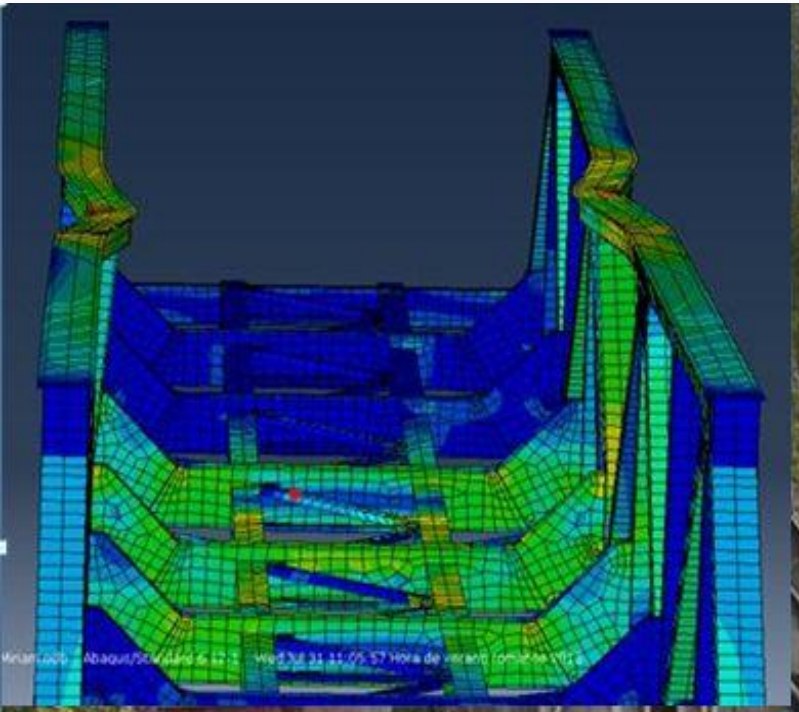
Loading to failure – Abacus model



Test Results

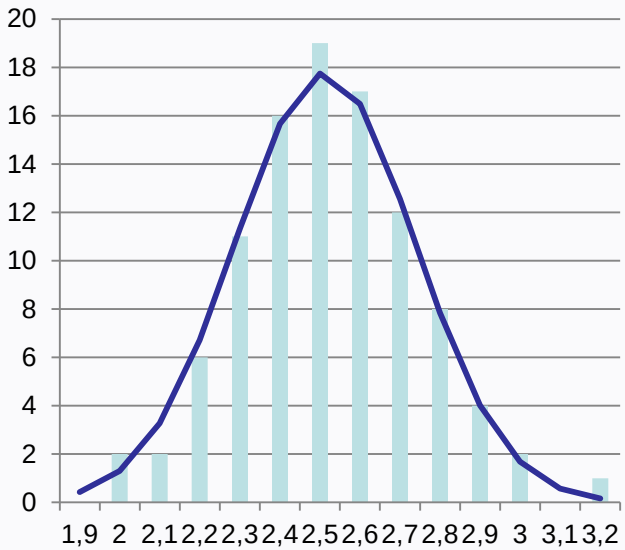


Final Failure



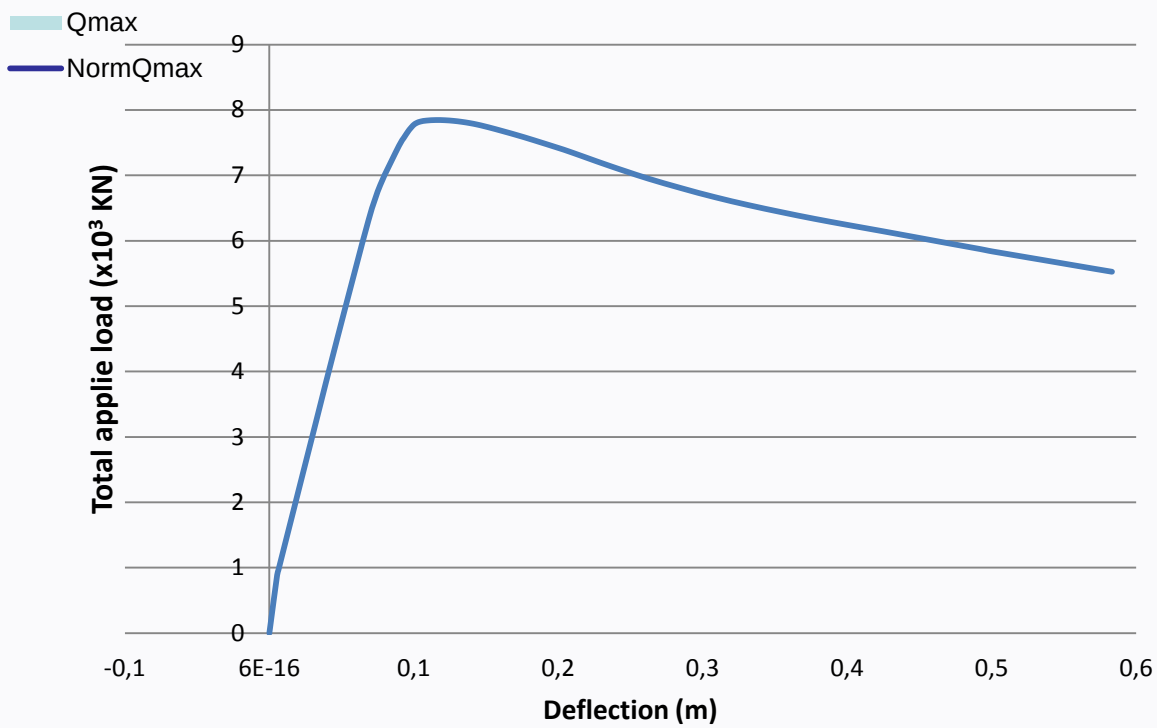
Surviving Brittle Member Failures

Results

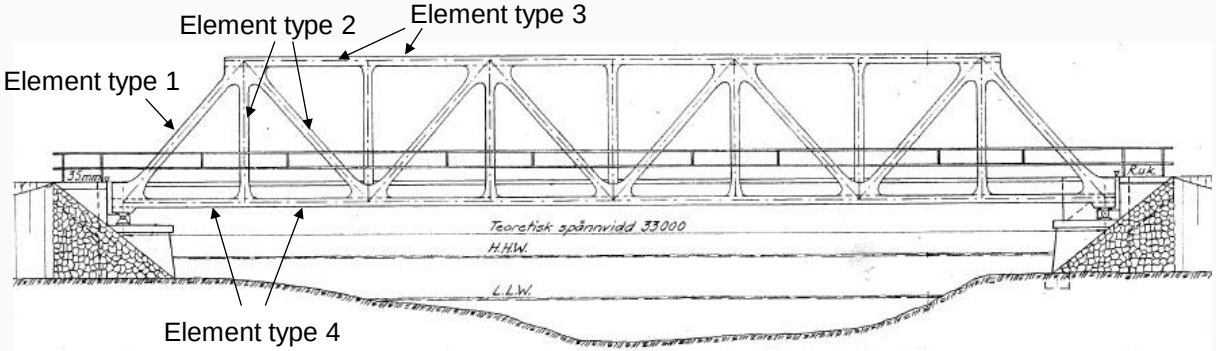


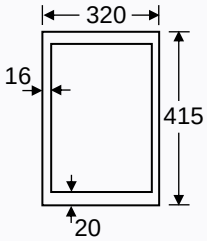
$$\beta = \frac{R - S}{\sqrt{{\sigma_R}^2 + {\sigma_S}^2}}$$

$$\beta = 5.96$$

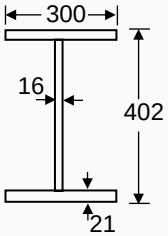


Robustness to corrosion

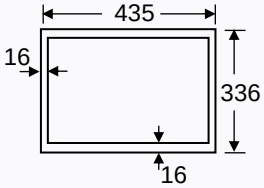




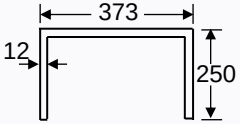
Element type 1



Element type 2



Element type 3

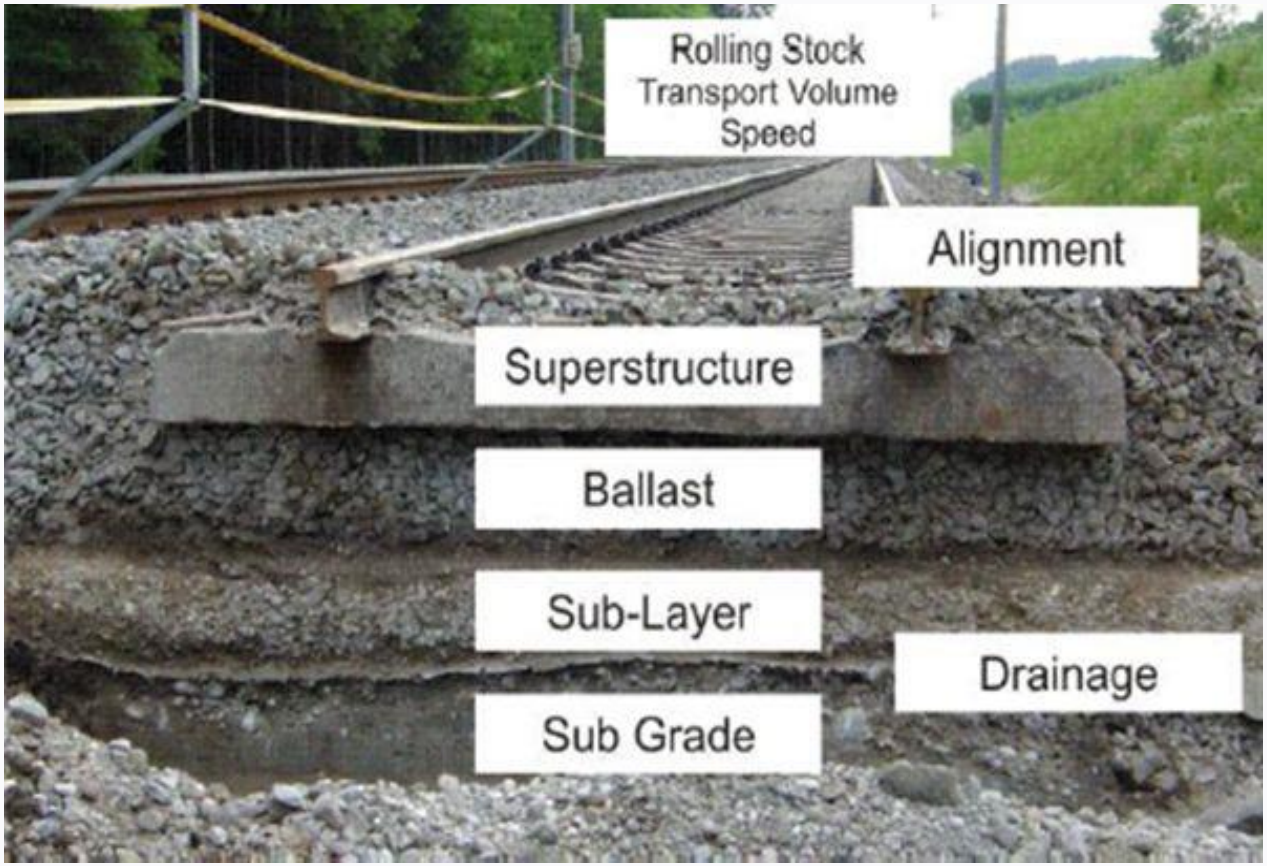


Element type 4

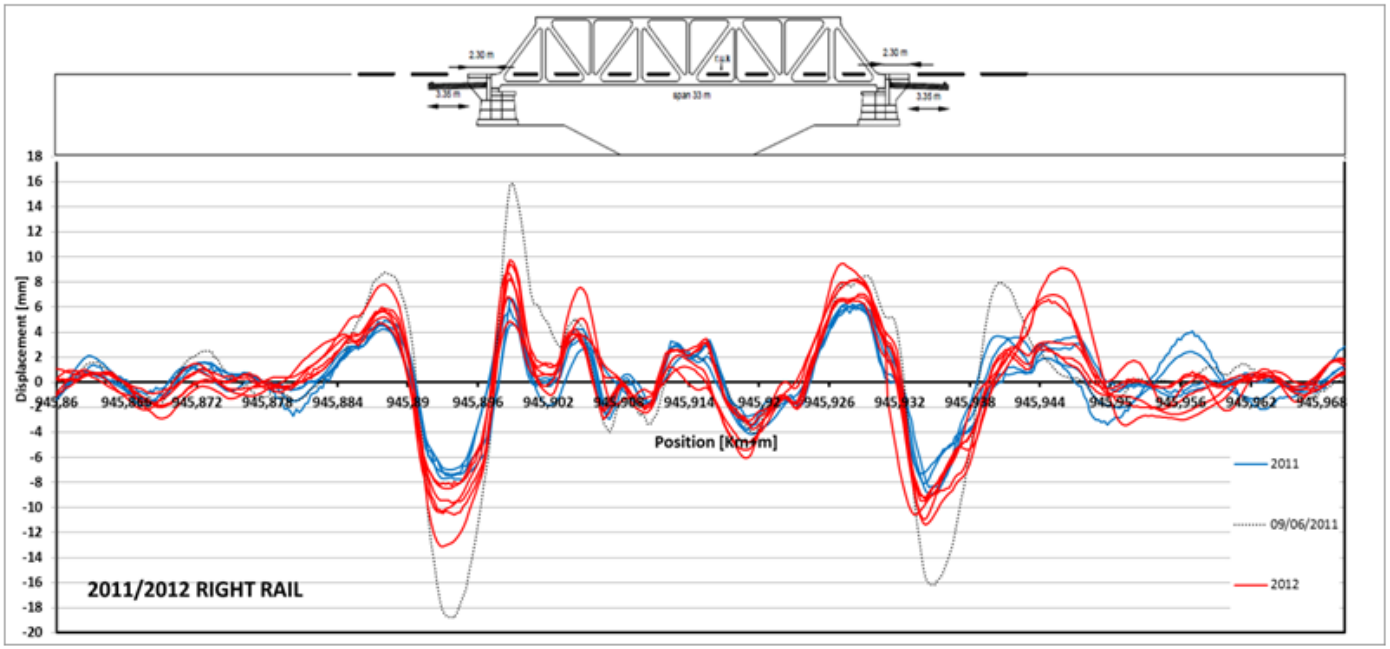
Tunnels

Tunnel Condition Monitoring Index (TCMI)
Reliability-based methods
Risk and robustness assessment

Track Earthwork



Transition zone slab - Sikån



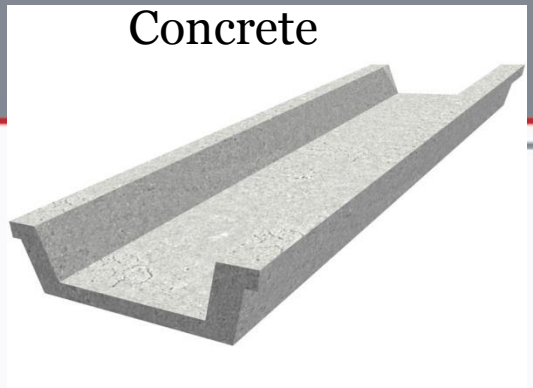
Under Seeper Pads (USP) may be more efficient

Outline

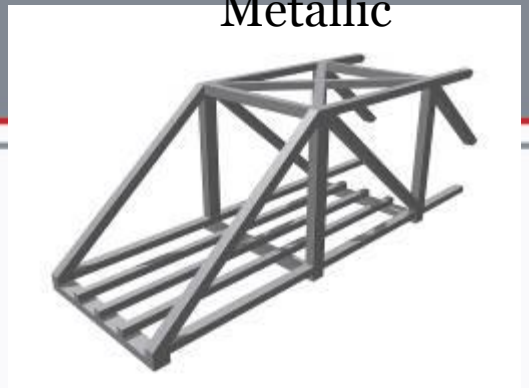
- **Background**
- **Assessment - Examples**
- **Strengthening - Examples**
- **Conclusions – Open questions**

Repair and Strengthening. First step: Selection of Materials

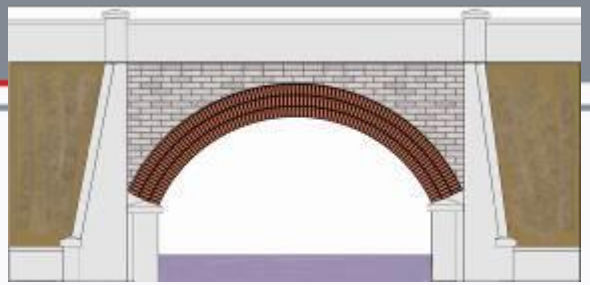
Concrete



Metallic

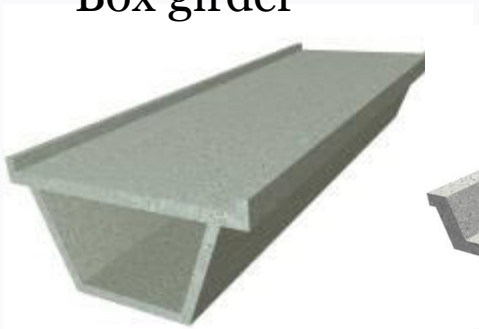


Masonry

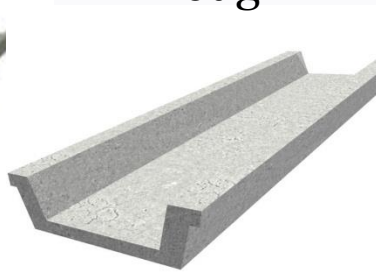


Second step: Selection of bridges, for example reinforced concrete

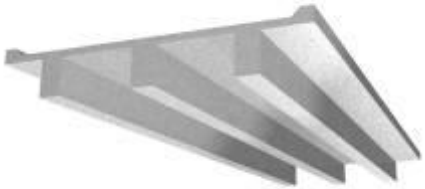
Box girder



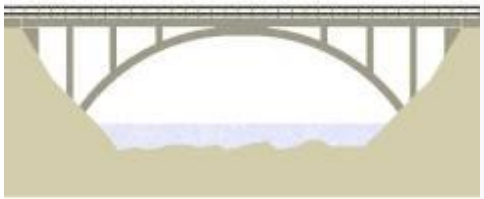
Trough



Beam/Slab

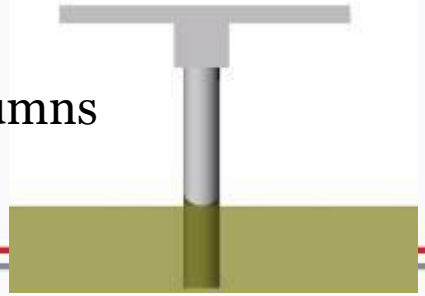


Arch

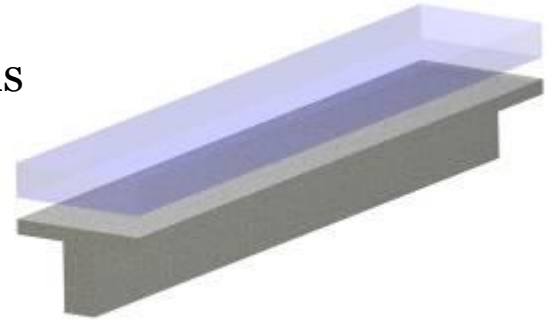


Or/and structural elements

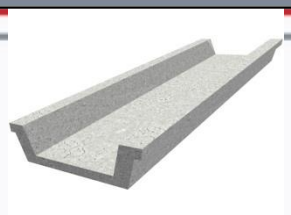
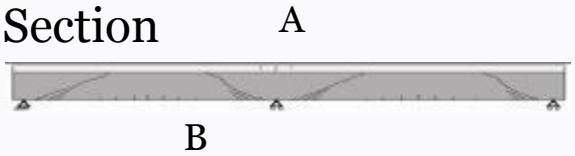
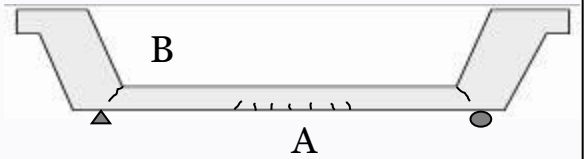
Columns



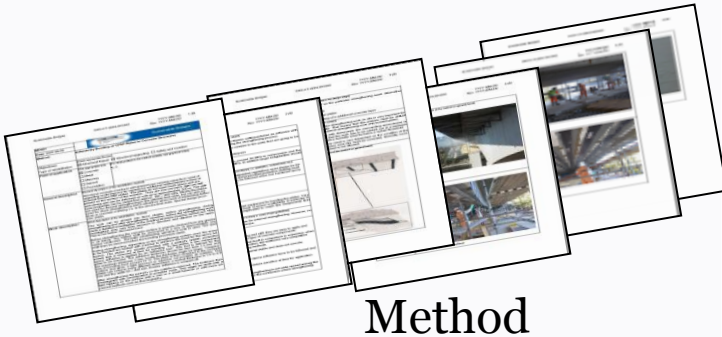
Beams



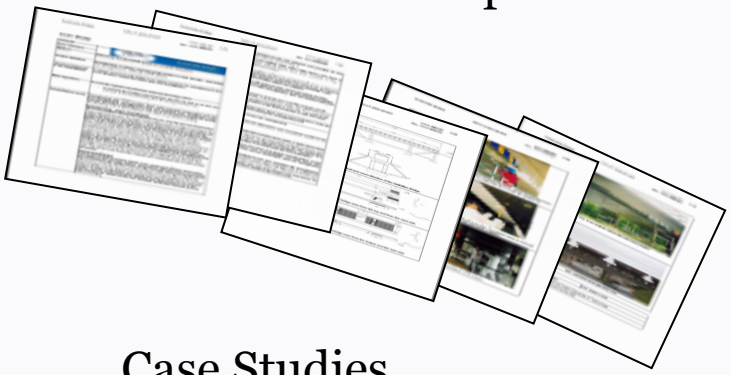
Third step: Focus on strengthening needs – a detailed description

View 	Section 
Photo(s) 	Section 

This is then related to method descriptions and case studies



Method Descriptions



Case Studies

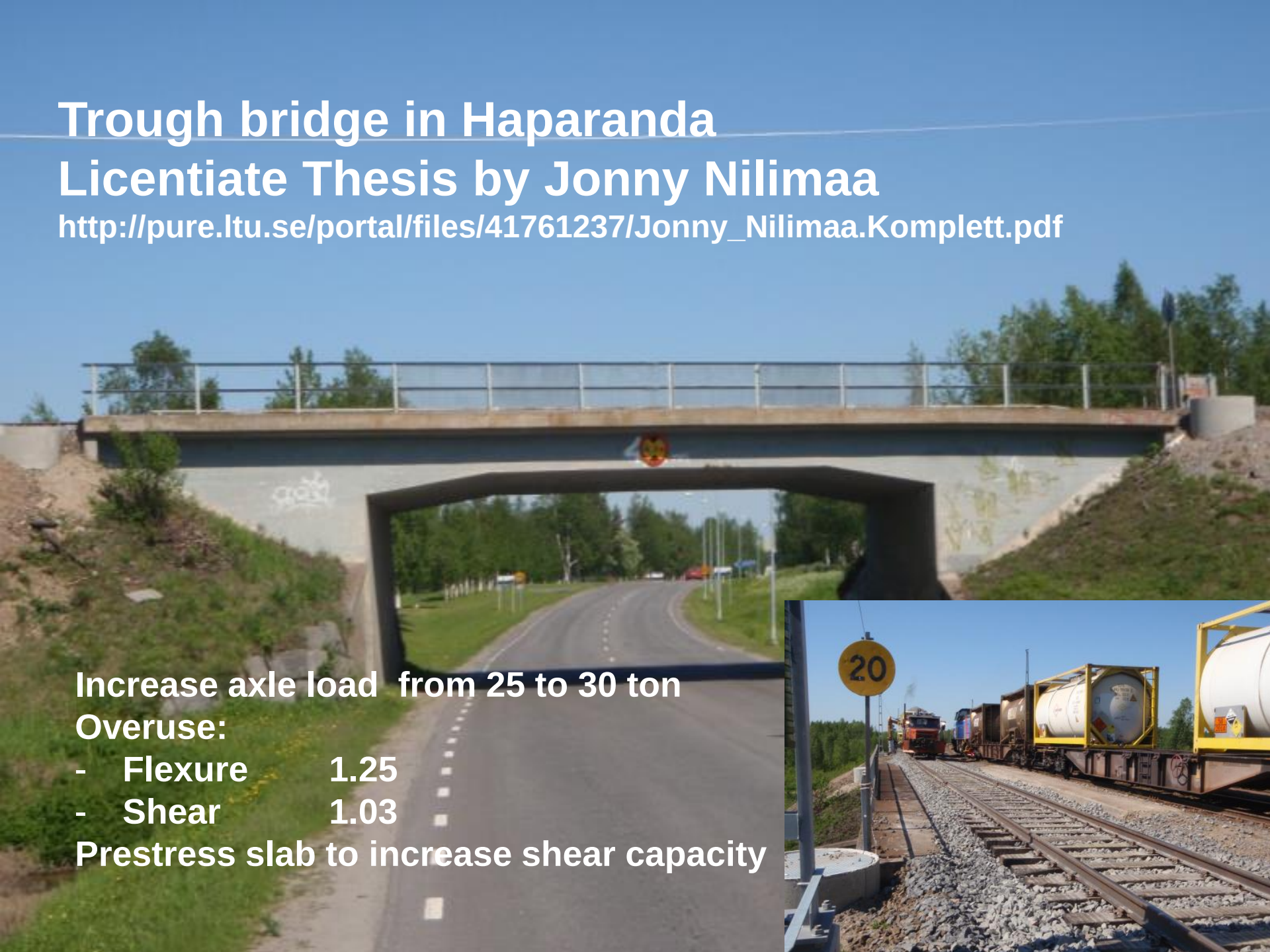
Easy to add-on

- Additional Methods
- Case studies
- Design examples
- Results from monitoring
- Damages

Prepared for databases

Trough bridge in Haparanda
Licentiate Thesis by Jonny Nilimaa

http://pure.ltu.se/portal/files/41761237/Jonny_Nilimaa.Komplett.pdf



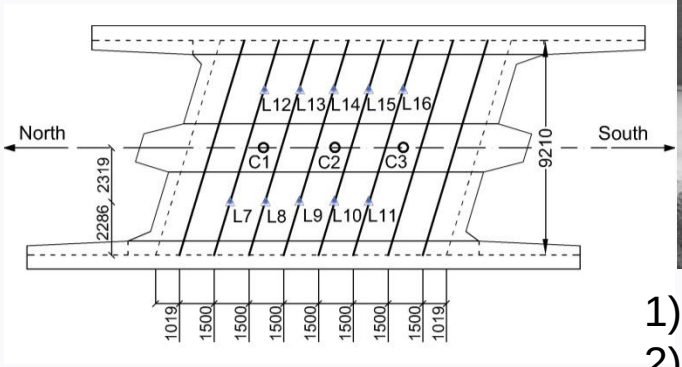
Increase axle load from 25 to 30 ton

Overuse:

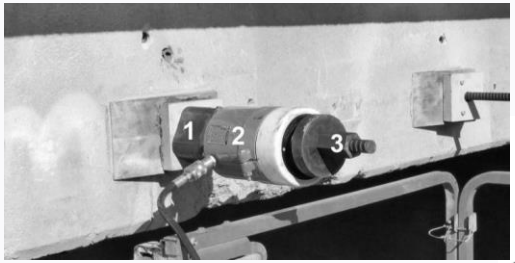
- **Flexure 1.25**
- **Shear 1.03**

Prestress slab to increase shear capacity

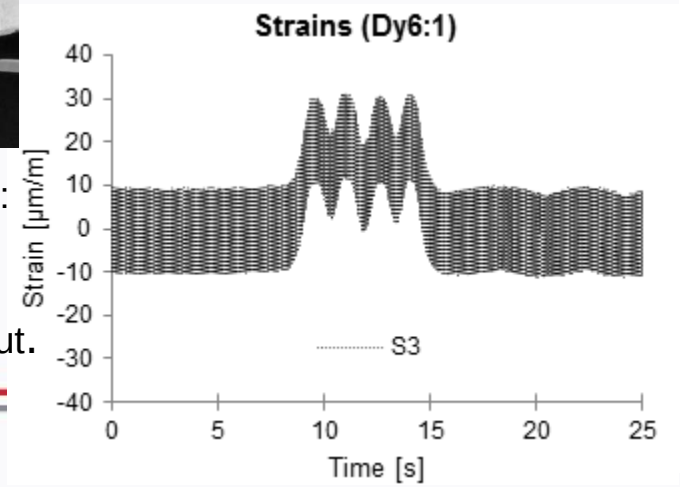
Prestressing Haparanda Bridge

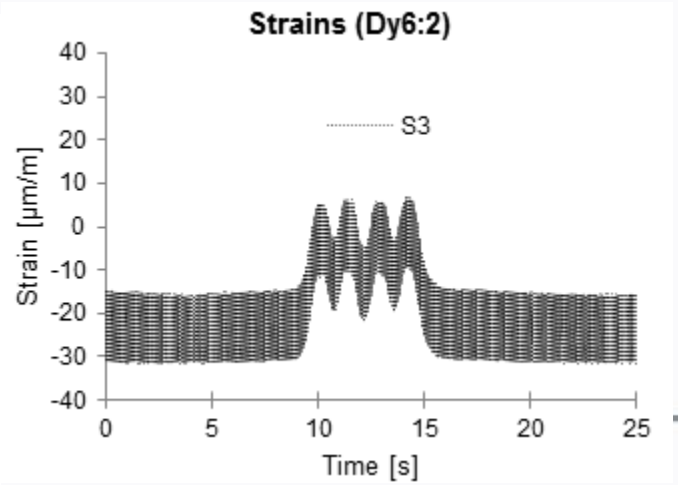


1) an anchoring nut
2) an anchoring plate and
3) load-distributing wedge



Prestressing setup including:
1) the steel frame,
2) the hydraulic jack and
3) the extra prestressing nut.





Implementation
The Örnsköldsvik bridge

Diagnosis

Inspection and Condition Assessment

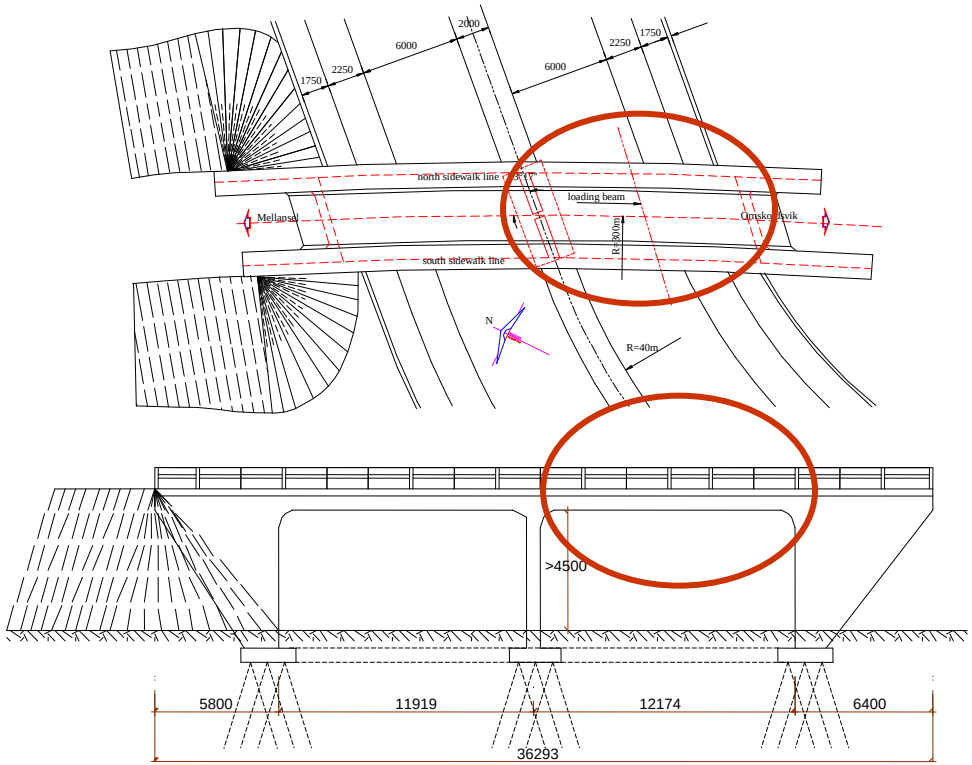
FE-analyses and more detailed calculations

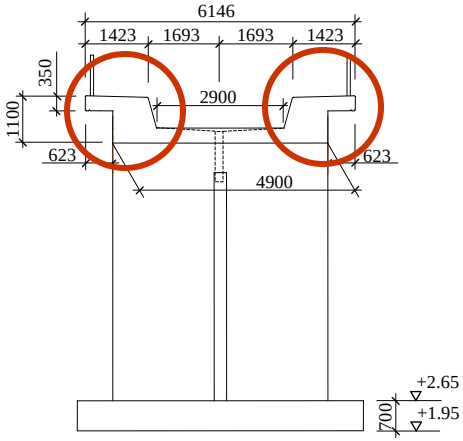
CFRP Strengthening with NSMR bars

Loading of slab through ballast and loading of strengthened main girders to failure

Further evaluations

Implementation
The Örnsköldsviks bridge

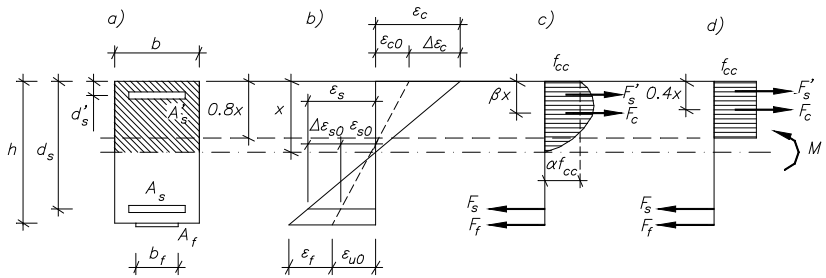




Implementation

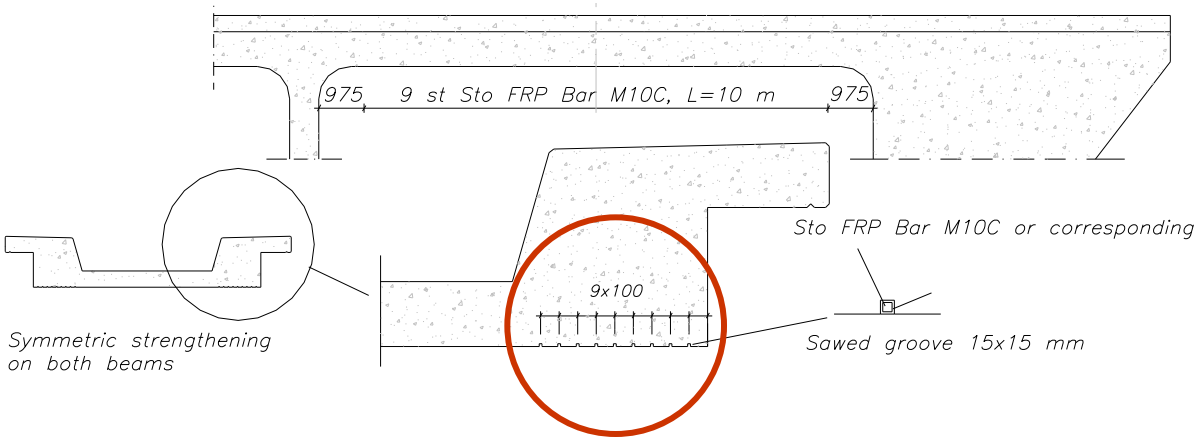
The Örnsköldsviks bridge - 2006

First the strengthening design was carried out

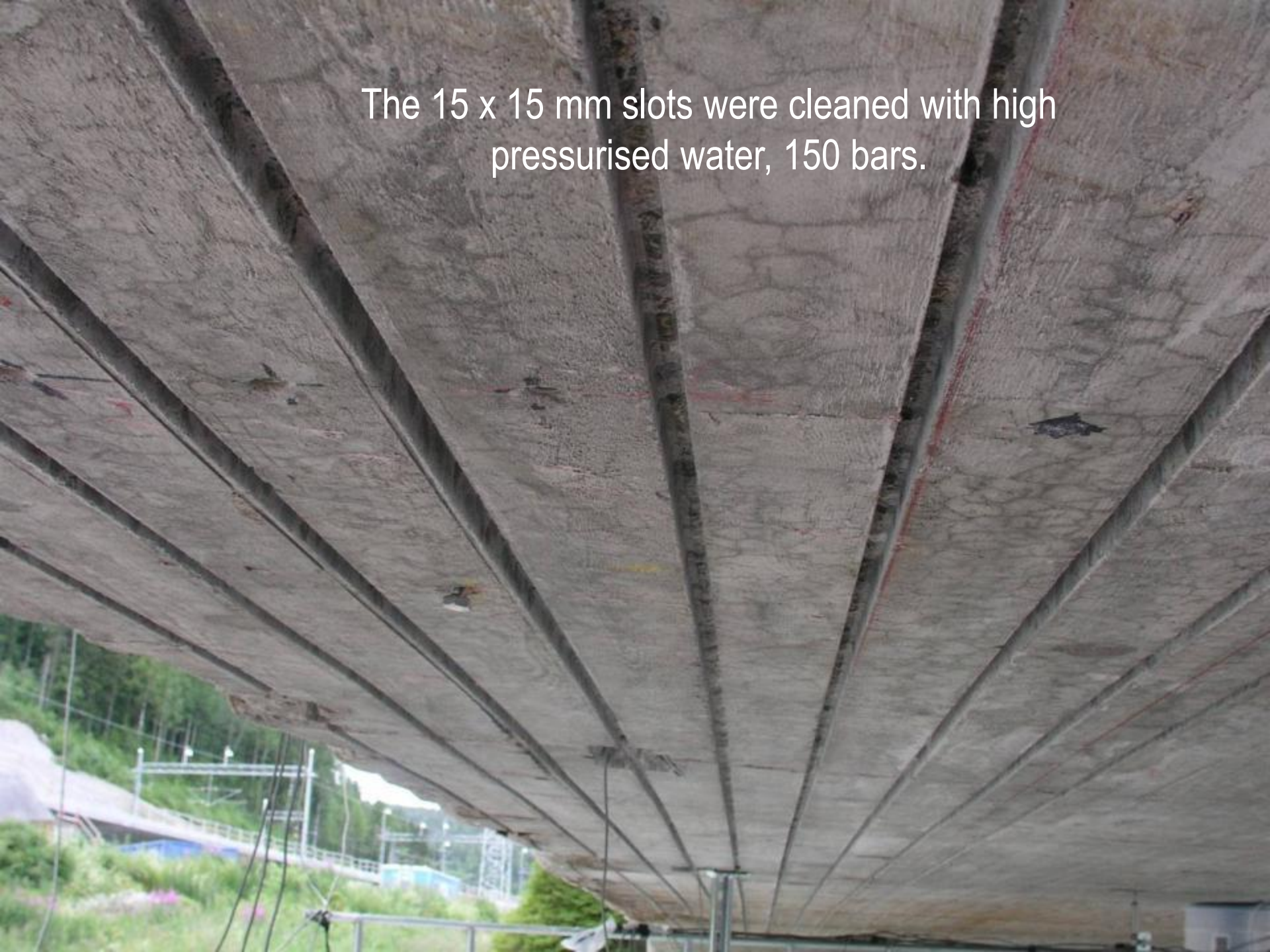


$$M = \frac{x - d_s'}{h - x}\left(\varepsilon_f + \varepsilon_{uo}\right)A_s' E_s\left(\beta x - d_s'\right) + A_s f_y\left(d_s - \beta x\right) + \varepsilon_f E_f A_f\left(h - \beta x\right)$$

Strain based design. Resulted in 9 bars (9x100mm^2/beam). E_f = 250 GPa. Moment capacity of 11.6 kNm per beam



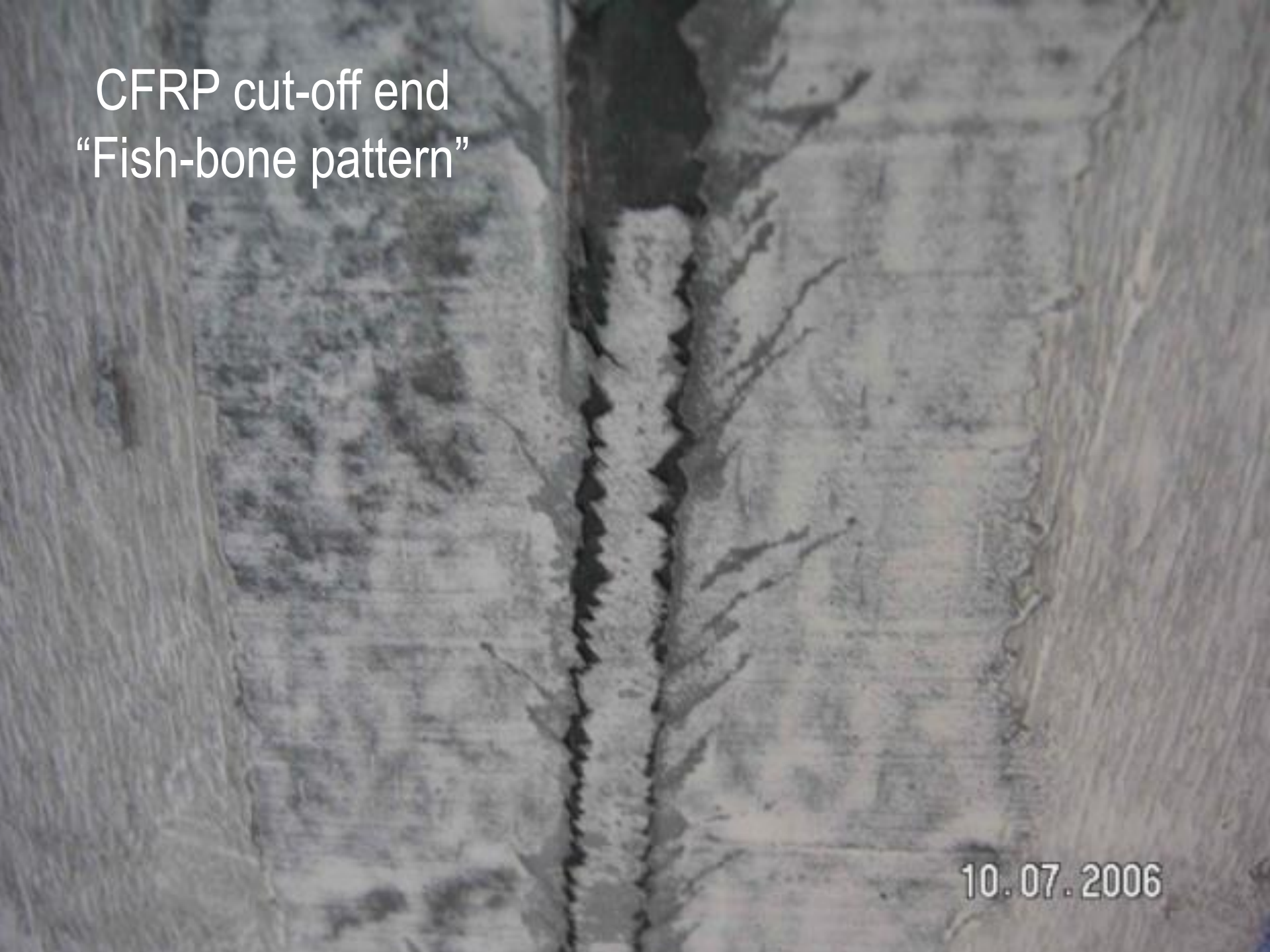

Sawing for Strengthening.
(Near Surface Mounted CFRP Rods)
27.06.2006


The 15 x 15 mm slots were cleaned with high pressurised water, 150 bars.


E4
HAPARANDA
SUNDSVALL
JÄRVED
50
Tyvek


Open time: ca 50 min


Final strengthening result


CFRP cut-off end
“Fish-bone pattern”
10.07.2006

Implementation

The Örnsköldsviks bridge - 2006

Outline

- **Background**
- **Assessment - Examples**
- **Strengthening - Examples**
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Conclusions – Life Extension

Use Refined Assessment Methods:
- Robustness
- Probabilistic Methods
- Proof load

Strengthen with
- Prestressing and Post-tensioning
- CFRP; Carbon Fibre Reinforced Polymers:
- Near surface mounted reinforcment (NSMR)

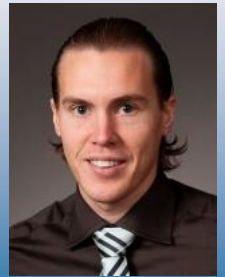
The better you understand a structure

– the longer service life can be achieved

Test of the Kiruna Mine Bridge

Preliminary Program 2014-05-10

Niklas Bagge, Jonny Nilimaa,
Thomas Blanksvärd, Björn Täljsten & Lennart Elfgren

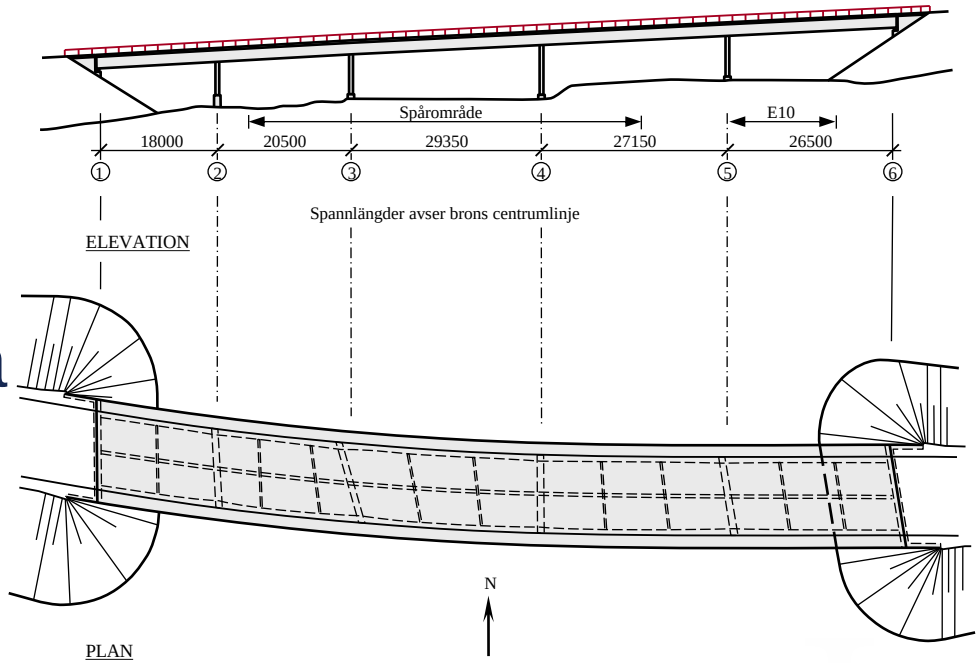




LULEÅ UNIVERSITY OF TECHNOLOGY

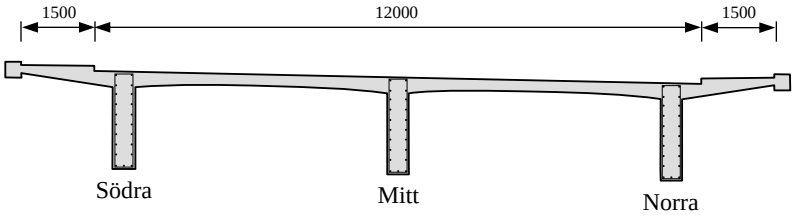

1910
Deformation zone
Fracture zone
Collapse zone
Bridge
Open pit
Mining level
2014 – 1000 m below surface
Hanging wall
Iron ore
Footwall

Geometry & Materials

- 121.5 m prestressed concrete bridge
- Continous beams with 5 spans
- Built 1960



- Concrete 30.40 MPa
- Rebar 400 & 600 MPa
- BBRV St1450/1700



Test of Strengthened Bridge

- Pre-loading – similar as for unstrengthened bridge (16 load cases)
- Loading to failure – moment-shear resistance

Southern beam

Central beam


Bridge beeing demolished,
September 2014

Open questions

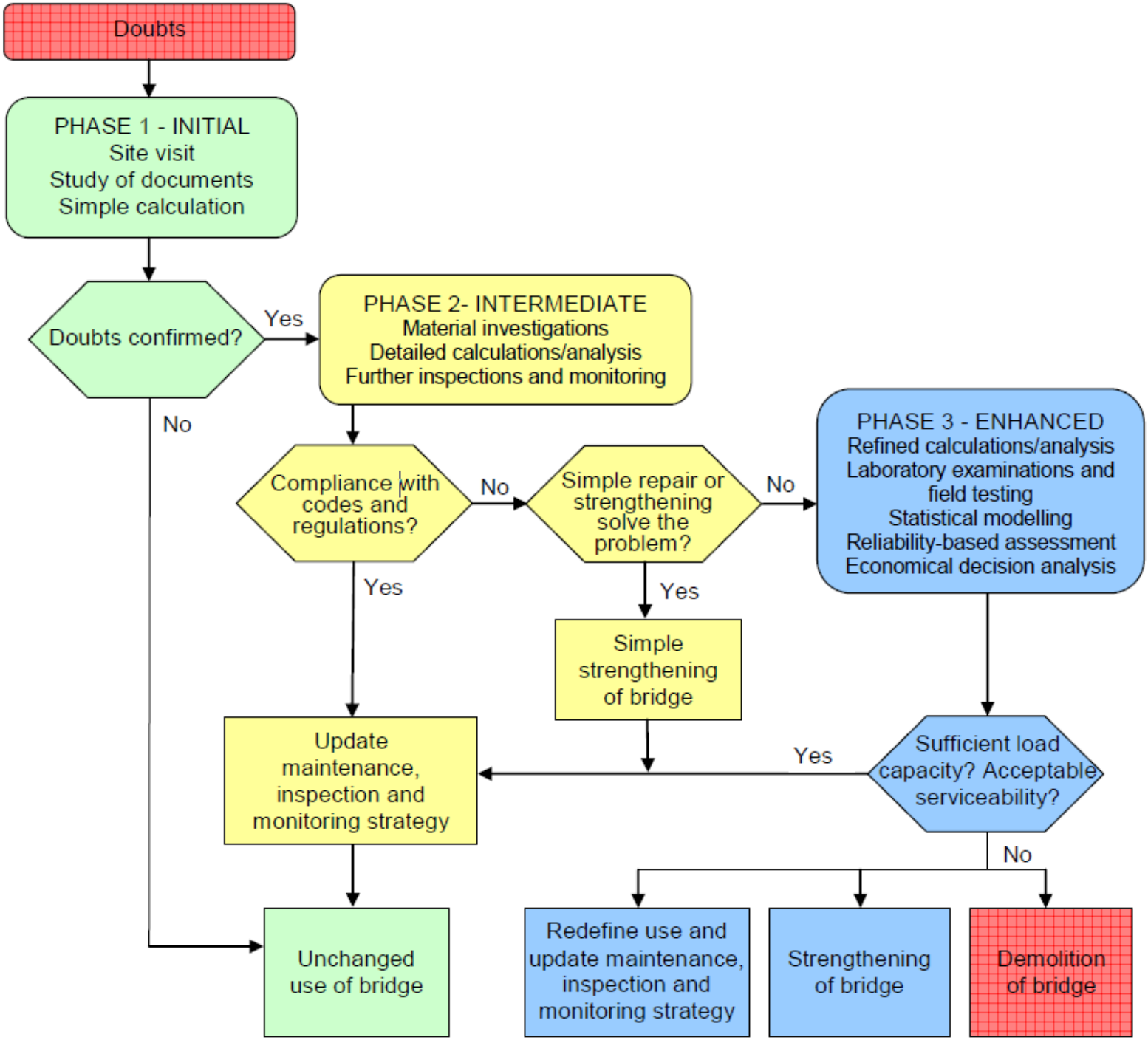
- How to meet increased demands on infrastructure caused by increased loads and climate change?
- How to develop assessment methods that can be easily used by infrastructure managers?
- How to understand the function of our infrastructure to be able to assess and strengthen it efficiently?
- How to monitor to secure a longer life when initial assessment is not passed?

End of Presentation

- Thank you for your kind attention!
- Questions?

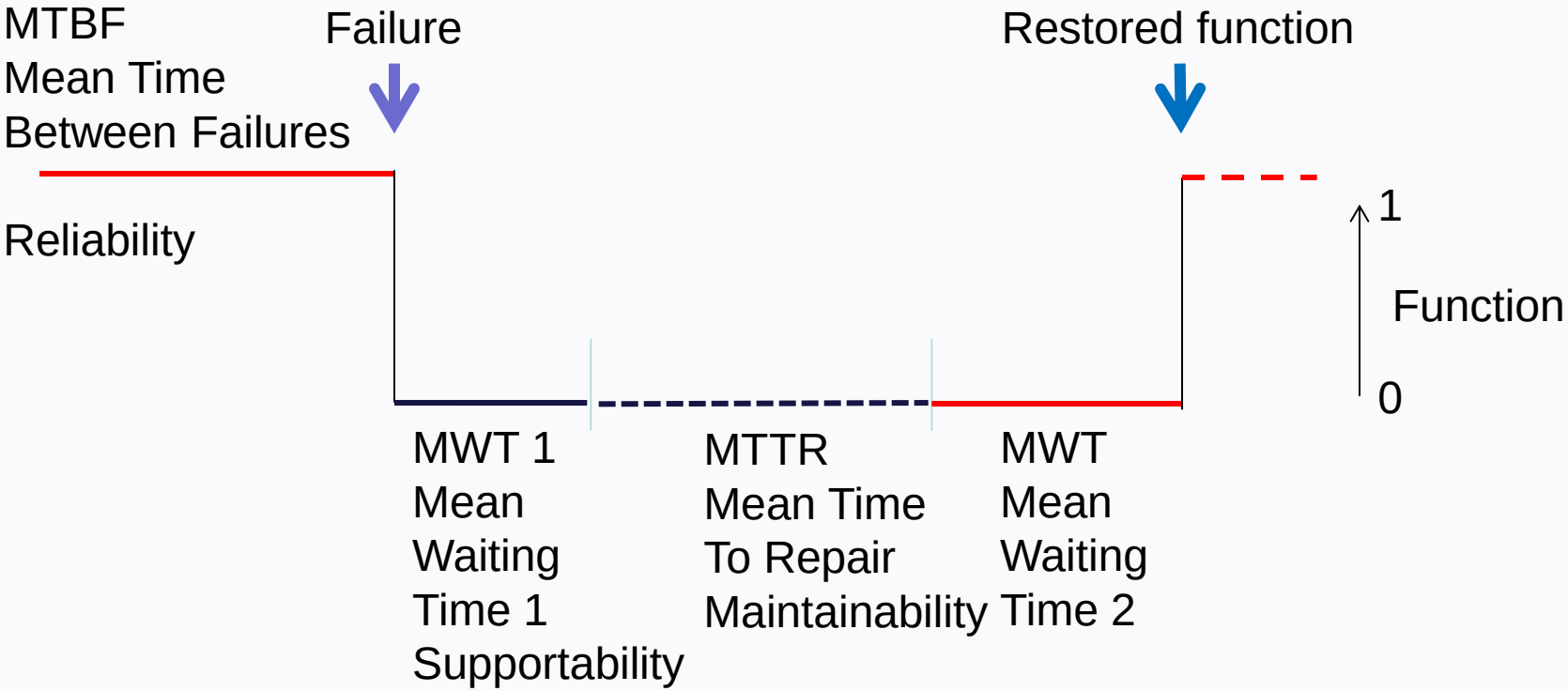
The better you understand a structure

– the longer service life can be achieved


Doubts
PHASE 1 - INITIAL
Site visit
Study of documents
Simple calculation
Doubts confirmed?
Yes
No
PHASE 2- INTERMEDIATE
Material investigations
Detailed calculations/analysis
Further inspections and monitoring
Compliance with codes and regulations?
No
Yes
Simple repair or strengthening solve the problem?
No
Yes
PHASE 3 - ENHANCED
Refined calculations/analysis
Laboratory examinations and field testing
Statistical modelling
Reliability-based assessment
Economical decision analysis
Simple strengthening of bridge
Update maintenance, inspection and monitoring strategy
Yes
Sufficient load capacity? Acceptable serviceability?
No
Unchanged use of bridge
Redefine use and update maintenance, inspection and monitoring strategy
Strengthening of bridge
Demolition of bridge

RAMS

(SS-EN_13306_2010)



Availability = MTBF / Total Time

RAMS

(SS-EN_13306_2010)

Safety

Availability

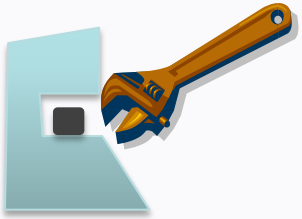
Reliability

Maintainability

Supportability

MTBF
Mean Time
Between Failure

MTTR
Mean Time
To Repair



MWT
Mean Waiting
Time

RAMS

- Railway RAMS
- (SIS-1999-SS-EN)
- **R**eliability
- **A**vailability
- **M**aintainability
- **S**afety

Maintenance terminology

(SS-EN_13306_2010)

Reliability

Availability

Maintainability

Supportability

Outline – Extend Life

- **Background**
- **Assessment**
- **Strengthening**
- **Track and Earth work**
- **Conclusions – Open questions**

Surviving Ductile Member Failures

System redundancy

column failure
due to collision

column failure
due to EQ.

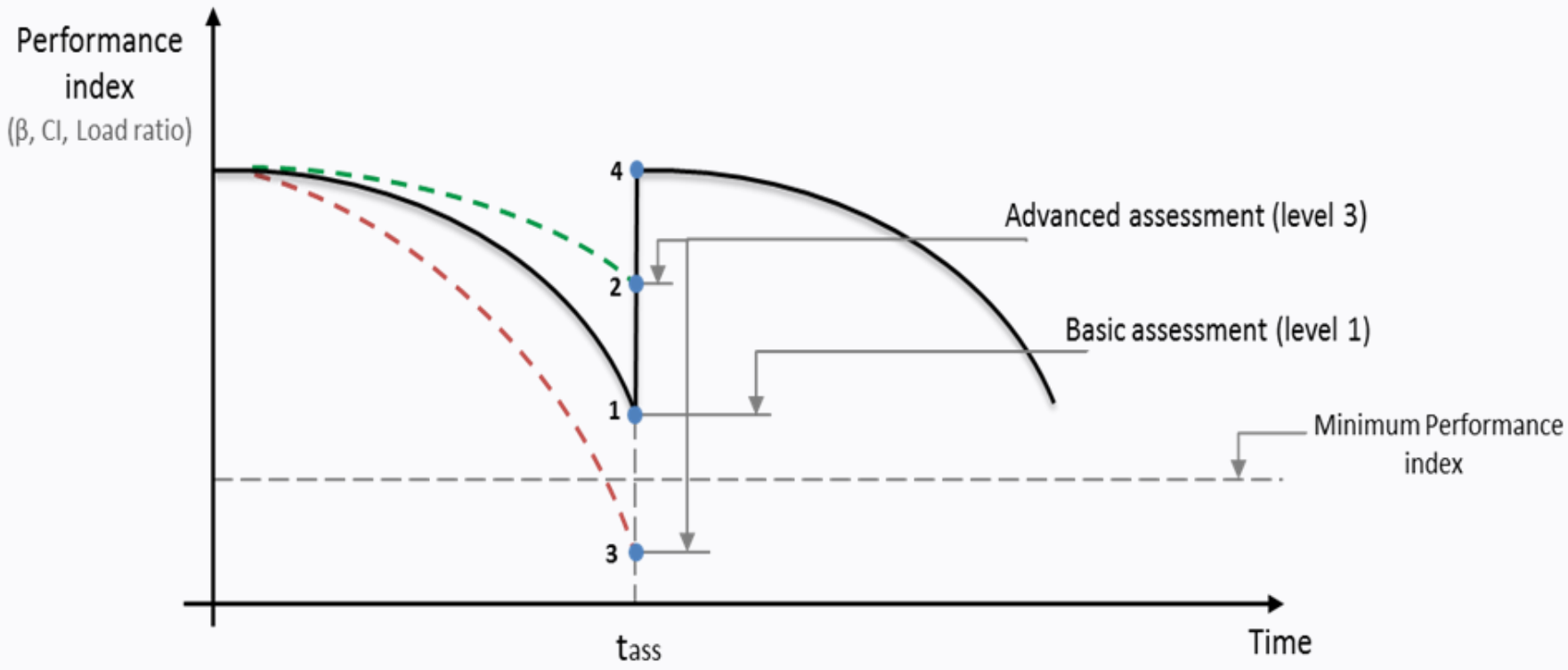
Surviving Brittle Member Failures

Damaged state redundancy

Shear failure from truck impact

Fatigue & Fracture

INTRODUCTION OF LCA PERSPECTIVE



Advanced assessment: Bridges

1.- Direct application of reliability-based assessment methods

2.- Consideration of system safety, redundancy and robustness criteria

3.- Site-specific live loads and dynamic amplification factors

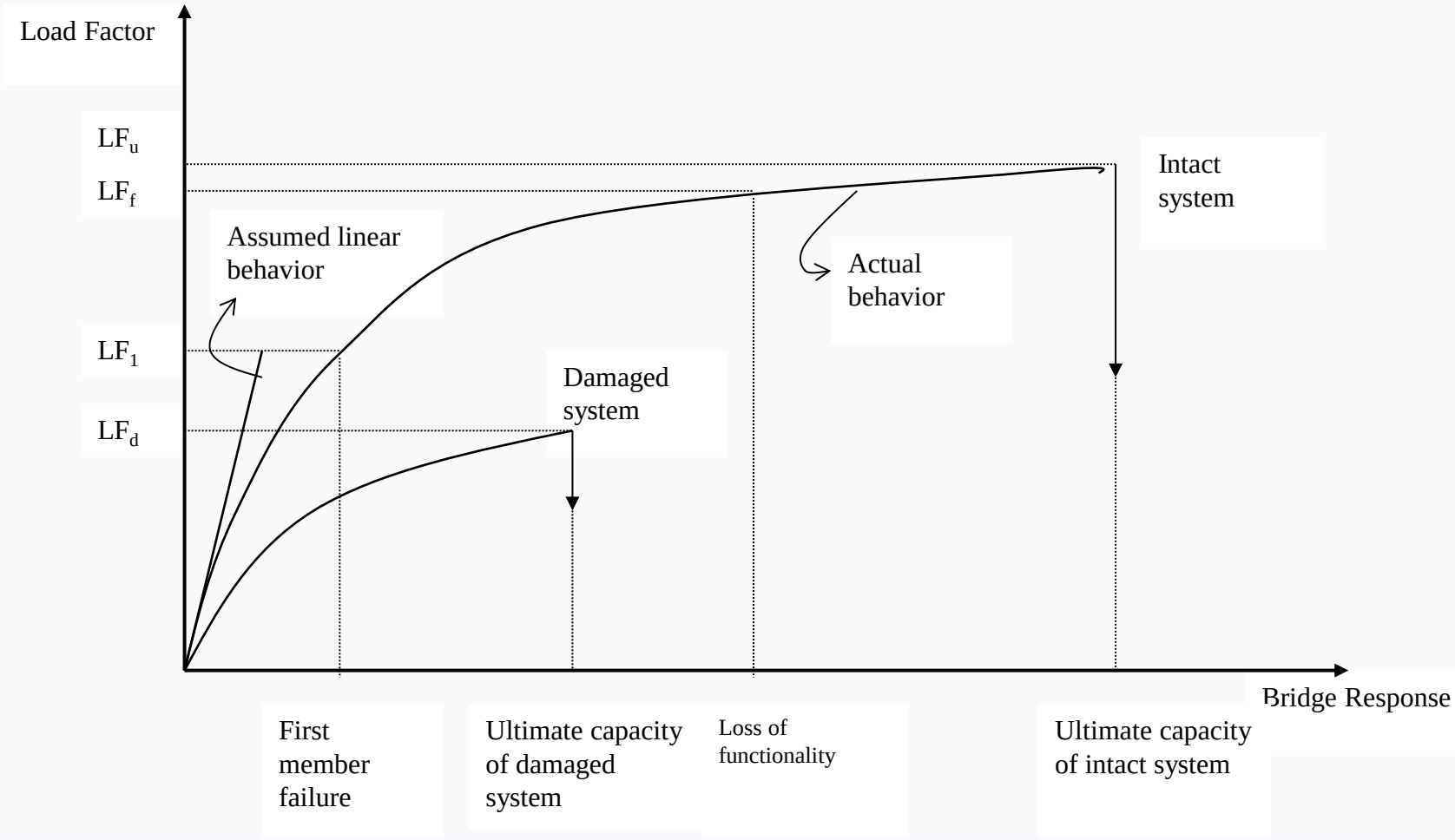
- **Traffic load, Temperature effects**

4.- Incorporation of data from inspection and monitoring. Model updating

- **FEM updating**
- **Degradation modelling: loss of area, loss of bond due to corrosion,…**

5.- Proof load testing

Definition of redundancy/robustness (I)



Updated Guideline from SB

FRP Strengthening of Concrete Structures

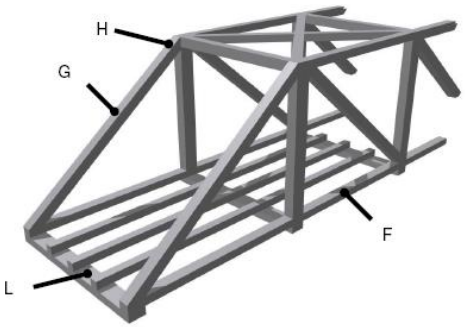
Content

1. Introduction
2. Basis for design
3. Material, systems and strengthening techniques
4. Strengthening for flexure
5. Strengthening for shear
6. Strengthening of columns
7. Extreme Loadings

- Calculation examples
- Checklists and quality control
- Typical material data

Sustainable Bridges

Repair and Strengthening of Railway Bridges - Guideline

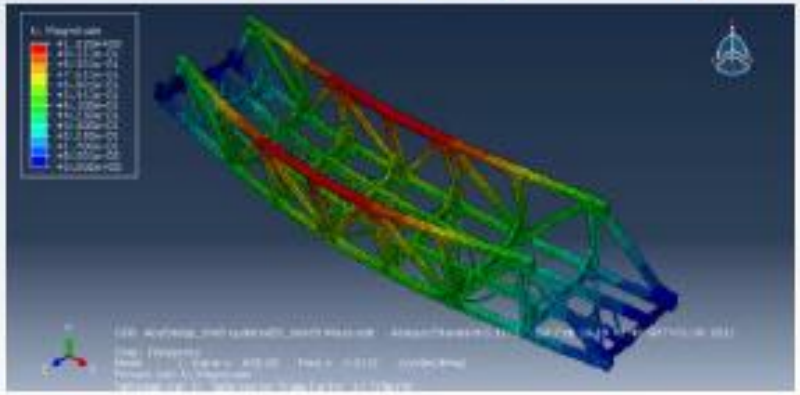


Sixth Framework Programme

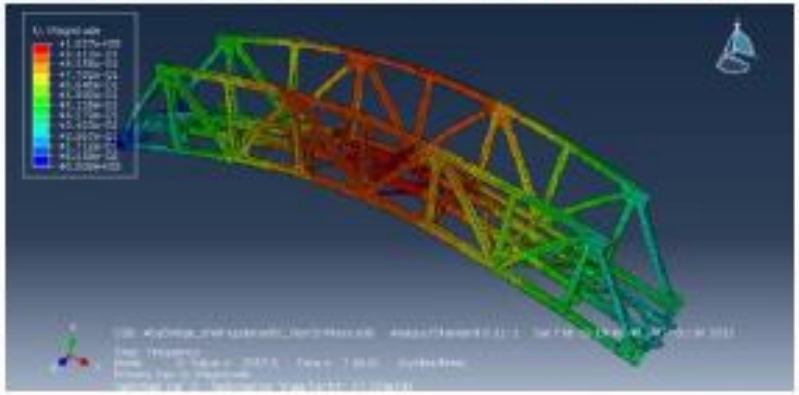
PRIORITY 6
SUSTAINABLE DEVELOPMENT
GLOBAL CHANGE & ECOSYSTEMS
INTEGRATED PROJECT

Eigenfrequencies

f = 4.01 Hz (No.1)

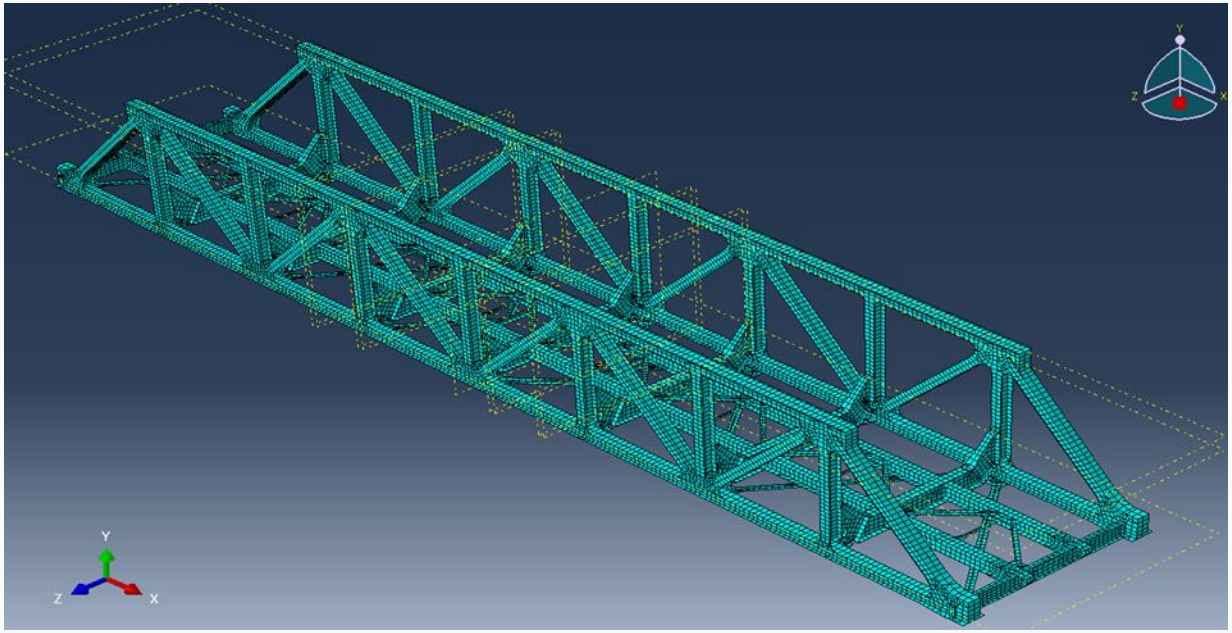


f = 7.56 Hz (No.2)

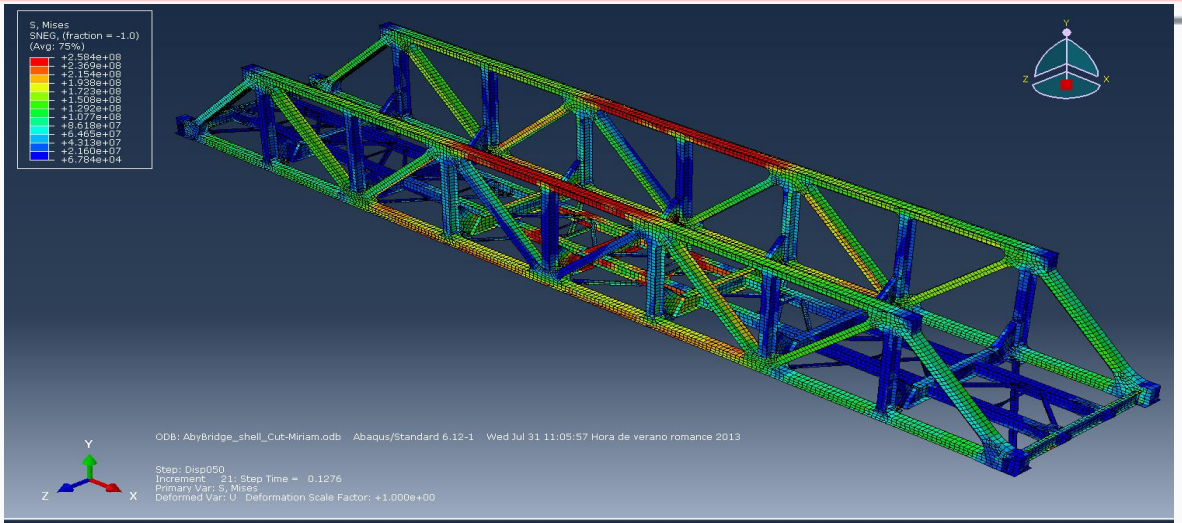


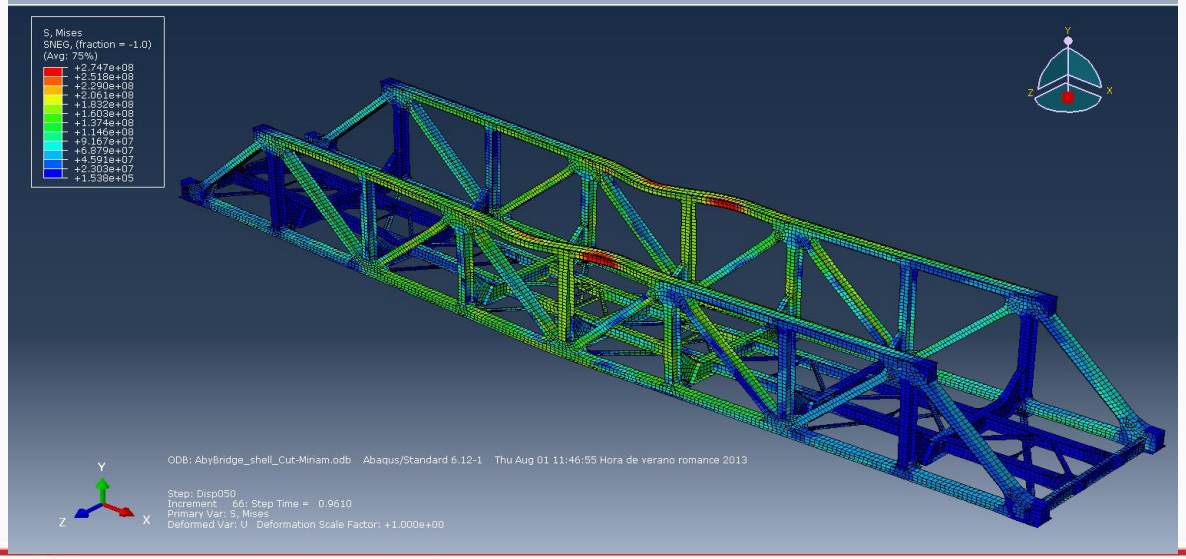
Reliability-based assessment: model and random variables

Random variable	Unit	Mean	COV (%)	PDF
Yield strength	MPa	220	10	Lognormal
Hardening modulus	MPa	1080	25	Lognormal
Self-weight	Kg/m^3	7800	3	Normal
Railway traffic load (concentrated)	kN	103.5 (4 loads per rail)	10	Normal
Railway traffic load (distributed)	kN/m	31.7/rail	10	Normal
Impact factor	-	1.10	25	Normal



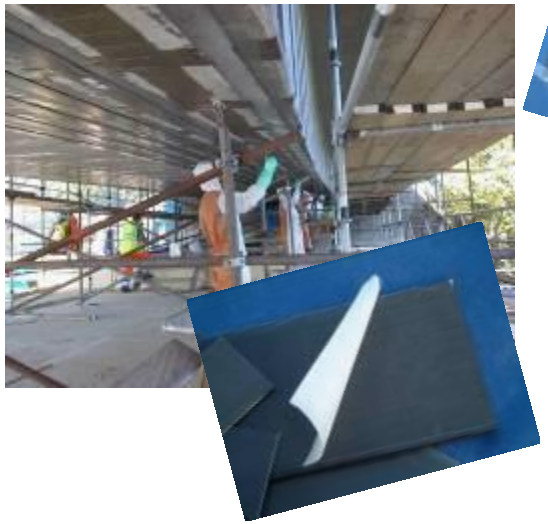
Stress (Von Mises) at maximum and ultimate loads



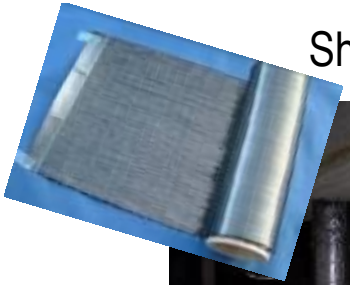


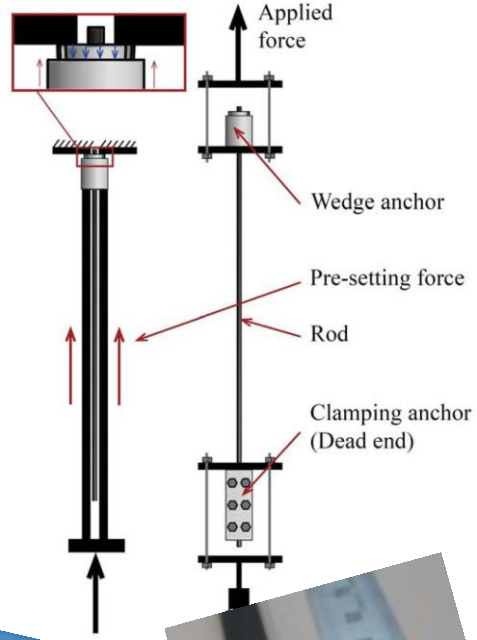
Evaluations of different CFRP strengthening systems

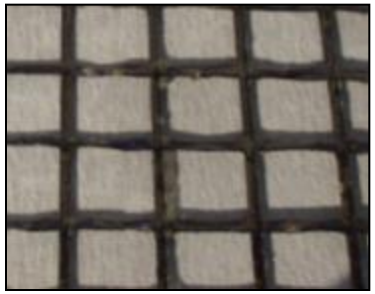
Plates



Sheets





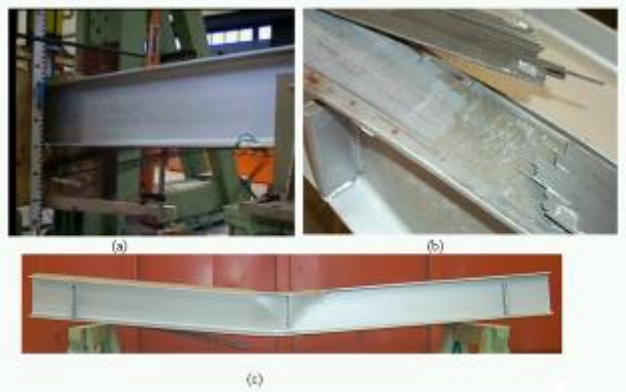


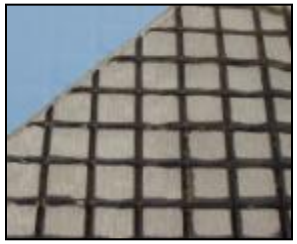
Grids, Mineral Based Strengthening Systems

Rods

- Prestressed
- Non prestressed

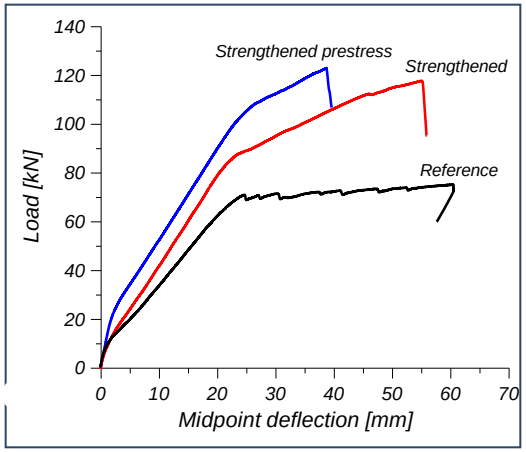
Strengthening of metallic structures



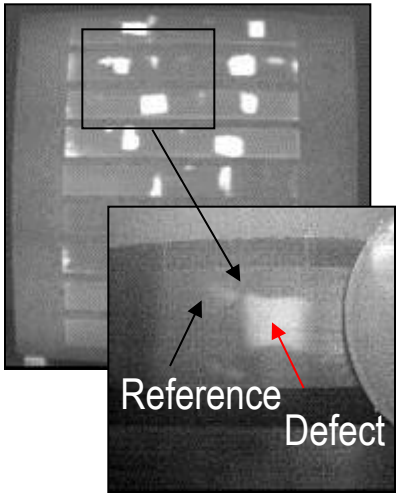


Mineral based CFRP strengthening

External prestressing

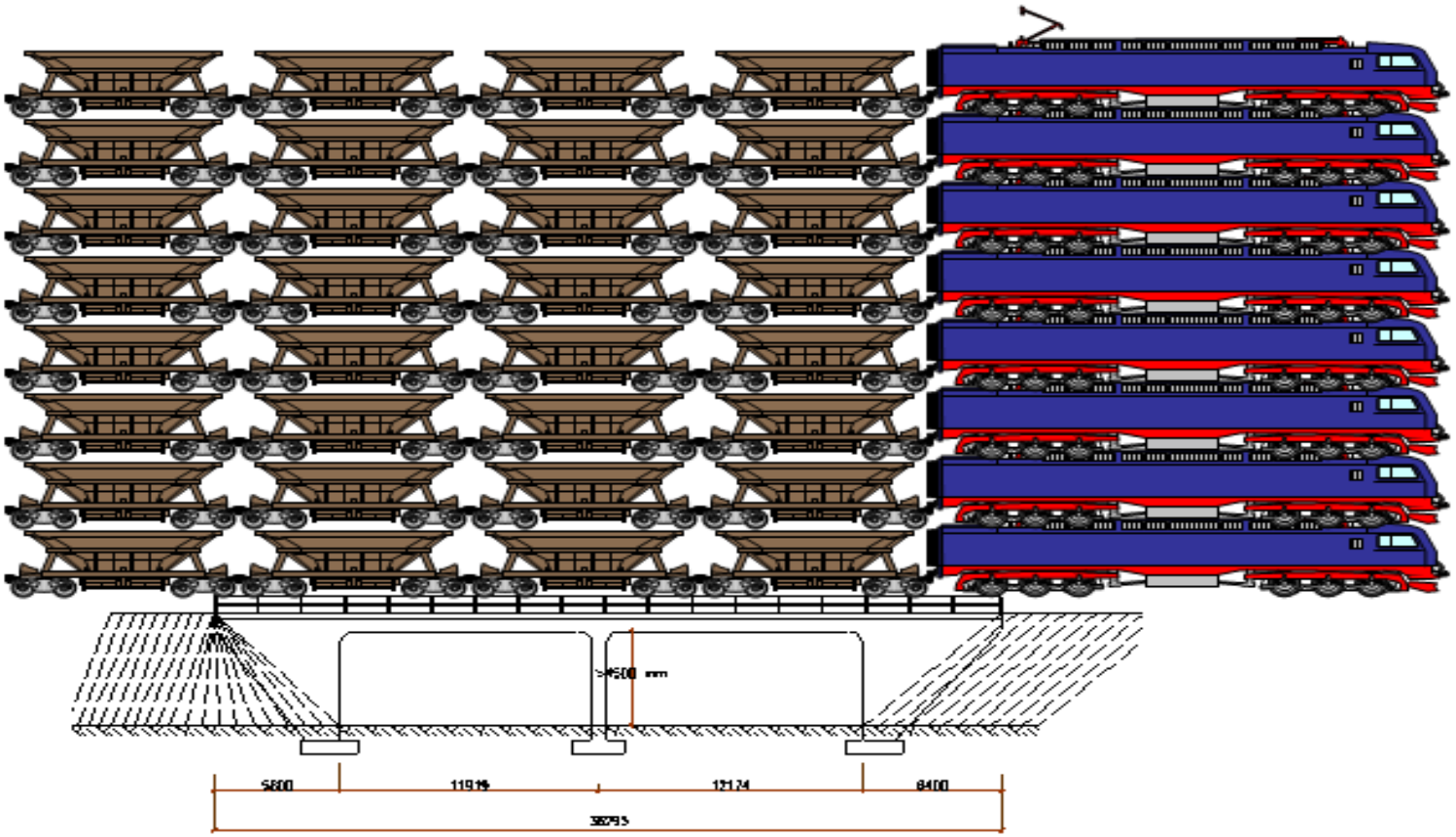


Thermography system



Integrated sensors

A little more than the design case



Reserve Capacity

The failure load 1170 ton corresponds to
1170 ton / 25 ton ≈ 47 axles

The span of 12 m has only room for 4 axles
47 axles /4 = 11,7 carriages (on top of each other)

The strengthening gives approx. 25 % of the capacity, so without strengthening we have a capacity of approx. 34/4 = 8,5 carriages