MAIN LINE

Workshop targeted to Central and Eastern Europe

Budapest, Hungary
15 May 2014

SEVENTH FRAMEWORK PROGRAMME

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

Agenda Thursday 15 May

15/05/14 – Public Workshop		
09:00	*Welcome/coffee*	
09:30	**Introduction**	Björn Paulsson, UIC/Trafikverket
09:45	**The role of LCAT in asset management**	David Castlo, Network Rail Justin LeBlanc, SKM
10:15	**Asset degradation & intervention strategies**	Marios Chryssanthopoulos, University of Surrey
10:45	*Break*	
11:15	**Methods to extend life of assets**	Lennart Elfgren, Luleå University of Technology
12:00	**Q&A**	
12:15	*Lunch*	
13:15	**Replacement of assets**	Britta Schewe, Deutsche Bahn
13:45	**Degradation monitoring: gaps & opportunities** **Case study presentation**	Polyvios Polyviou, TWI Zoltán ORBÁN, University of Pécs
14:30	**Demonstration of the LCAT**	Justin LeBlanc, SKM
15:30	**Q&A**	
15:45	**Feedback and conclusions**	Björn Paulsson, UIC/Trafikverket
16:00	*Break – end of workshop*	
16:30	**Advisory Committee meeting**	AC + EB members
18:00	*End of meeting*	

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Methods to Extend Life of Assets

Lennart Elfgren, LTU, and Joan Ramon Casas, UPC

Budapest, Hungary
15 May 2014

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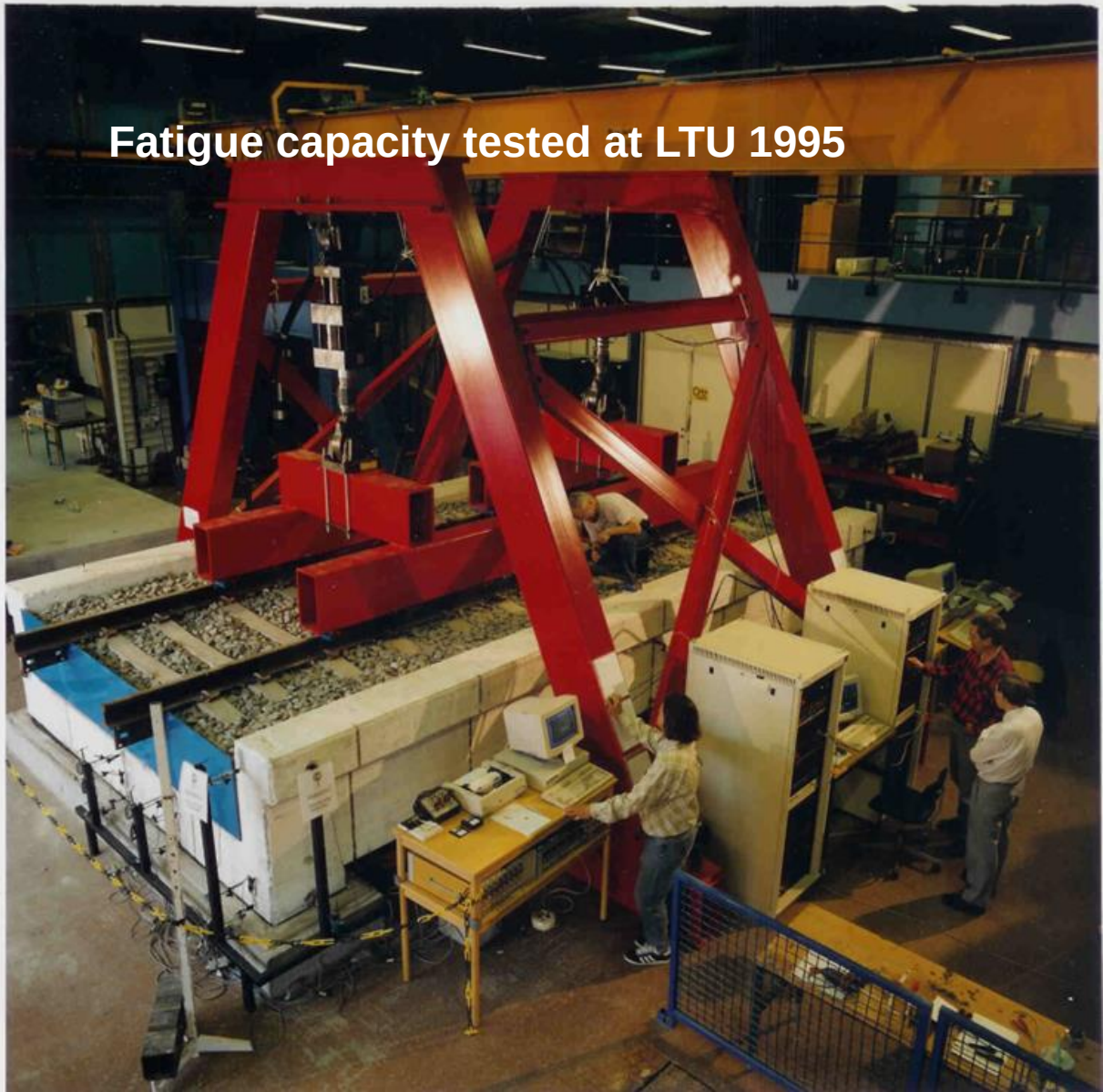
Methods to Extend Life of Assets

Outline

- **Background**
- Refined assessment metods – Joan Casas
- Strengthening methods
- Track and Earthwork
- Case studies – Four bridges


Iron ore in
Northern
Scandinavia
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

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Guideline - Extend Life of Assets

- Good ”house-keeping” saves money and makes our lives brighter

- We should care for and maintain our Rail Infrastructure in an optimal way

- There are two main categories of methods:

  - Administrative Methods – **Assess condition**, LCAT
  - Technical Methods – **Maintain, Strengthen,** Monitor, Exchange

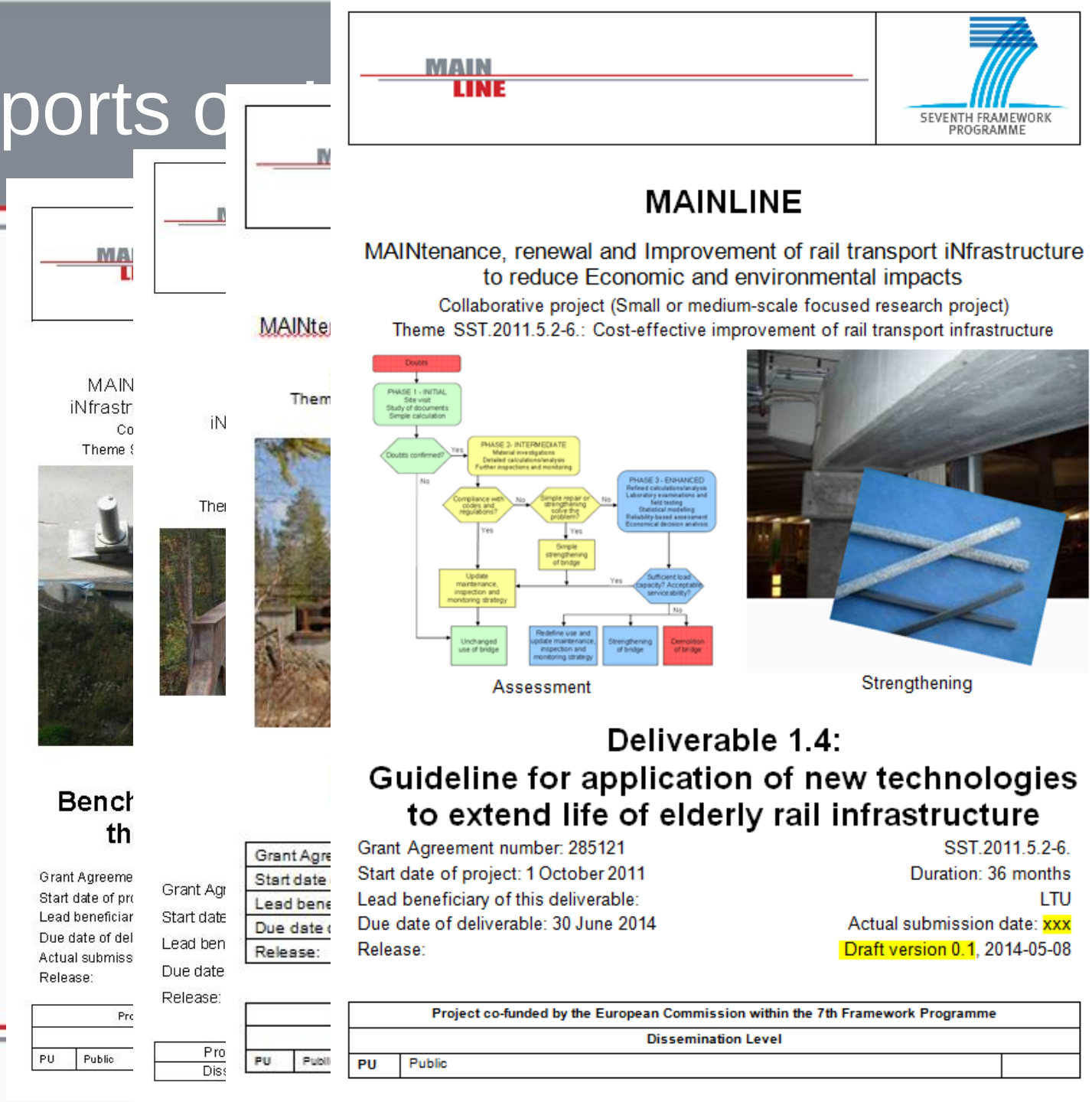
Four Reports o

Benchmark, D1.1

Assessment Methods, D1.2

Case Studies, D1.3

Guideline, D1.4



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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

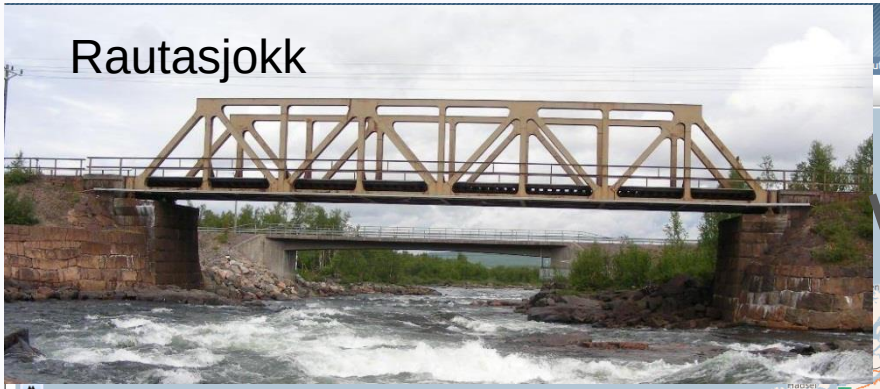
Lead beneficiary of this deliverable: LTU

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	

Four bridges to be tested/upgraded



Methods to Extend Life of Assets

Outline

- Background
- **Refined assessment metods** – Joan Casas
- Strengthening methods
- Track and Earthwork
- Case studies – Four bridges

WP 1 Objectives

- Explore and evaluate **new technologies** to extend life of old infrastructure

- **FIRST STEP and CHEAPEST TECHNOLOGY**:

  TO DO NOTHING !!

- Consequence: Develop advanced **assessment methods** to determine if the service life has to be extended

Justification of advanced assessment methods

- Standard methods for bridge design and assessment focus on the behavior of individual members using conservative estimates of member capacity.

- Generally, no instructions are provided on how to quantify redundancy or ductility

Surviving Ductile Member Failures

System redundancy

column failure
due to collision

column failure
due to EQ.

Surviving Brittle Member Failures

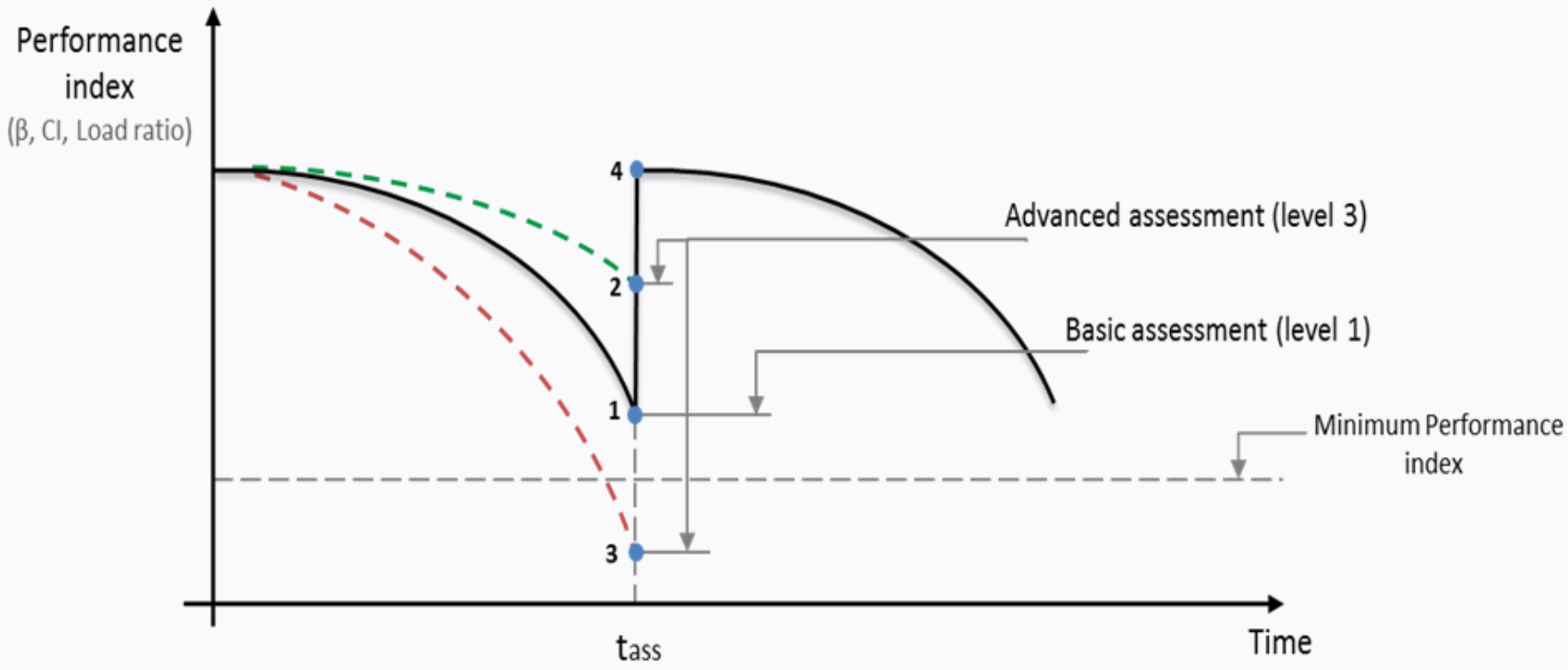
Damaged state redundancy

Shear failure from truck impact

Fatigue & Fracture

Surviving Brittle Member Failures

INTRODUCTION OF LCA PERSPECTIVE



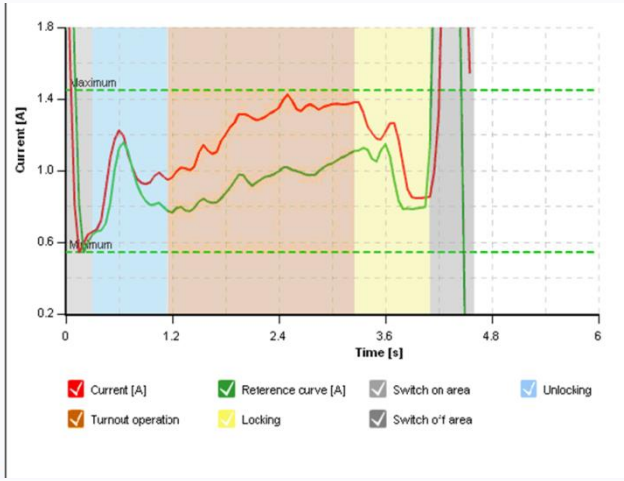
Railway assets

- **1.- Bridges**
- **2.- Tunnels**
- **3.- Track: Rail, switches and crossings**
- **4.- Earthworks**

Advanced assessment

- *Tunnels*
  - Tunnel Condition Monitoring Index (TCMI) - Network Rail
  - Reliability-based methods and risk and robustness assessments

- *track system: Rail, switches and crossings*
  - base-line reference curve of the measured intensity



Advanced assessment

- *Earth works*
  - Soil cutting stability: see embankments in SMARTRAIL
  - Soil Slope Hazard Index (SSHI) and Rock Slope Hazard Index (RSHI) adopted by NR
  - See deliverables D2.2 and D2.3 of MAINLINE

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

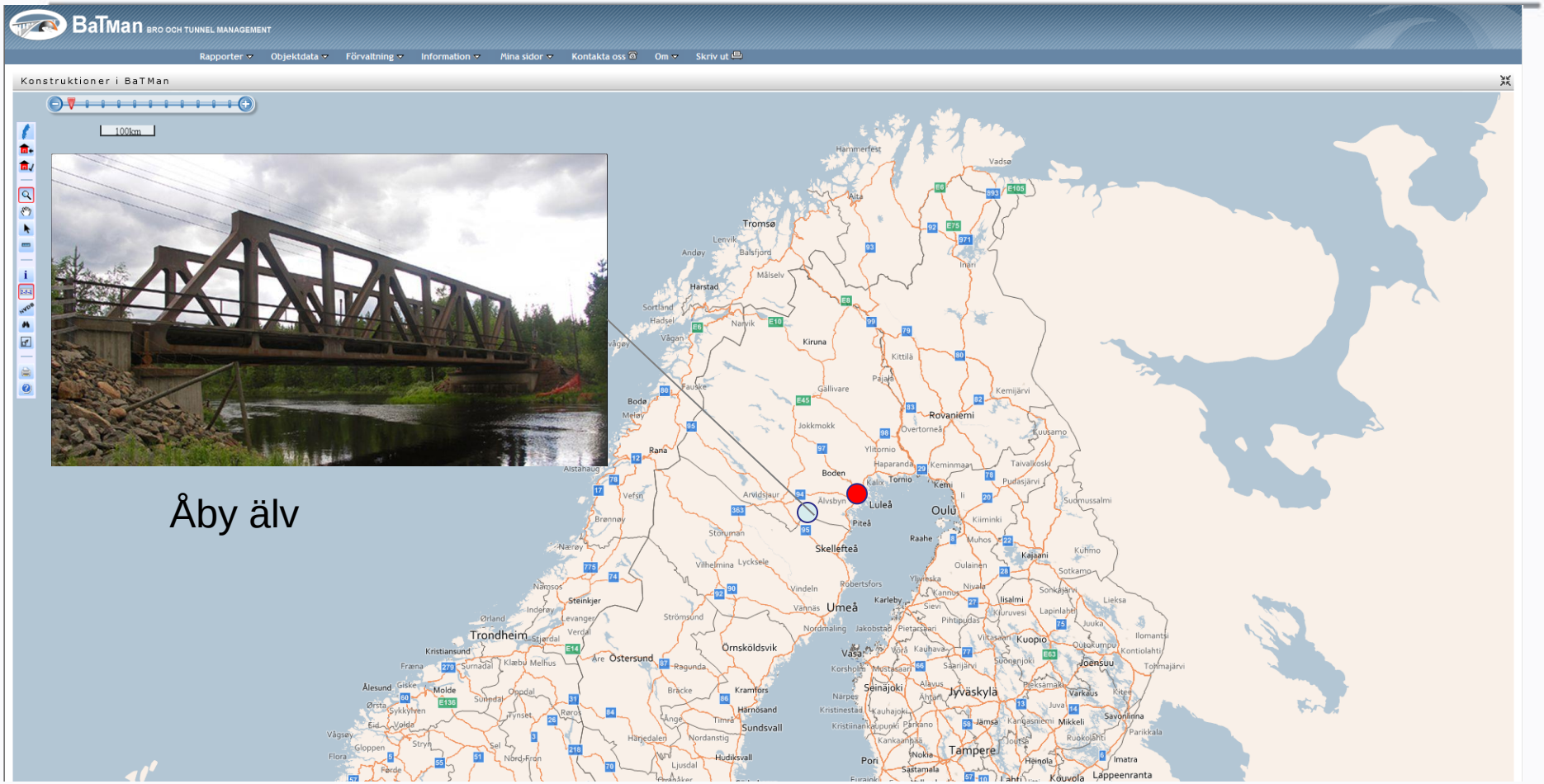
- **Traffic load, Temperature effects**

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

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

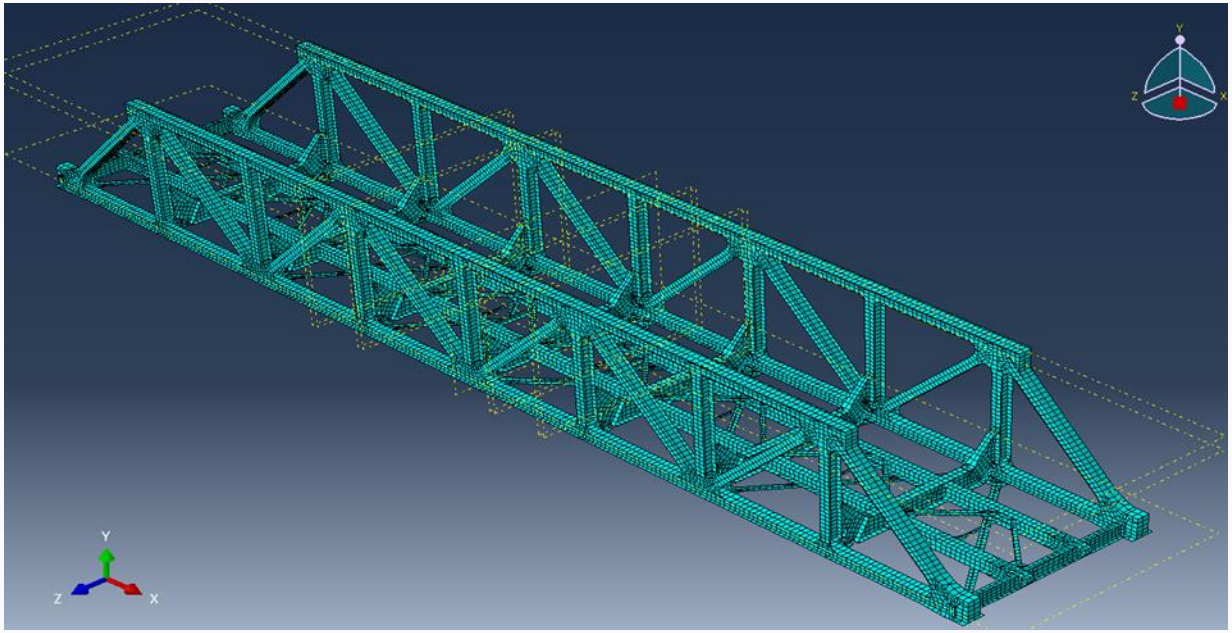
5.- Proof load testing

Examples: Aby alv river bridge

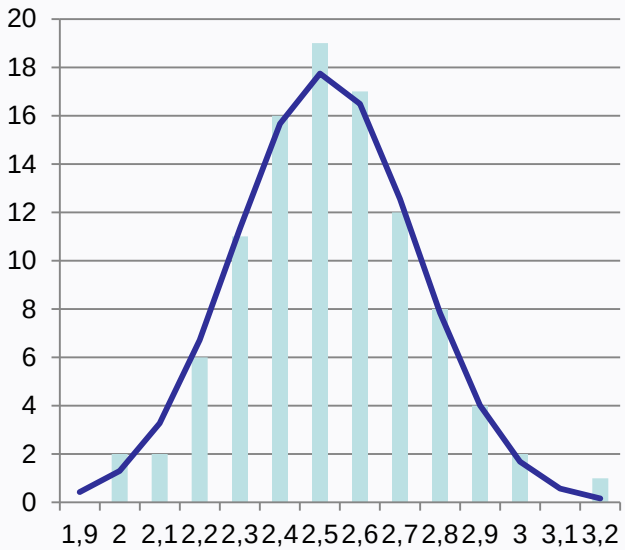


Reliability-based assessment: model and random variables

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

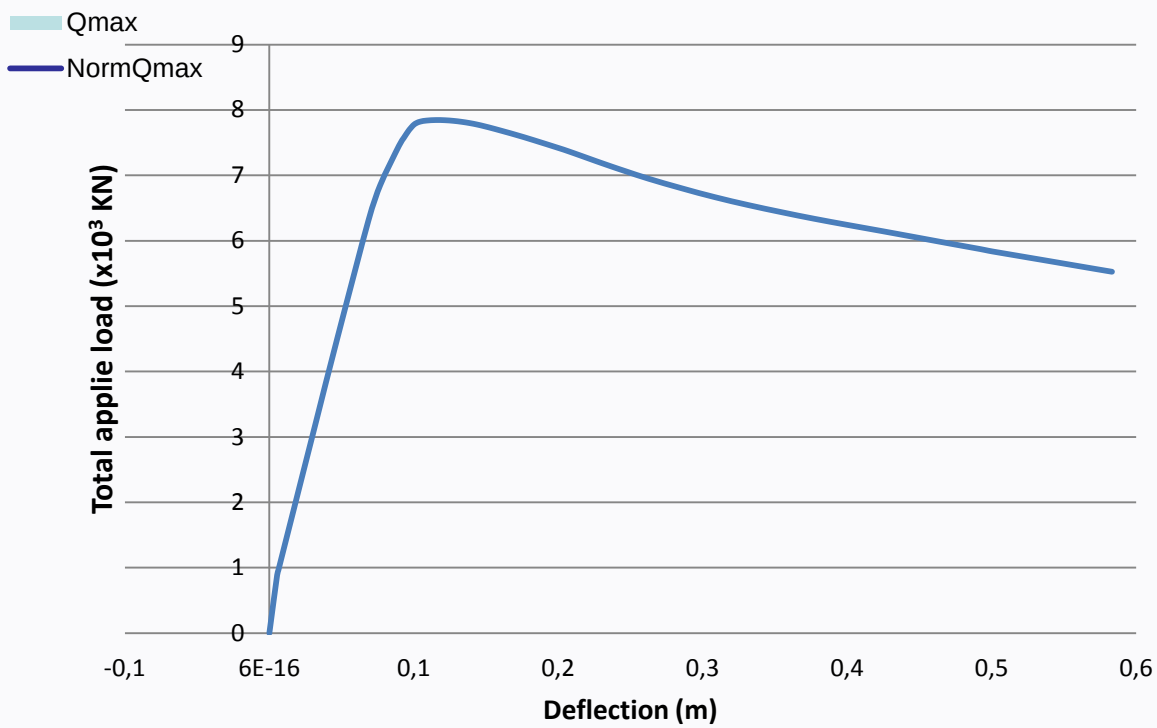


Results

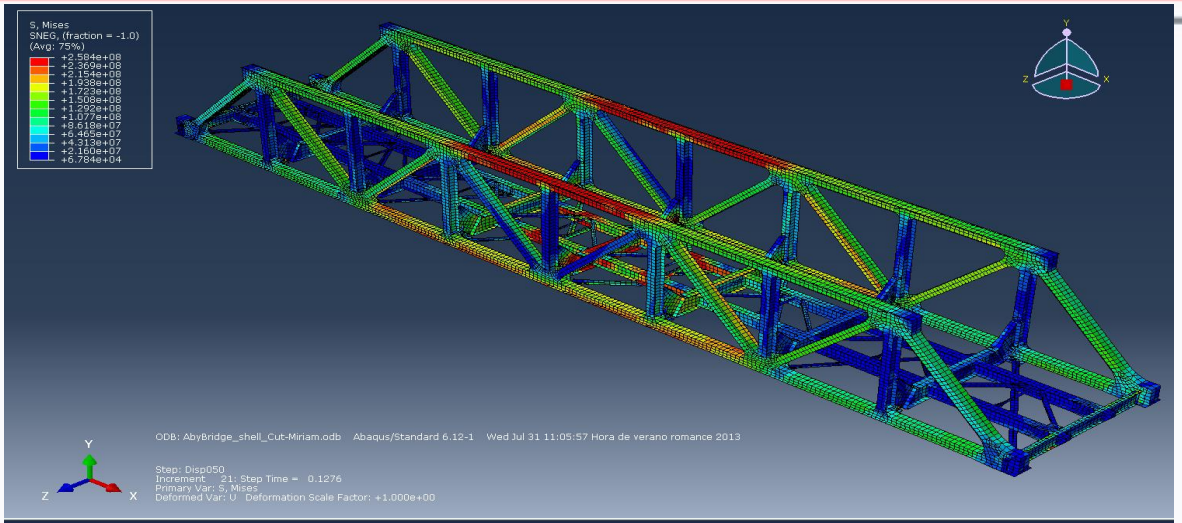


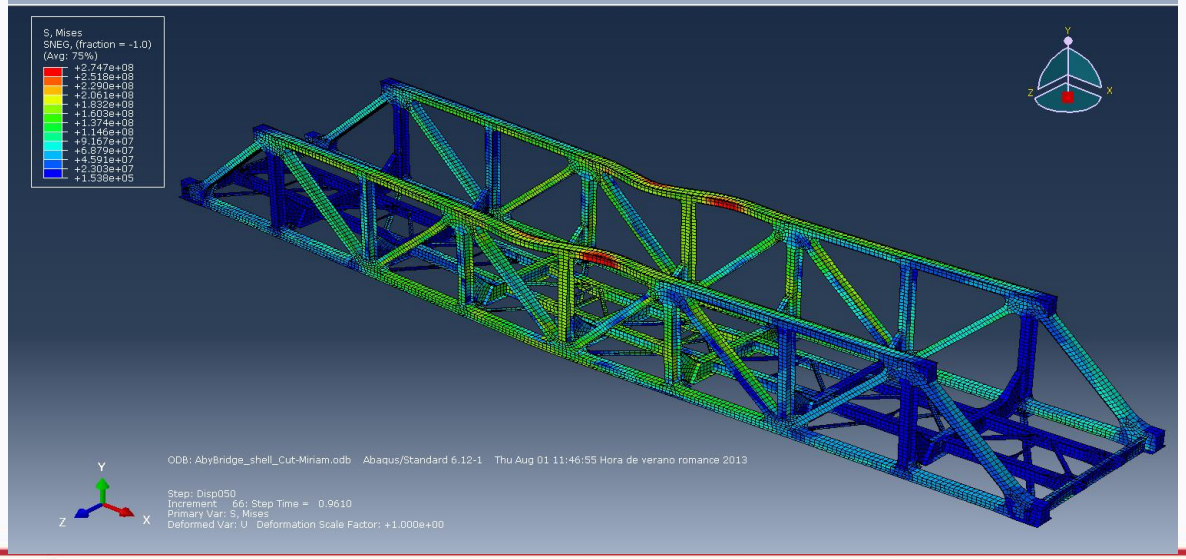
$$\beta = \frac{R - S}{\sqrt{{\sigma_R}^2 + {\sigma_S}^2}}$$

$$\beta = 5.96$$

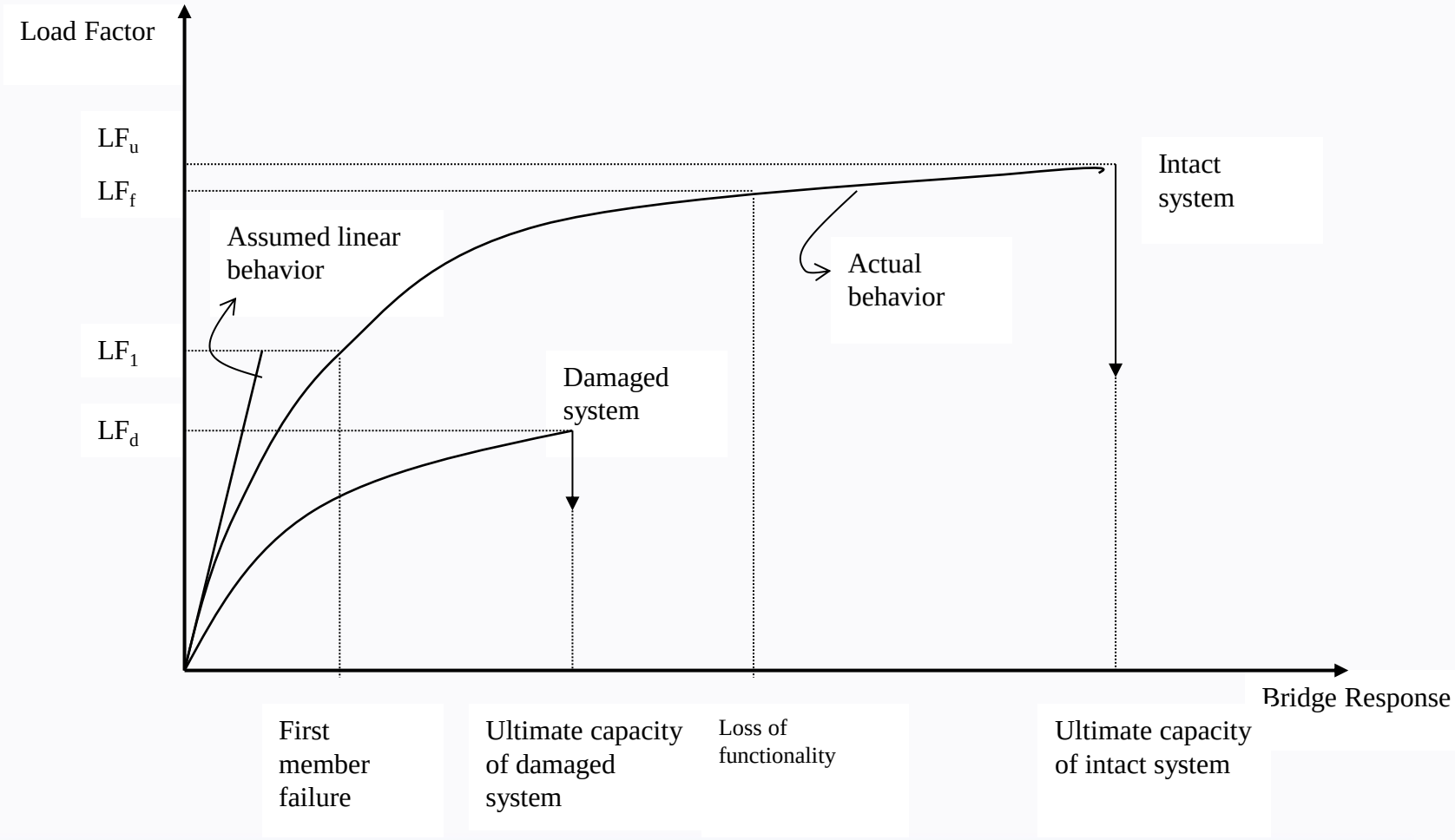


Stress (Von Mises) at maximum and ultimate loads





Definition of redundancy/robustness (I)

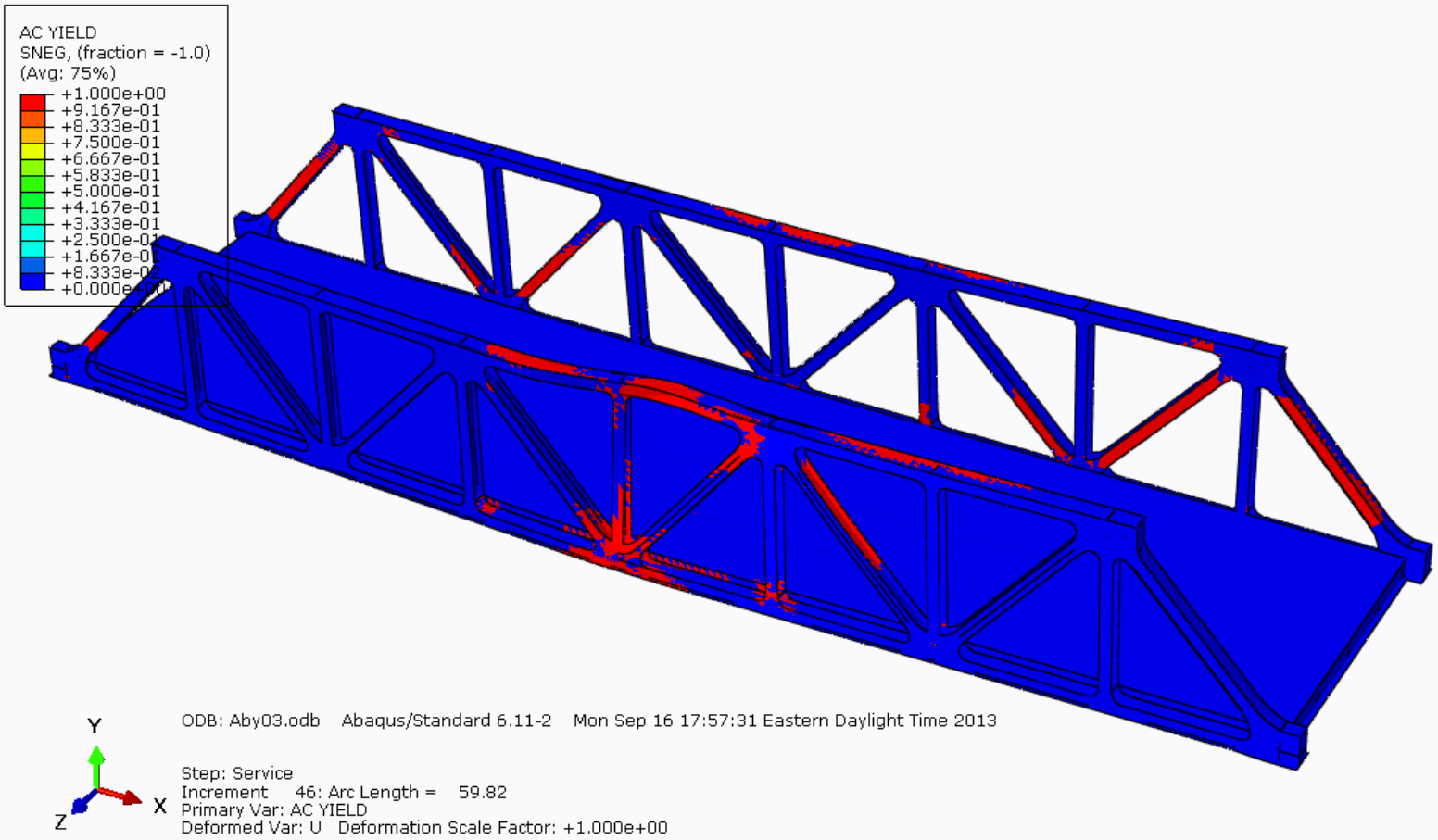


Redundancy Measures (SB)

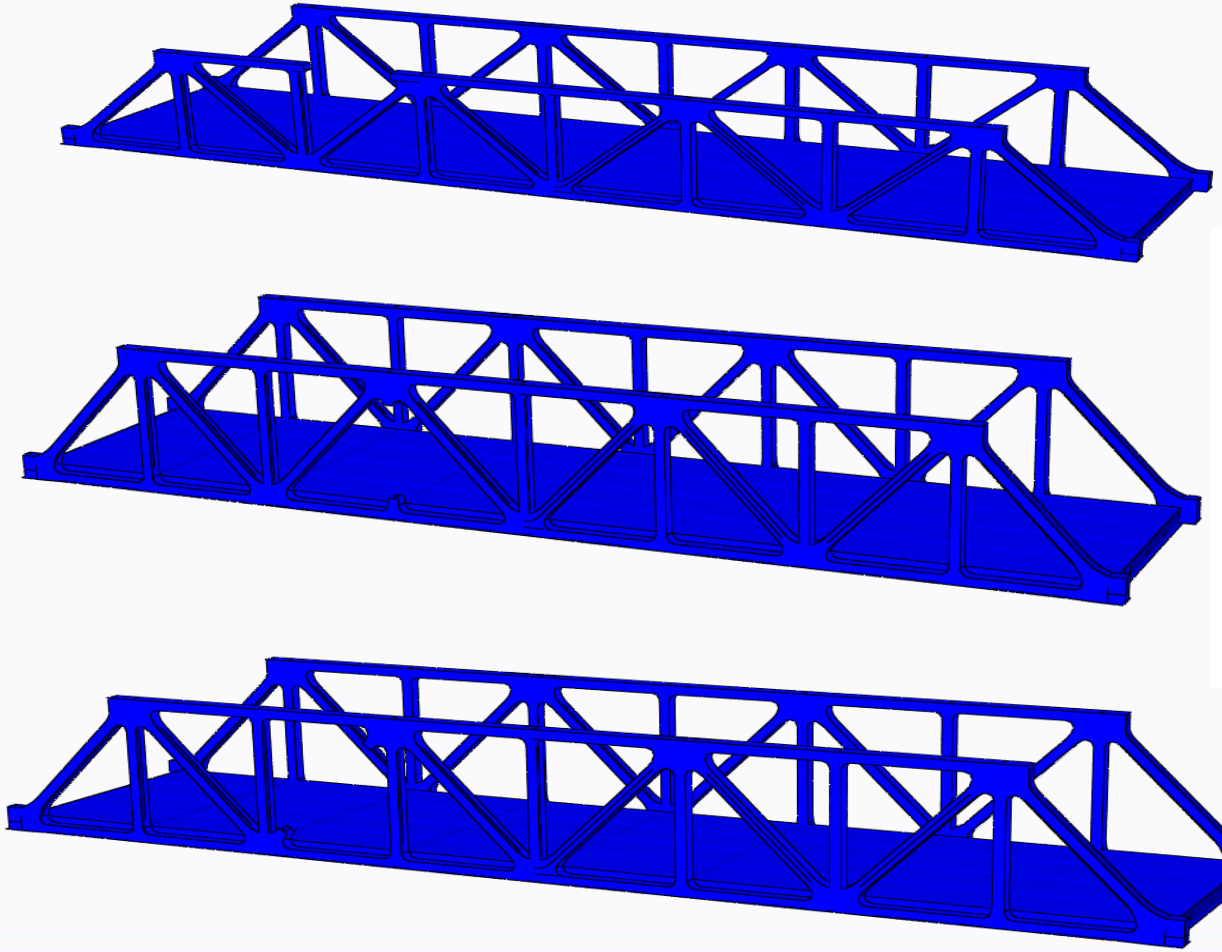
- Redundancy is the capability of a bridge system to continue to carry loads after the failure of a main member.
- For ductile member failures, the performance follows "intact system" curve.
- For brittle member failures (e.g. fracture, shear, or connections), the performance follows "damaged system" curve.
- Redundancy ratios:

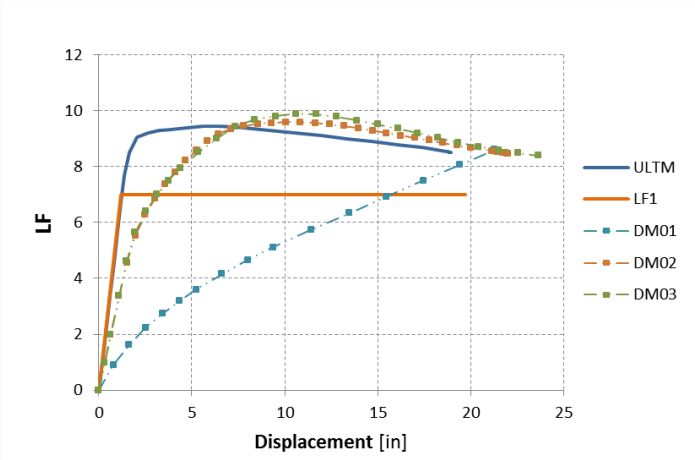
$$R_u = \frac{LF_U}{LF_1} \qquad R_f = \frac{LF_f}{LF_1} \qquad R_d = \frac{LF_d}{LF_1}$$

Original bridge



Damaged bridge





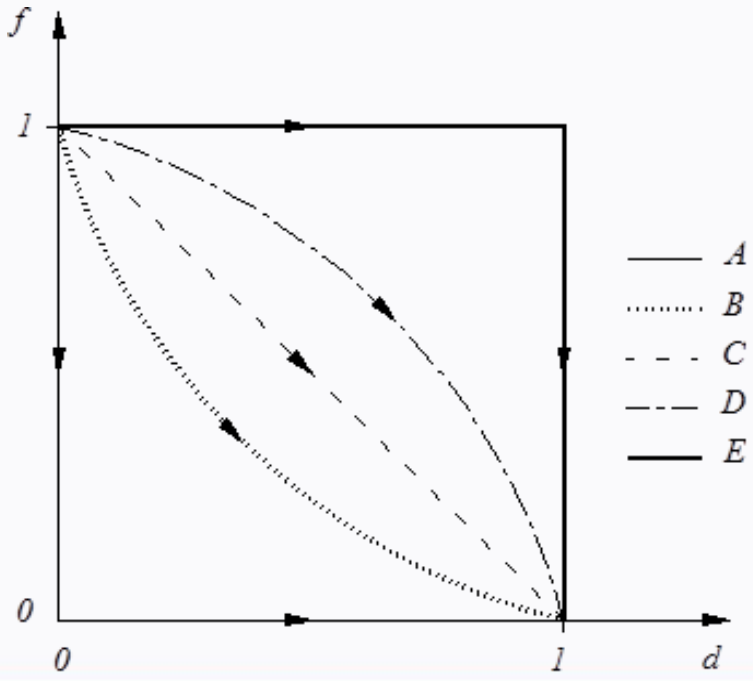
Results

Redundancy Ratios for Aby Bridge (shaded cell shows low redundancy level)

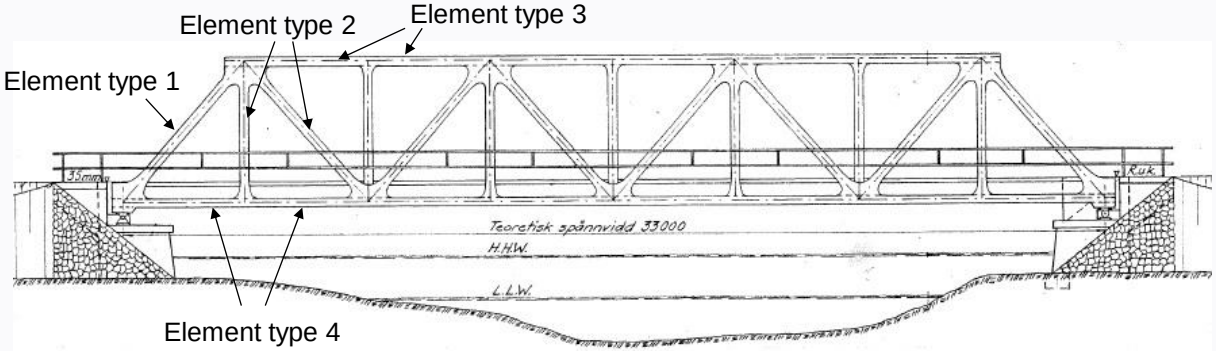
Analysis Case	LFu/LF1 Ultimate limit state of originally intact bridge	LFf/LF1 Functionality limit state of originally intact bridge	LFd/LF1 Redundancy ratio for damaged bridge scenarios	LF100/LF1 for damaged bridge scenarios
ULTM	1.35	1.29	-	
CM01	-		0.30	0.21
CM02	-		0.57	0.40
CM03	-		0.67	0.40
VM01	-		1.35	1.29
VM02	-		1.35	1.29
VM03	-		1.30	1.25
VM04	-		1.27	1.14
DM01	-		1.23	0.91
DM02	-		1.37	1.35
DM03	-		1.41	1.40

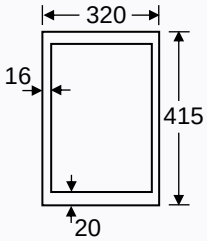
Definition of robustness (II)

$$R_d = \int_{d=0}^{d=1} f(x)dx$$

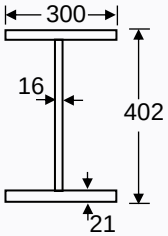


Robustness to corrosion

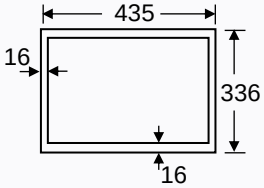




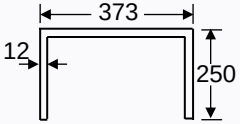
Element type 1



Element type 2



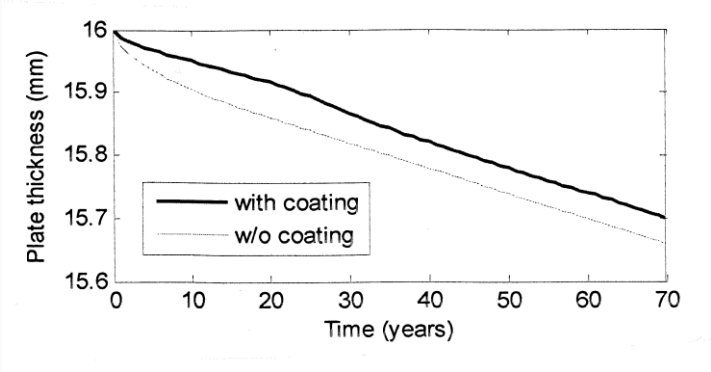
Element type 3



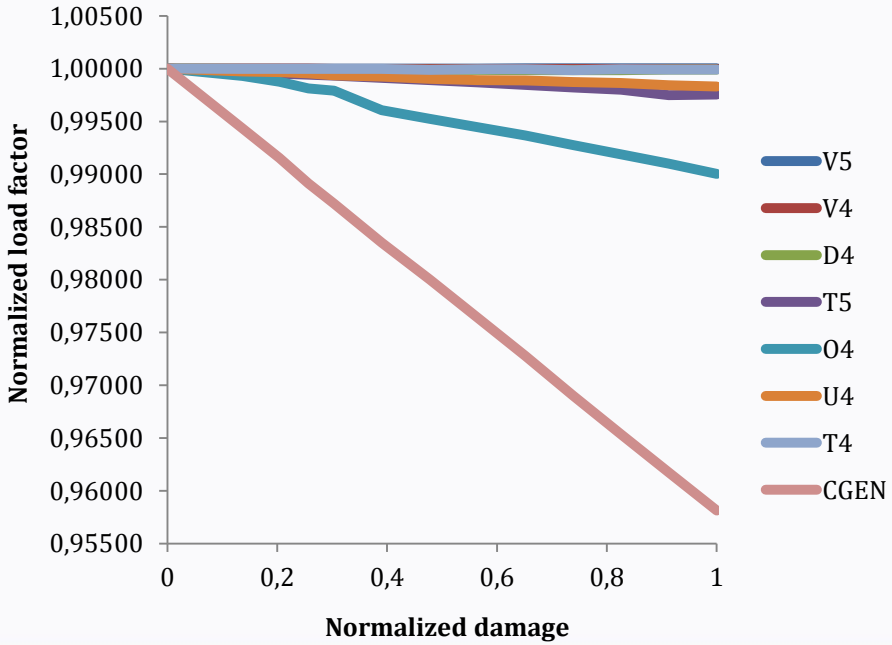
Element type 4

Robustness to corrosion

$$C = A \cdot t^B$$



Thickness profile for element type 3 and class C2



$$R_d = 0.98$$

Thank you !

Methods to Extend Life of Assets

Outline

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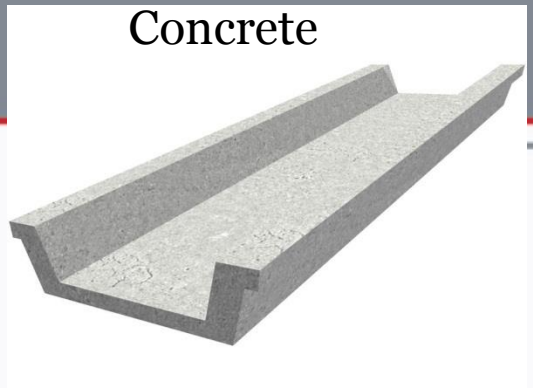
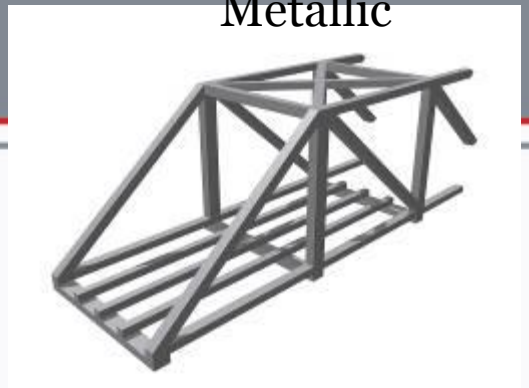
Repair and Strengthening. First step: Selection of Materials

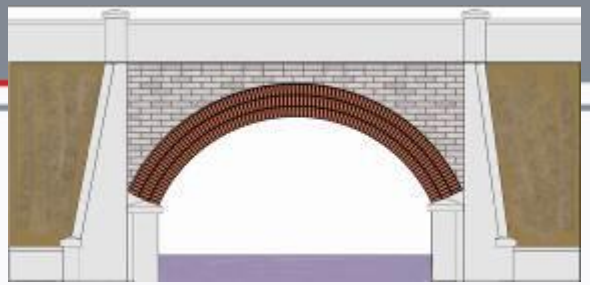
Concrete



Metallic

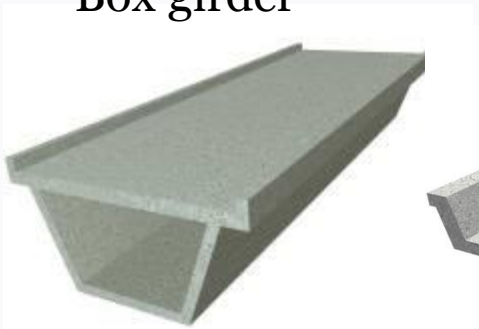


Masonry

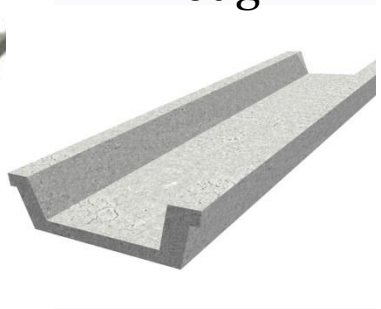


Second step: Selection of bridges, for example reinforced concrete

Box girder



Trough

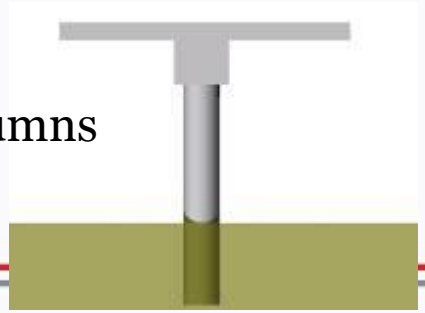


Beam/Slab

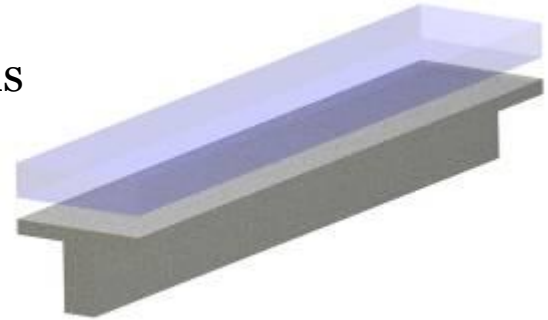
Arch

Or/and structural elements

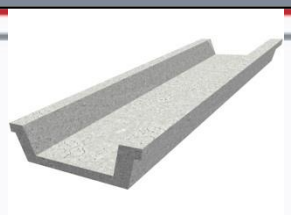
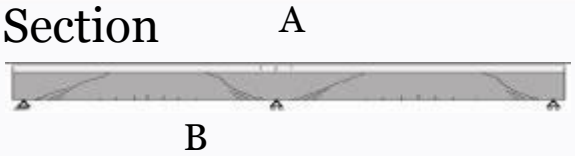
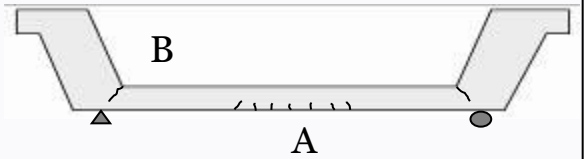
Columns



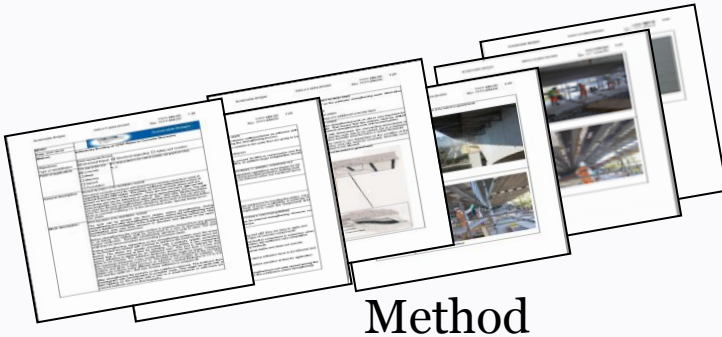
Beams



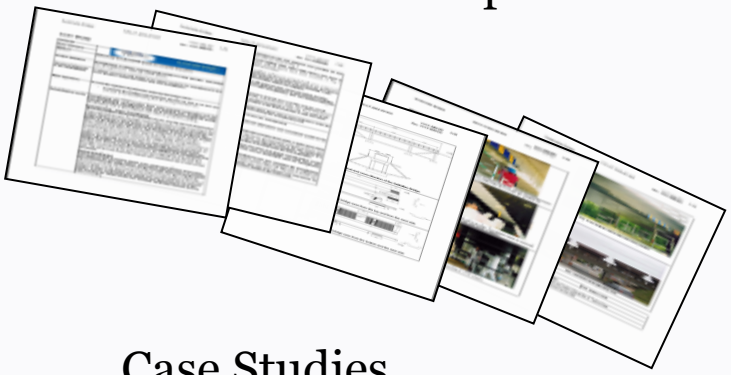
Third step: Focus on strengthening needs – a detailed description

View 	Section 
Photo(s) 	Section 

This is then related to method descriptions and case studies



Method Descriptions



Case Studies

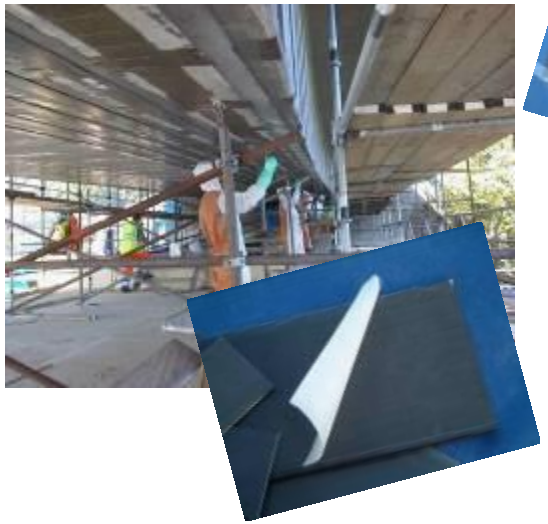
Easy to add-on

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

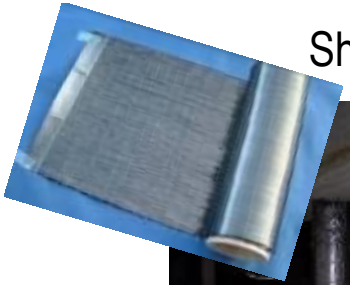
Prepared for databases

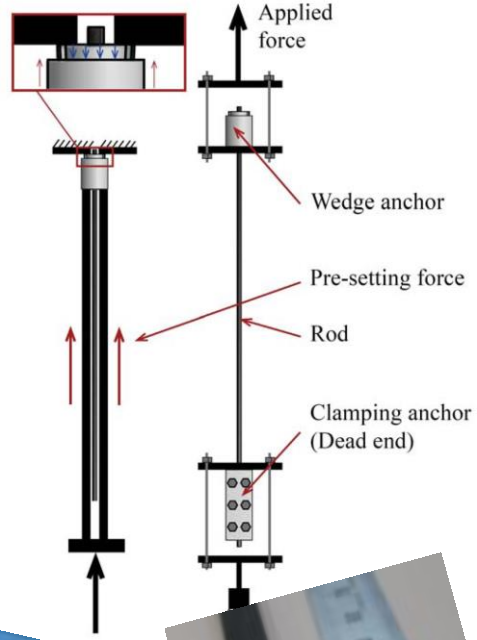
Evaluations of different CFRP strengthening systems

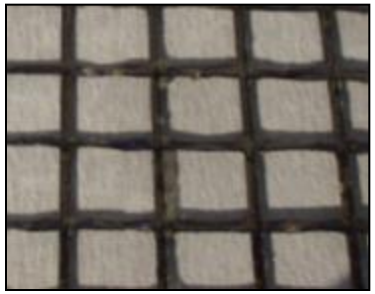
Plates



Sheets





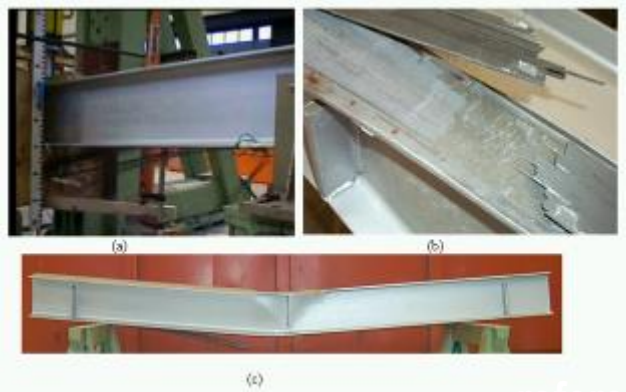


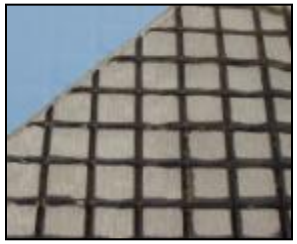
Grids, Mineral Based Strengthening Systems

Rods

- Prestressed
- Non prestressed

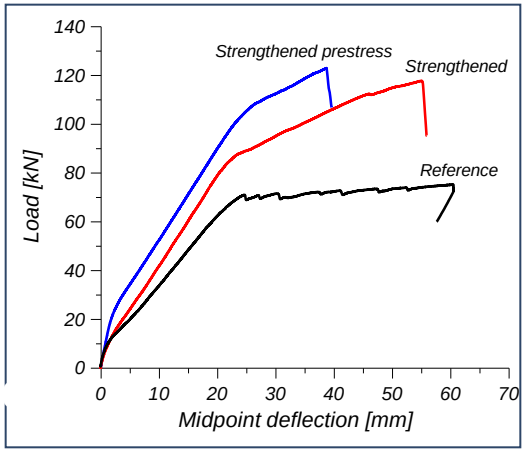
Strengthening of metallic structures



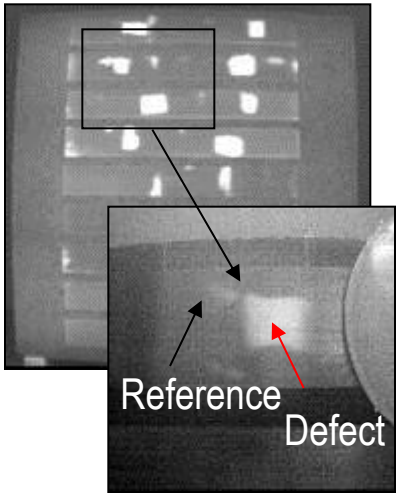


Mineral based CFRP strengthening

External prestressing



Thermography system



Integrated sensors

Implementation
The Örnsköldsvik bridge

Diagnosis

Inspection and Condition Assessment

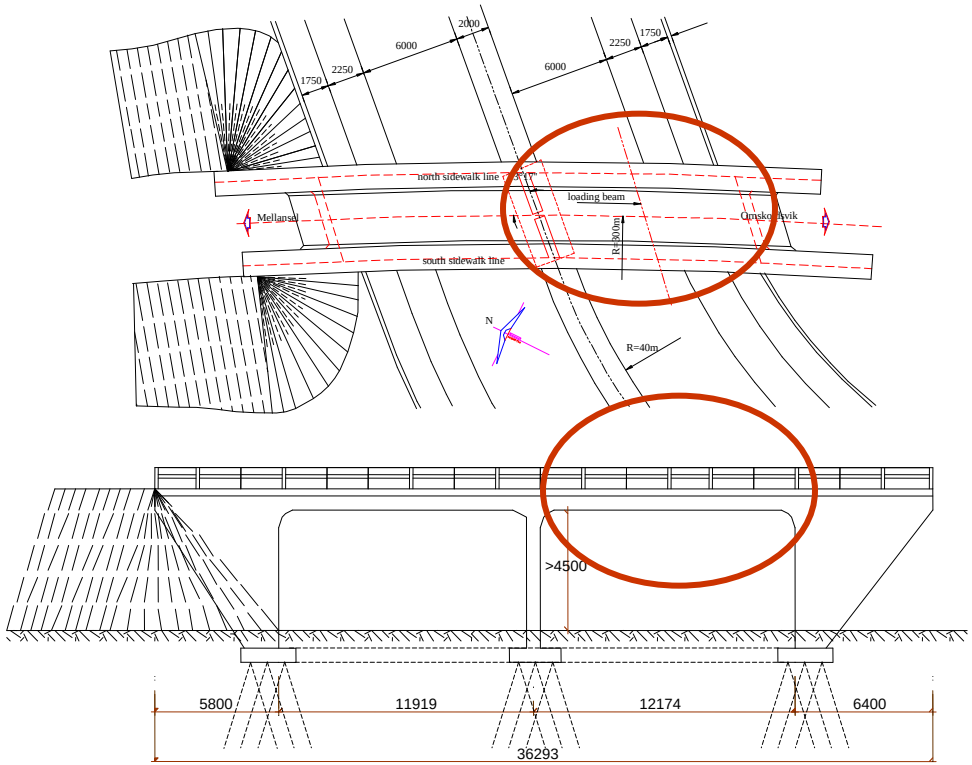
FE-analyses and more detailed calculations

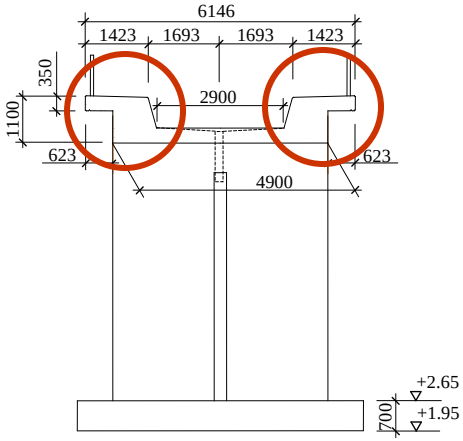
CFRP Strengthening with NSMR bars

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

Further evaluations

Implementation
The Örnsköldsviks bridge

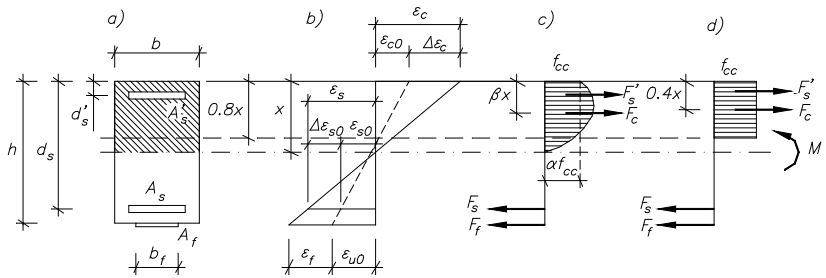




Implementation

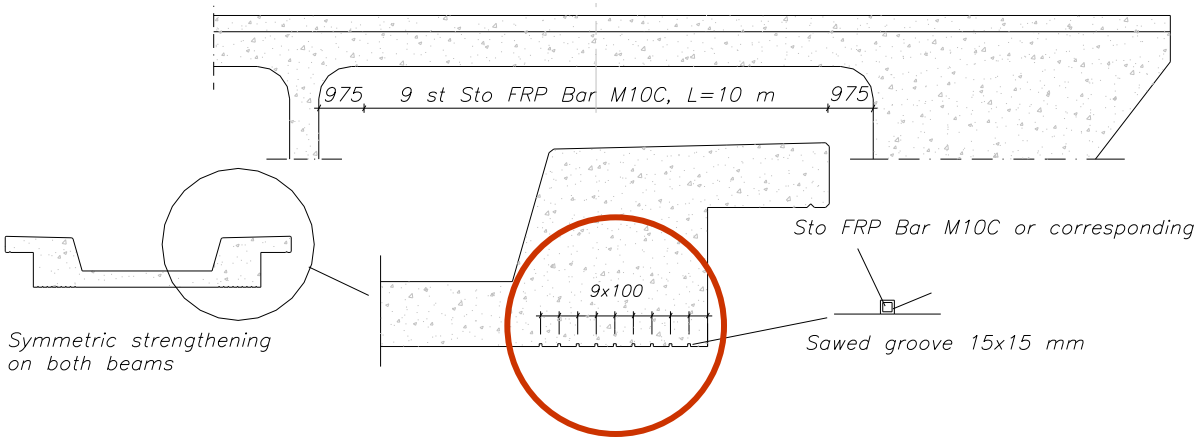
The Örnsköldsviks bridge - 2006

First the strengthening design was carried out

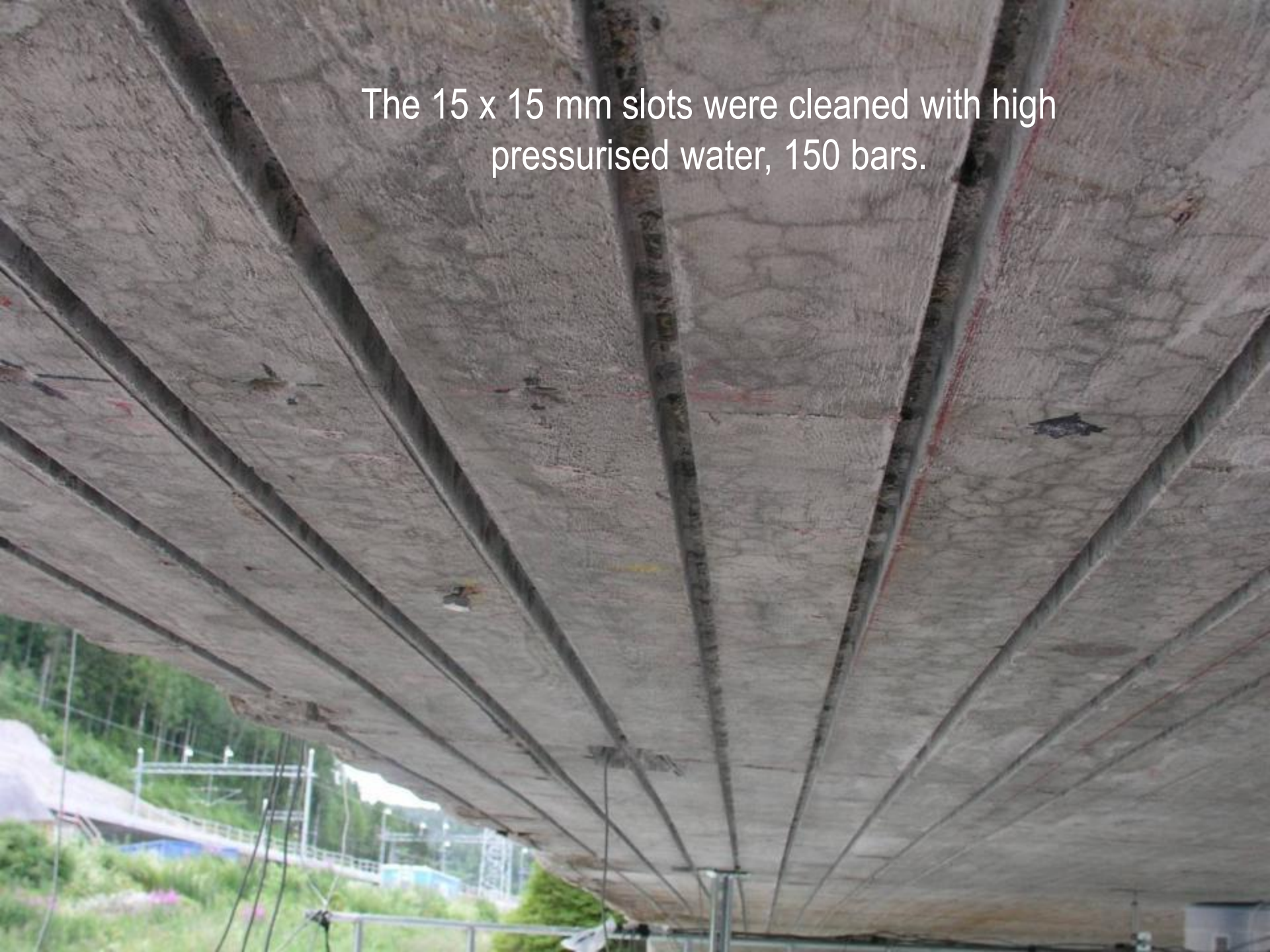


$$M = \frac{x - d_s'}{h - x}\left(\varepsilon_f + \varepsilon_{uo}\right)A_s' E_s\left(\beta x - d_s'\right) + A_s f_y\left(d_s - \beta x\right) + \varepsilon_f E_f A_f\left(h - \beta x\right)$$

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



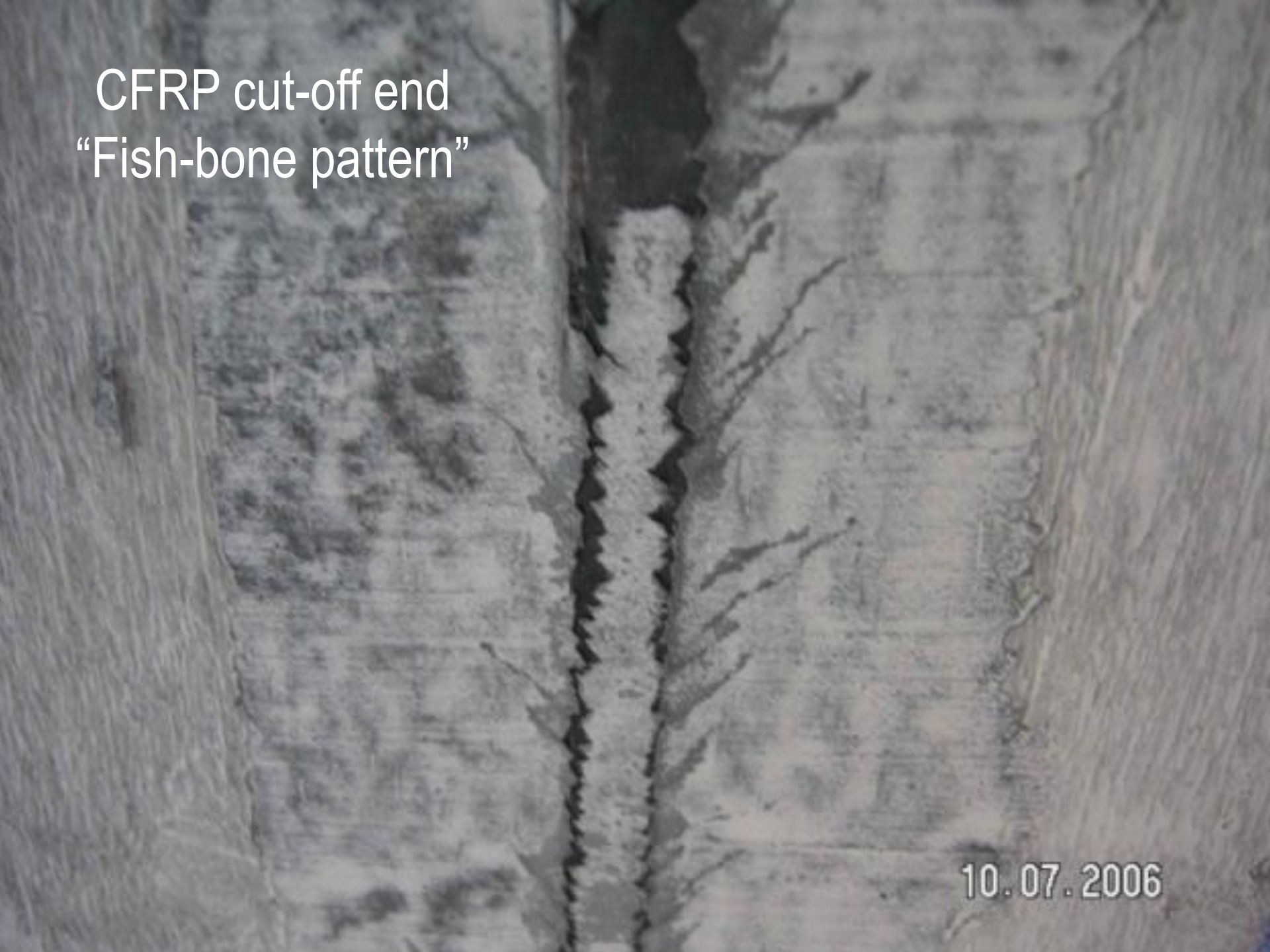

Sawing for Strengthening.
(Near Surface Mounted CFRP Rods)
27.06.2006


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

Failure of Övik Bridge

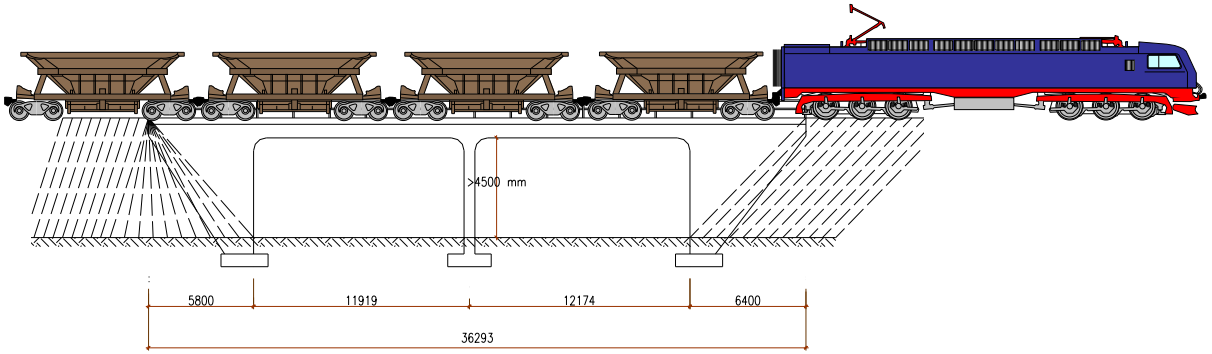
- Movie clip

Reserve Capacity

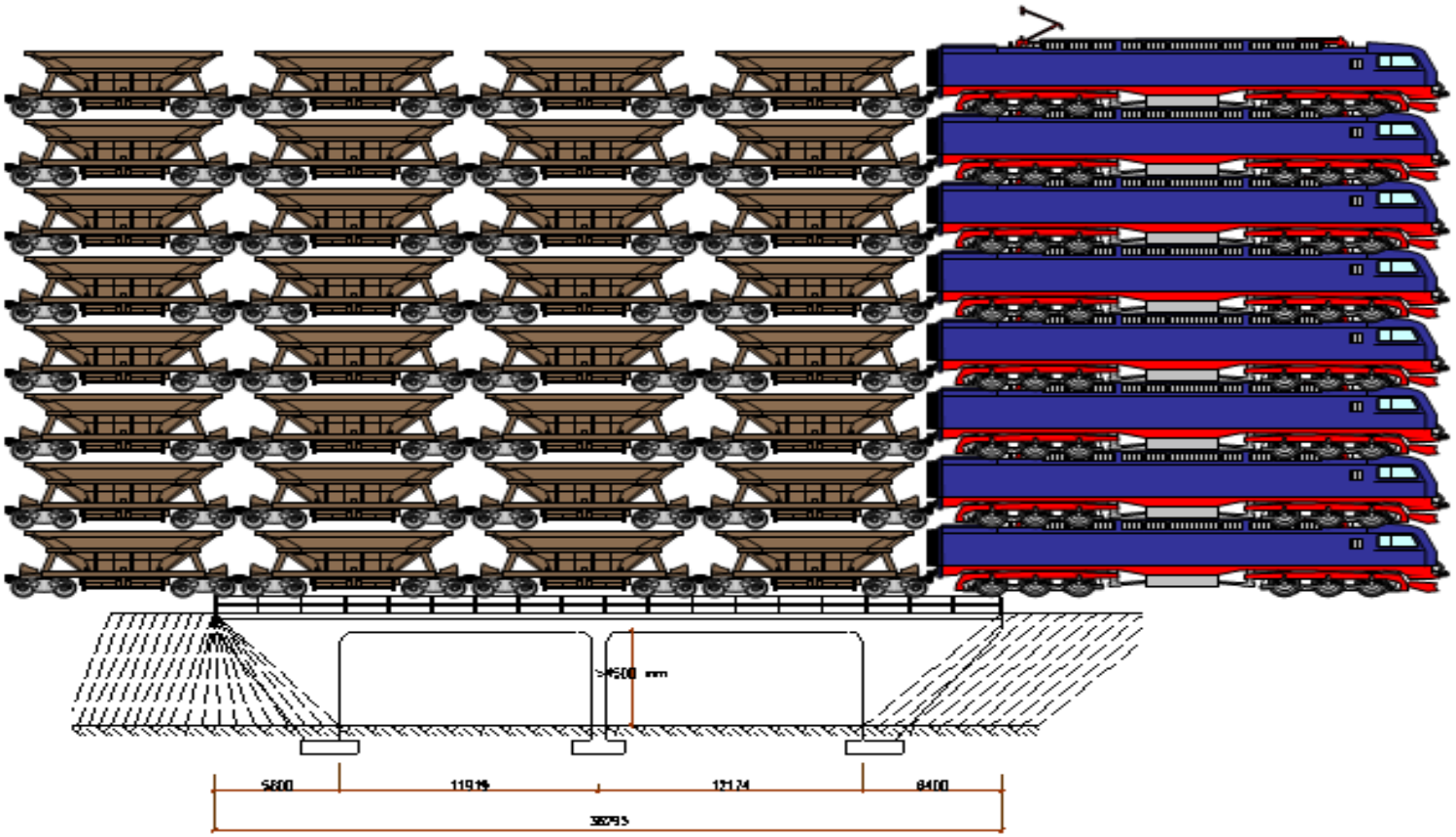
The failure load 1170 ton corresponds to
1170 ton / 25 ton ≈ 47 axles

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

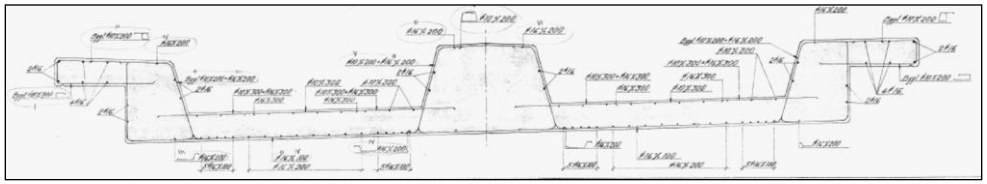


A little more than the design case

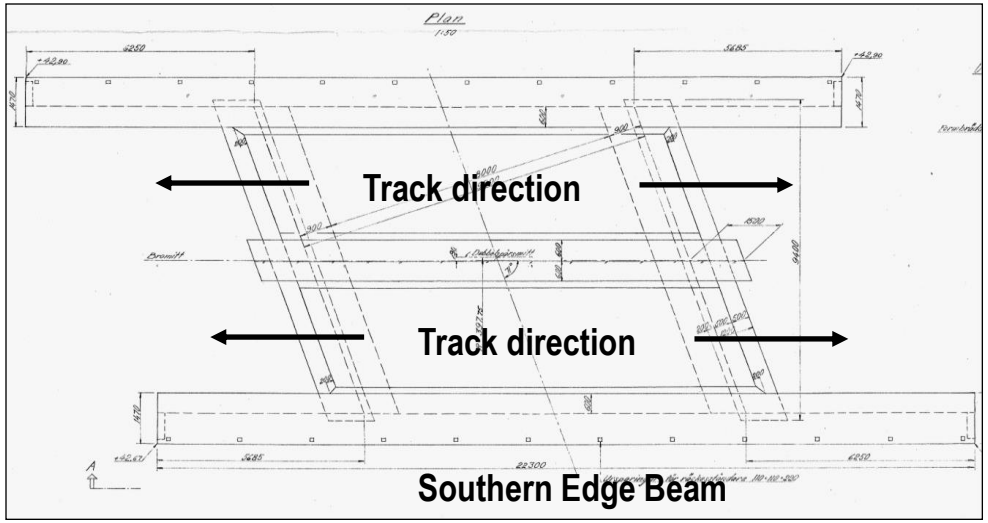


Implementation

The Frövi Bridge



Cross sectional view



View from the top

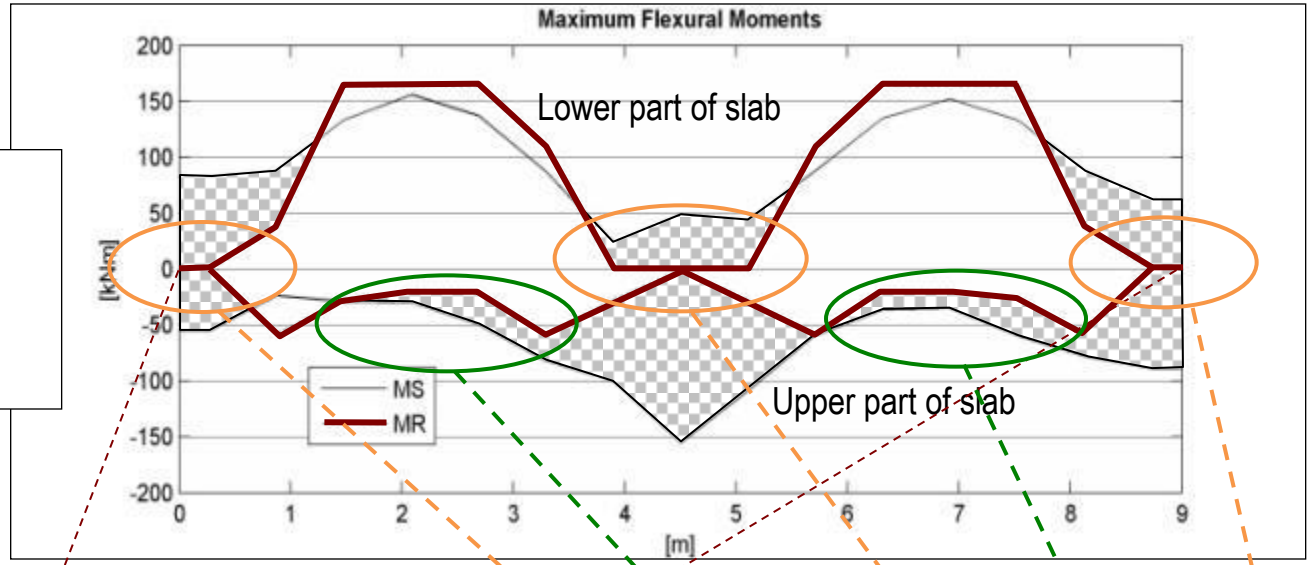
Assessment, monitoring and Strengthening of a railway bridge with NSMR and CFRP tubes

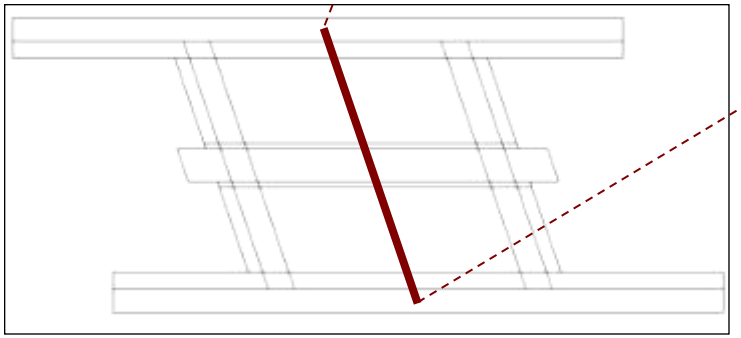
Implementation

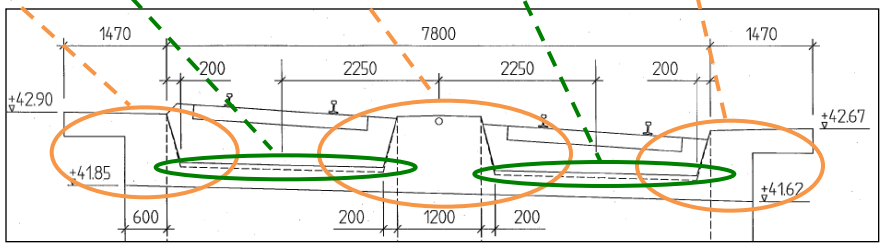
Insufficient transverse capacity

- Design moment from FE-model

- Calculated flexural capacity



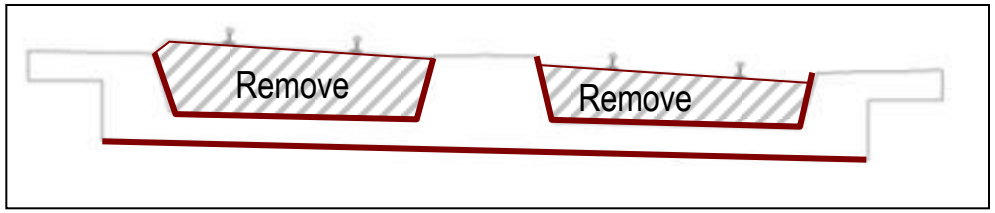




Implementation

Strengthening system

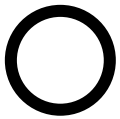
Traditional technique

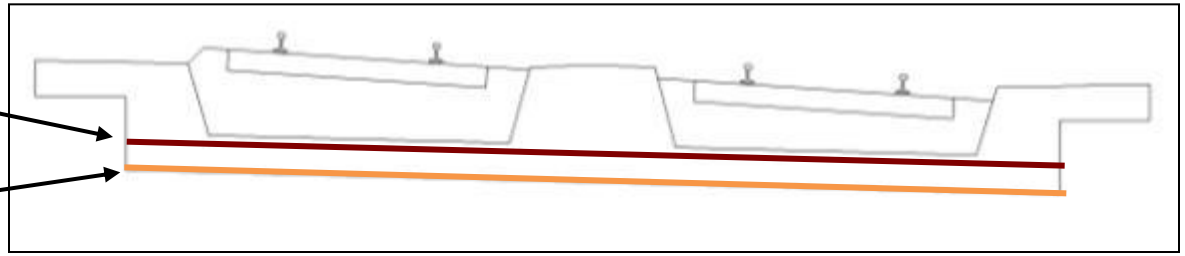


Laboratory test

New technique

CFRP tube Ø32 t4 mm





NSMR bar 10x10 mm

Updated Guideline from SB

FRP Strengthening of Concrete Structures

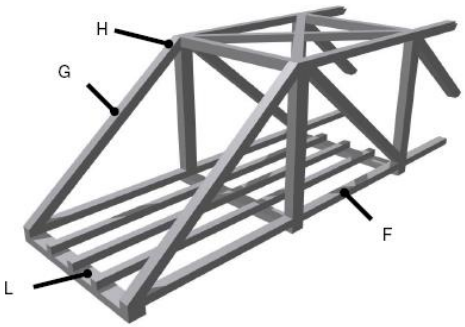
Content

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

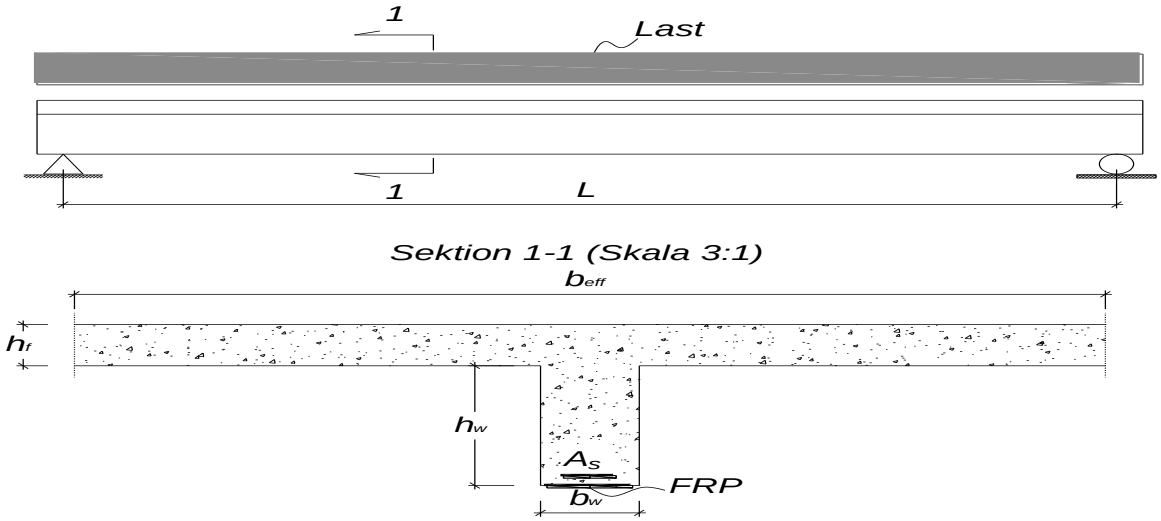


Sixth Framework Programme

PRIORITY 6
SUSTAINABLE DEVELOPMENT
GLOBAL CHANGE & ECOSYSTEMS
INTEGRATED PROJECT

Calculation Example

Strengthening for flexure



The beam is a part of a slab in a parking garage and needs to be strengthened for additional load. Simply supported with L=8.0 m. Distributed load. Max moment due to service load 200 kNm and additional moment 430 kNm in ultimate limit state. The load during strengthening can be decreased to 170 kNm.

Calculation Example

Geometrical Properties

Notation	Value	Unit	Description
$b_f = b_{eff}$=	2610	mm	Effective flange (EC2 5.3.2.1)
h_f=	180	mm	Heigth on flange
h_w=	520	mm	Heigth on web
h=	700	mm	Total heigth
c=	30	mm	Concrete cover
b_w=	250	mm	Width web
A_c=	599800	mm2	Cross sectional area concrete
A_s=	1256.6	mm2	Area steel reinfordement
$Ø_t$=	20	mm	Diameter steel reinforcement
d=	660	mm	Level arm
L=	8000	mm	Distance between supports
B =	5000	mm	Distance between beams
A_{sw}=	157.1	mm2	Area of stirrups
$Ø_s$=	10	mm	Area shear reinforcement
s=	250	mm	Internal distance shear reinforcement

Partical coeffecient factors

Concrete	Steel	FRP
γ_c =1.5	γ_s =1.15	γ_{frp} =1.2
α_{cc}=0.85	α_{ct}=0.85	
φ_{ef}=2.0		
γ_{cE} =1.2		

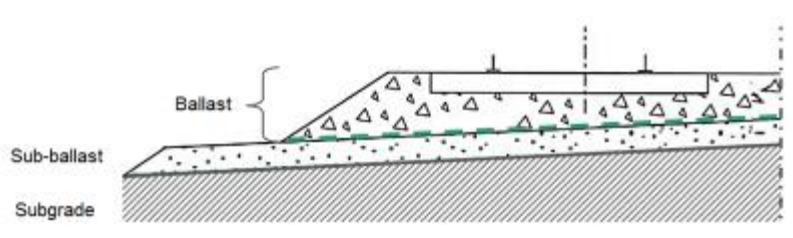
Methods to Extend Life of Assets

Outline

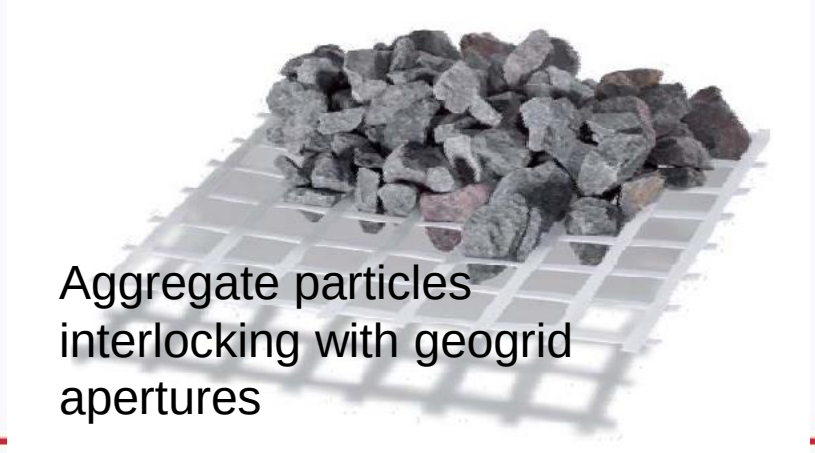
- Background
- Refined assessment metods – Joan Casas
- Strengthening methods
- **Track and Earthwork**
- Case studies – Four bridges

Geogrids – 5 year tests

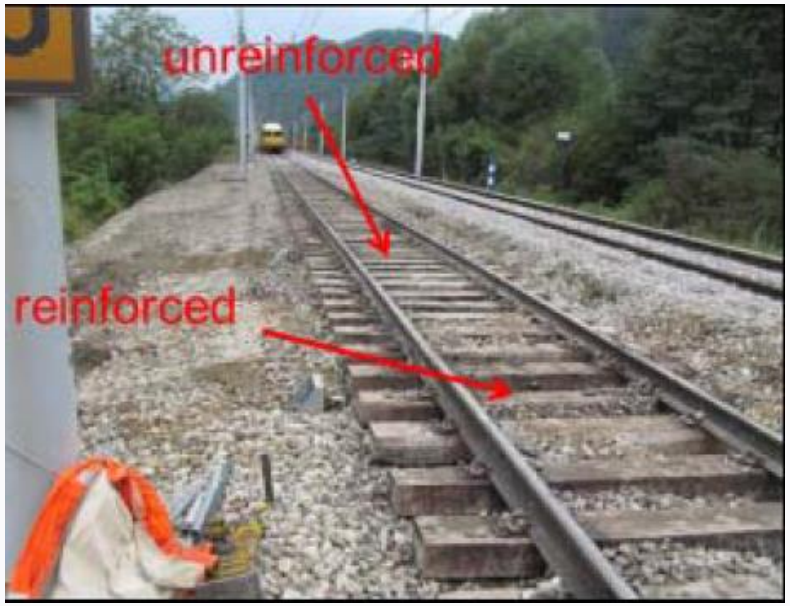
Ballast layer clogged with fines from subgrade as a result of “mud pumping”



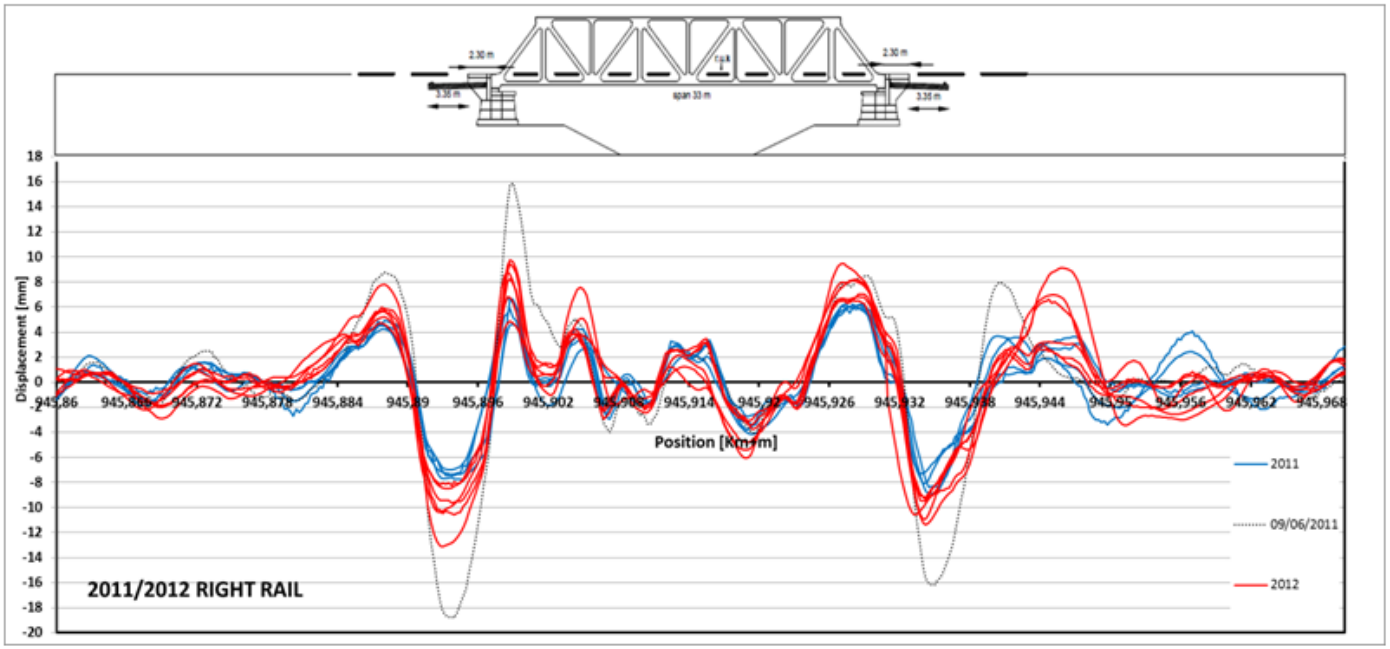
Geogrid reinforcement of the ballast layer for maintenance reduction



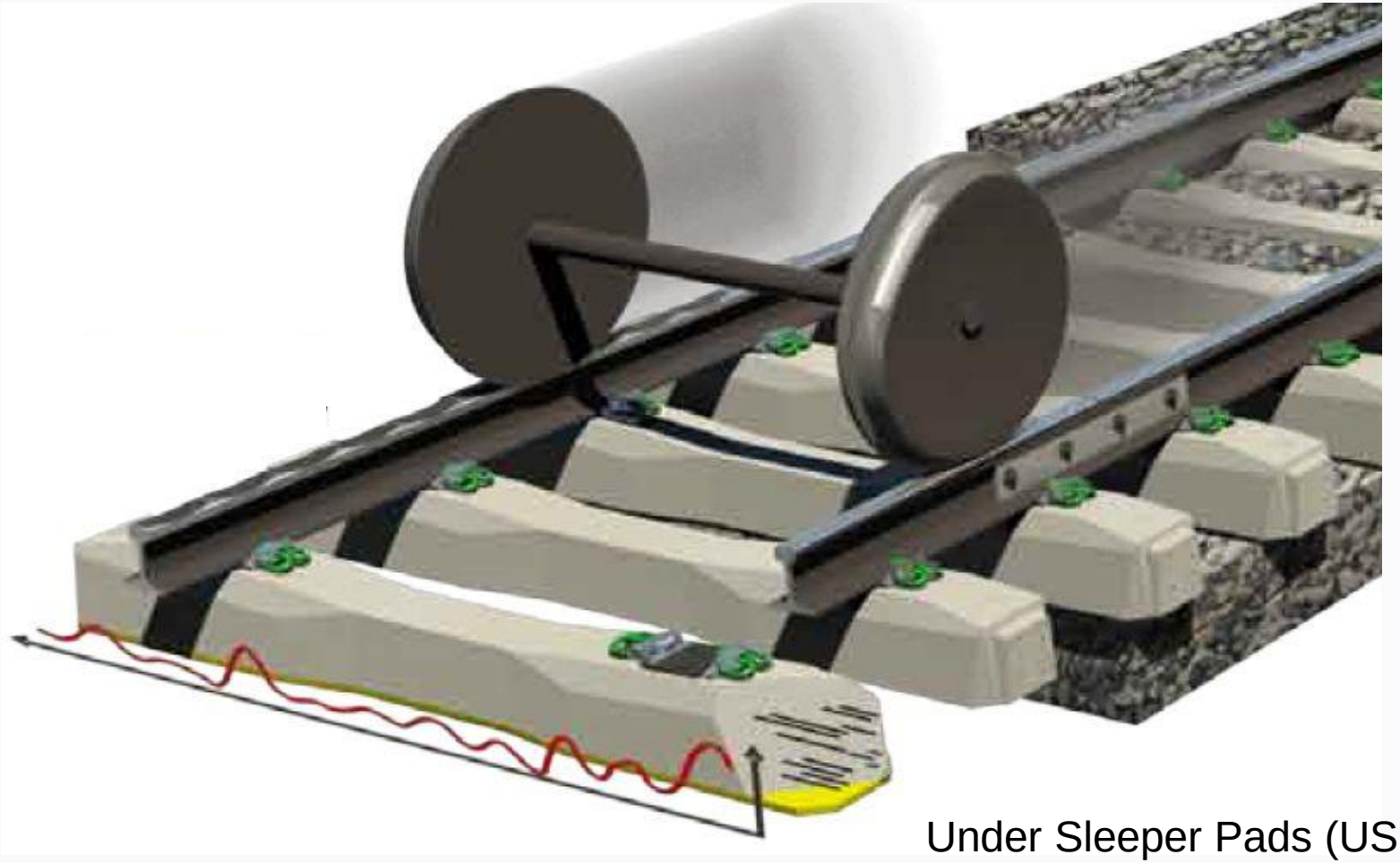
Aggregate particles interlocking with geogrid apertures



Transition zone slab - Sikån



Under Seeper Pads (USP) may be more efficient



Under Sleeper Pads (USP)

Climate changes can give high water flows

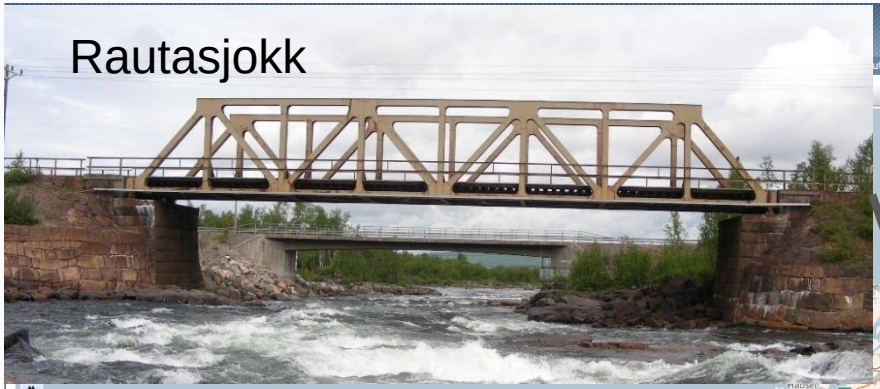
Ånn, Sweden (2006). Göran Holm, Swedgeo

Methods to Extend Life of Assets

Outline

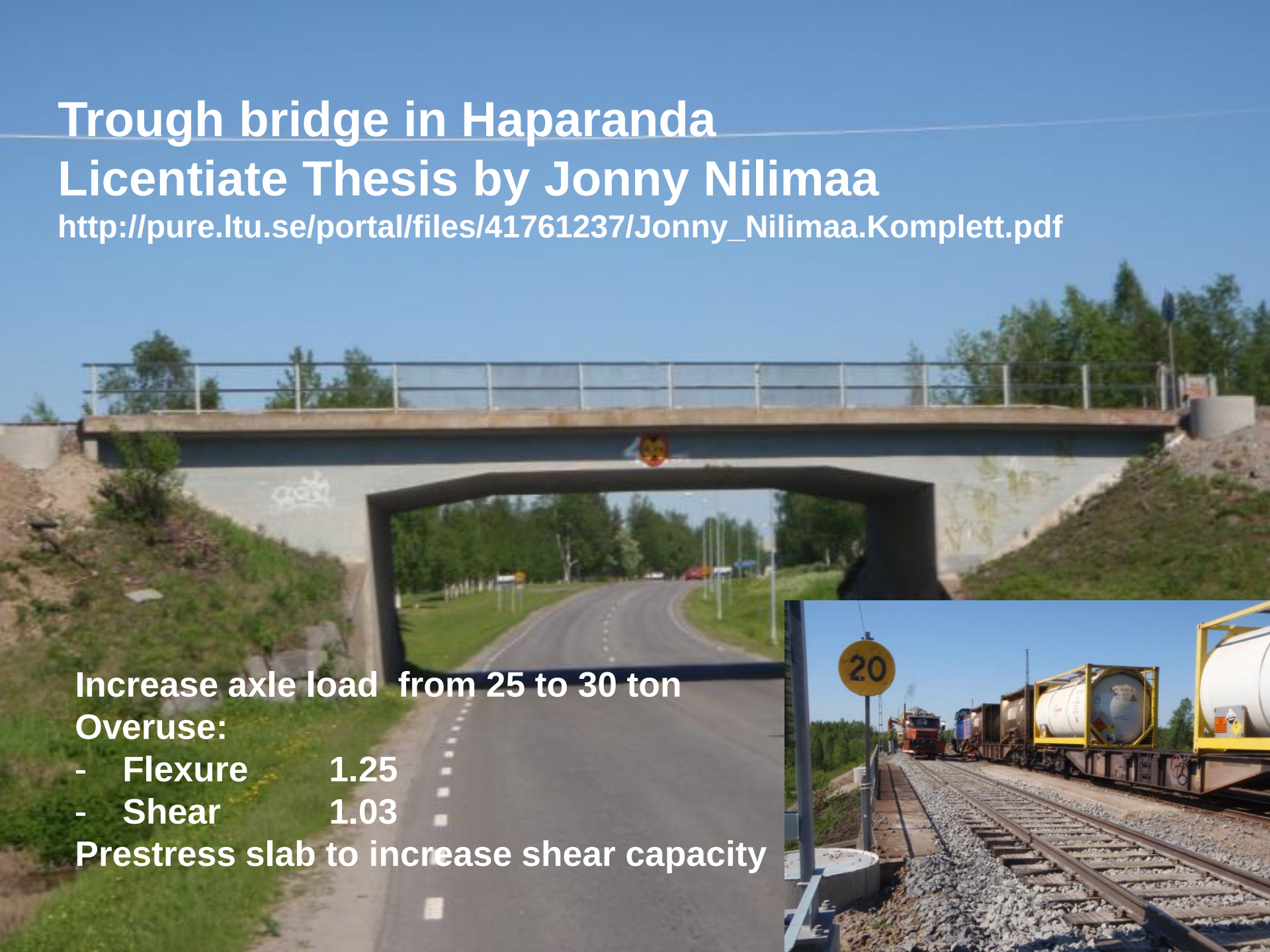
- Background
- Refined assessment metods – Joan Casas
- Strengthening methods
- Track and Earthwork
- **Case studies – Four bridges**

Four bridges to be tested/upgraded



Trough bridge in Haparanda
Licentiate Thesis by Jonny Nilimaa

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



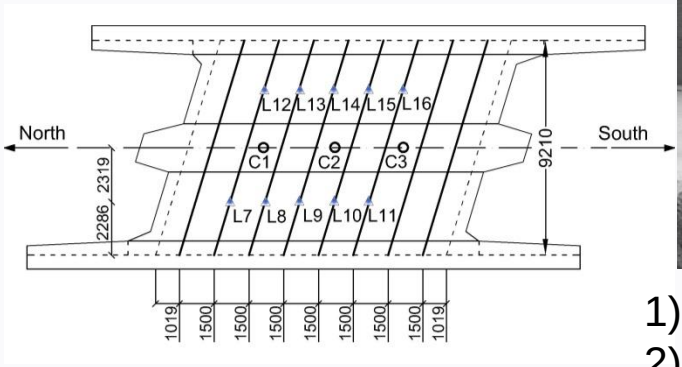
Increase axle load from 25 to 30 ton

Overuse:

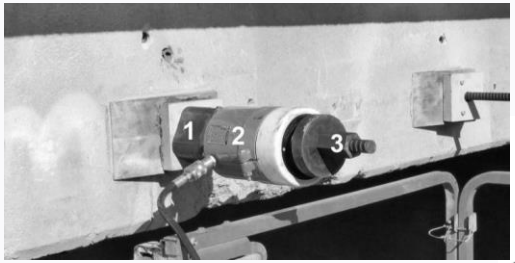
- **Flexure 1.25**
- **Shear 1.03**

Prestress slab to increase shear capacity

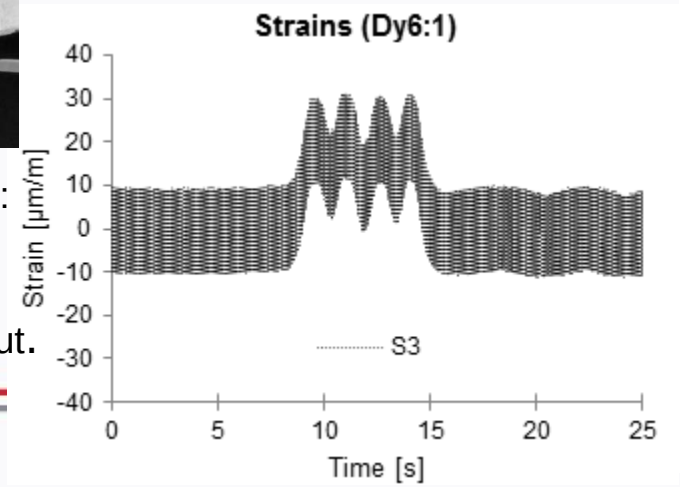
Prestressing Haparanda Bridge

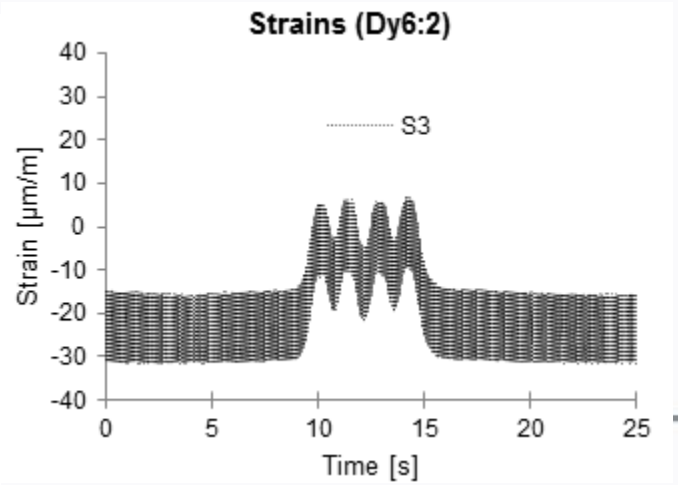


1) an anchoring nut
2) an anchoring plate and
3) load-distributing wedge



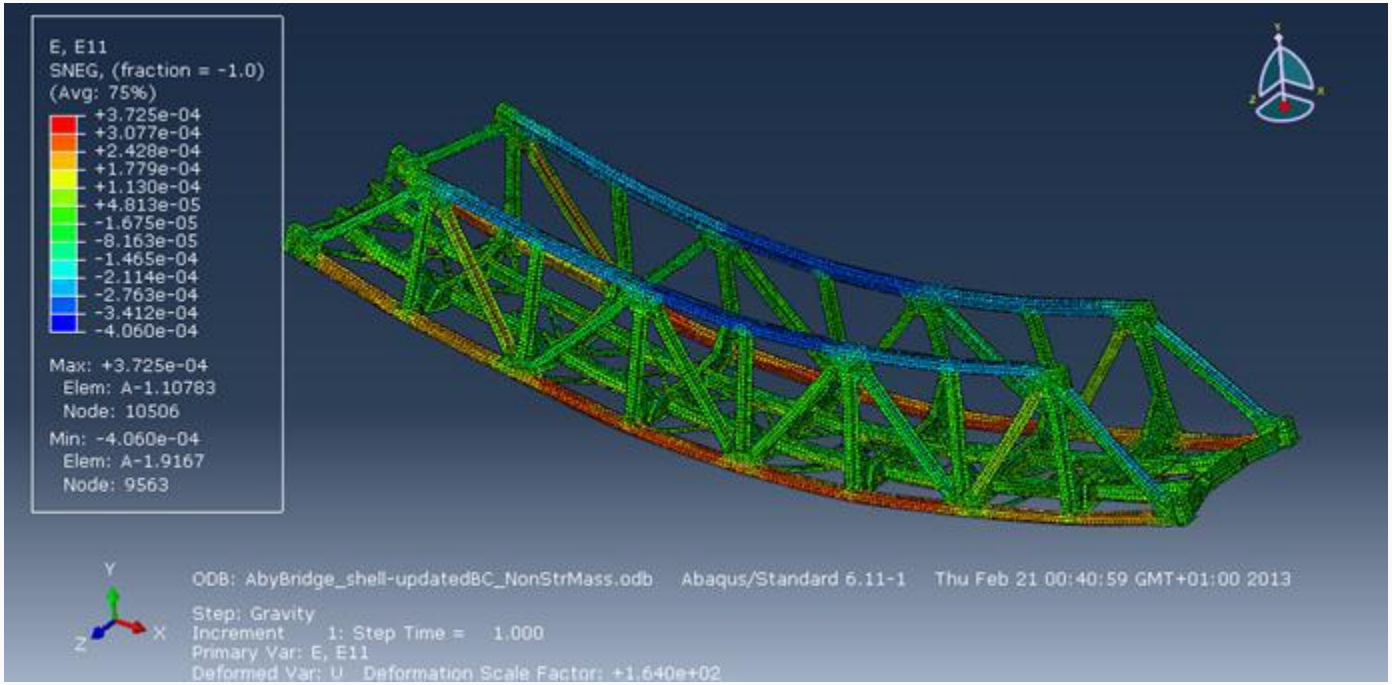
Prestressing setup including:
1) the steel frame,
2) the hydraulic jack and
3) the extra prestressing nut.





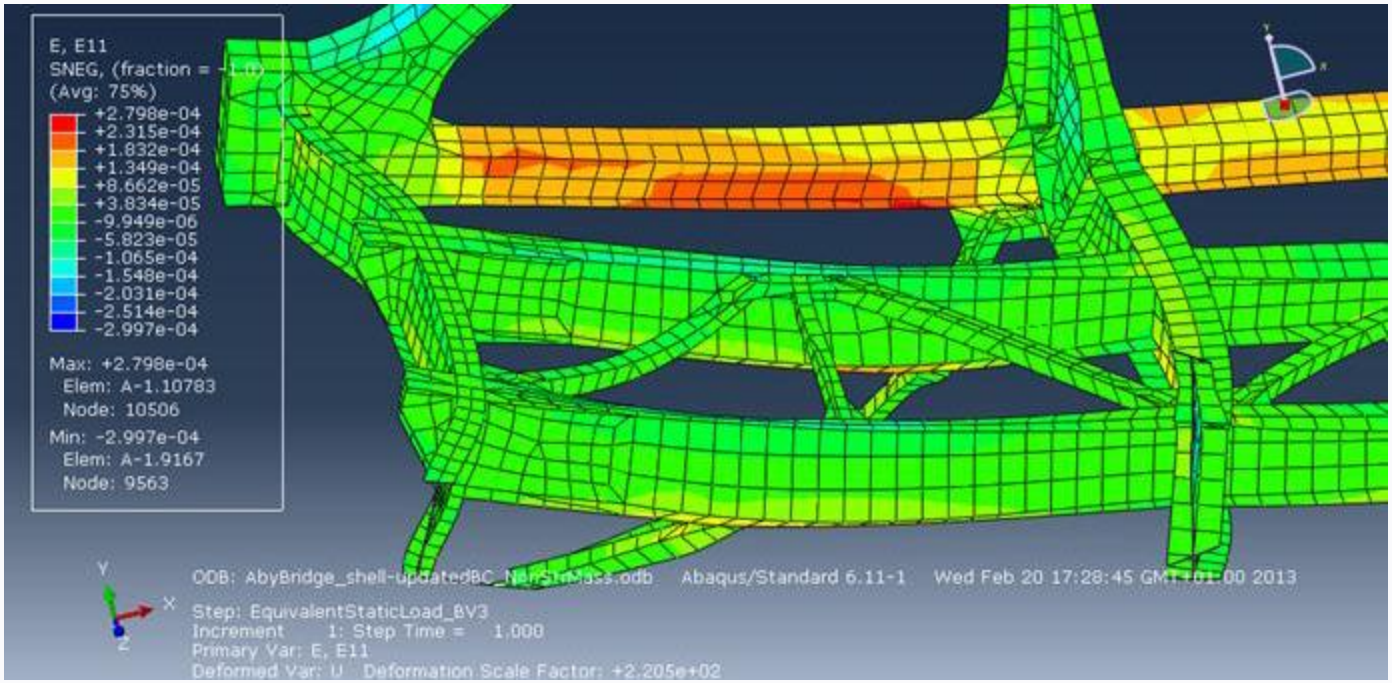
Åby Älv
50 km W Piteå
1894, truss 1957

Södra Rautas
20 km NW Kiruna
1902, truss 1962



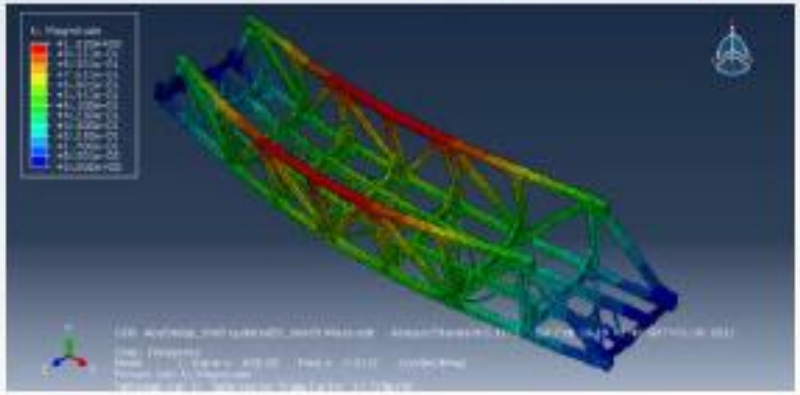
Global view of the E11 strain of deformed Åby Bridge under 250 kN axle load (including self-weight)

Support strain – Abacus model

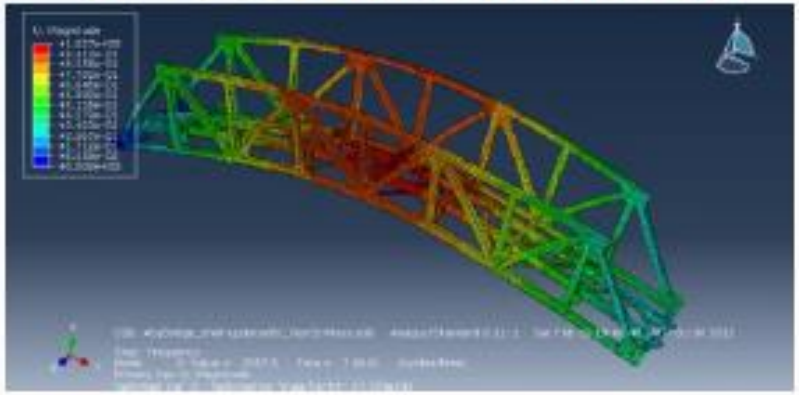


Eigenfrequencies

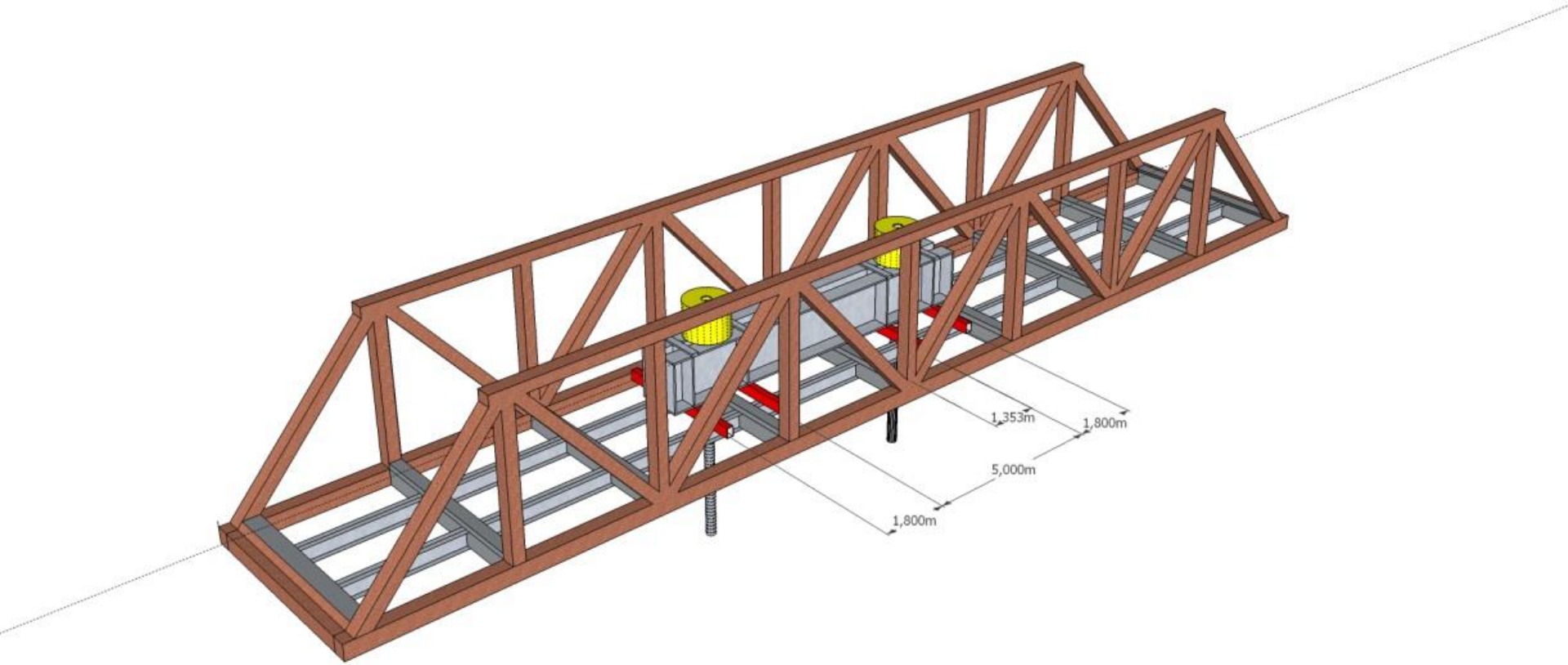
f = 4.01 Hz (No.1)



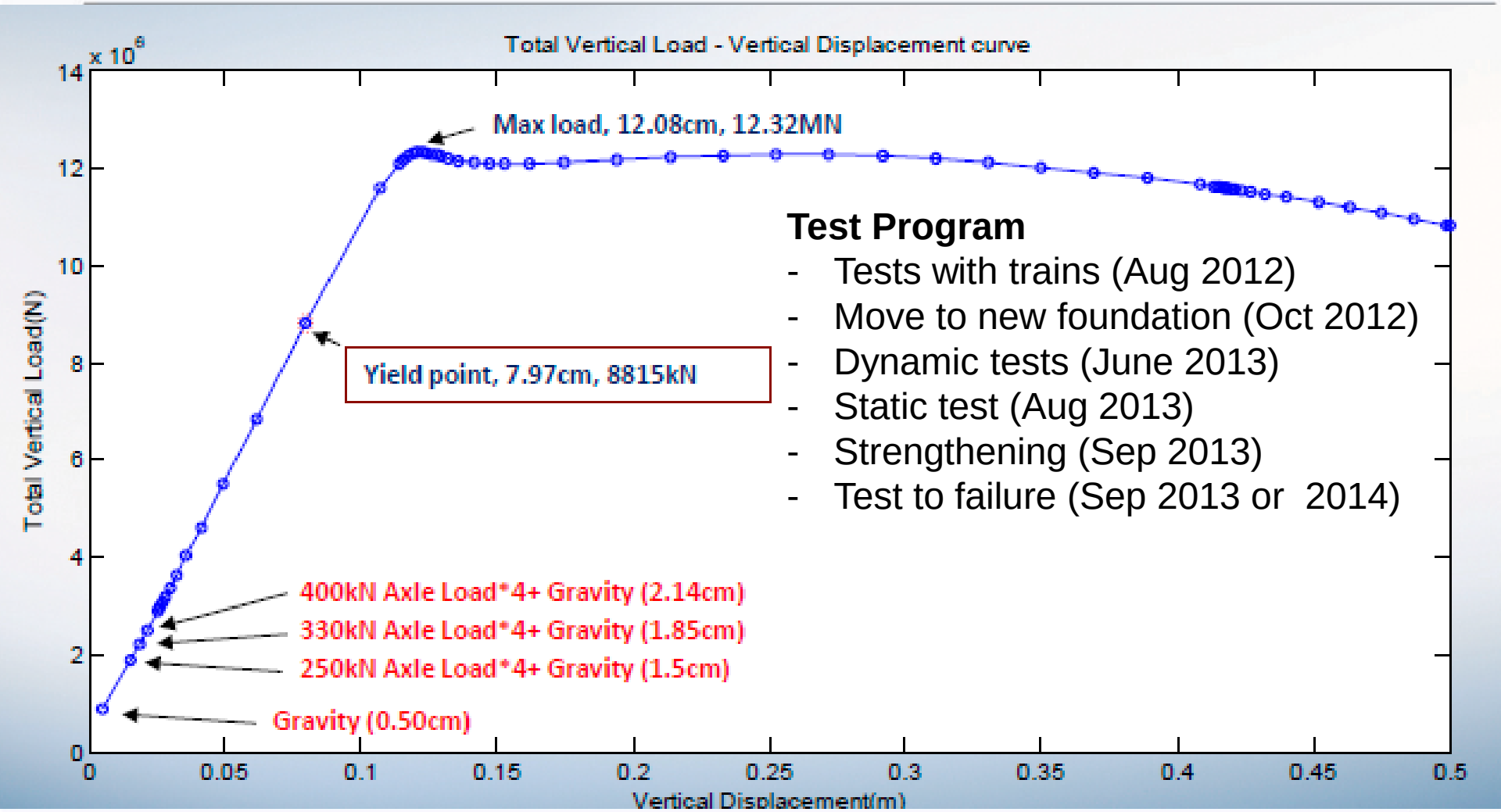
f = 7.56 Hz (No.2)



Loading to failure



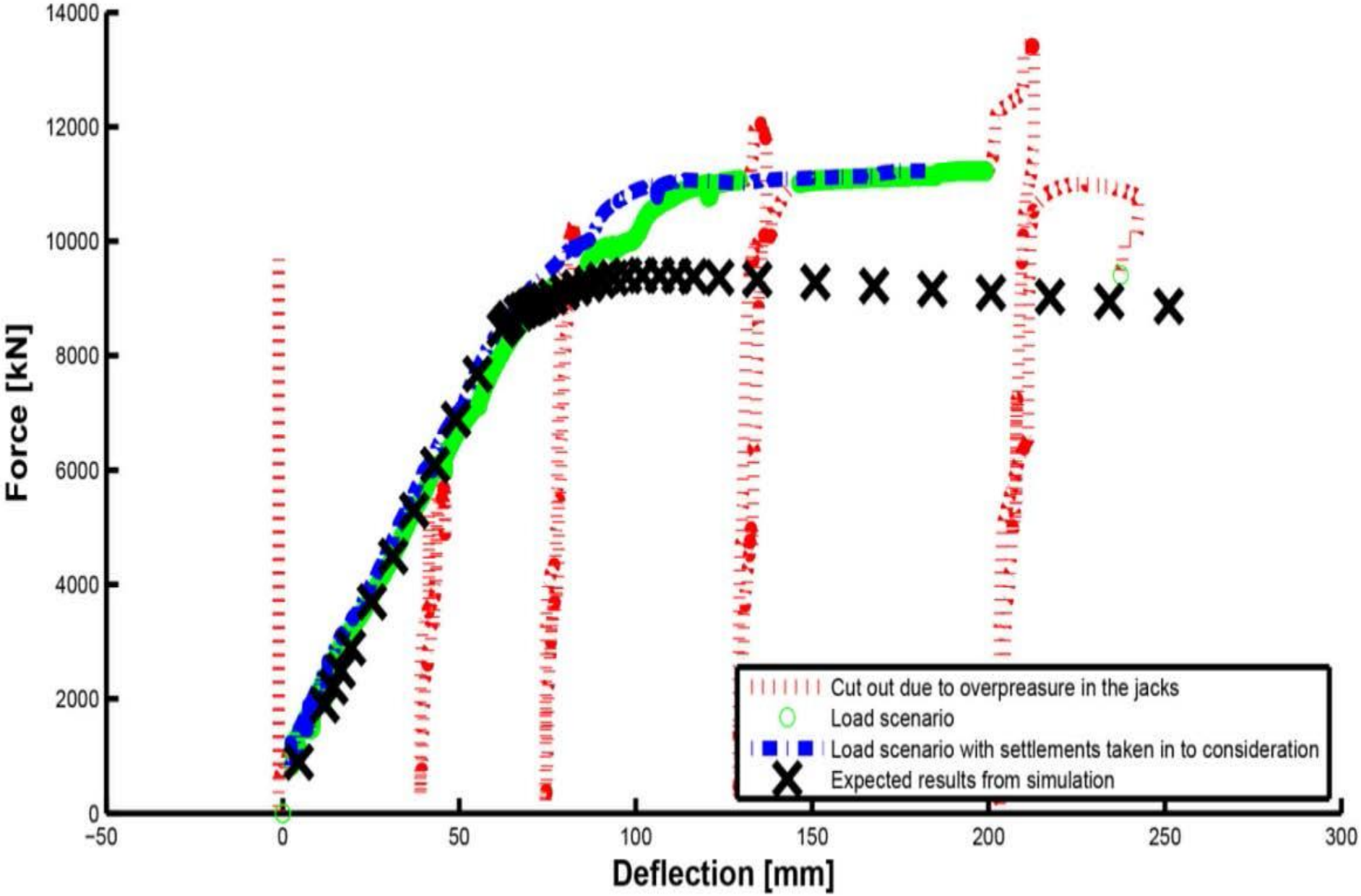
Loading to failure – Abacus model



Test Program

- Tests with trains (Aug 2012)
- Move to new foundation (Oct 2012)
- Dynamic tests (June 2013)
- Static test (Aug 2013)
- Strengthening (Sep 2013)
- Test to failure (Sep 2013 or 2014)

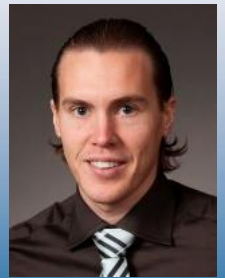
Test Results



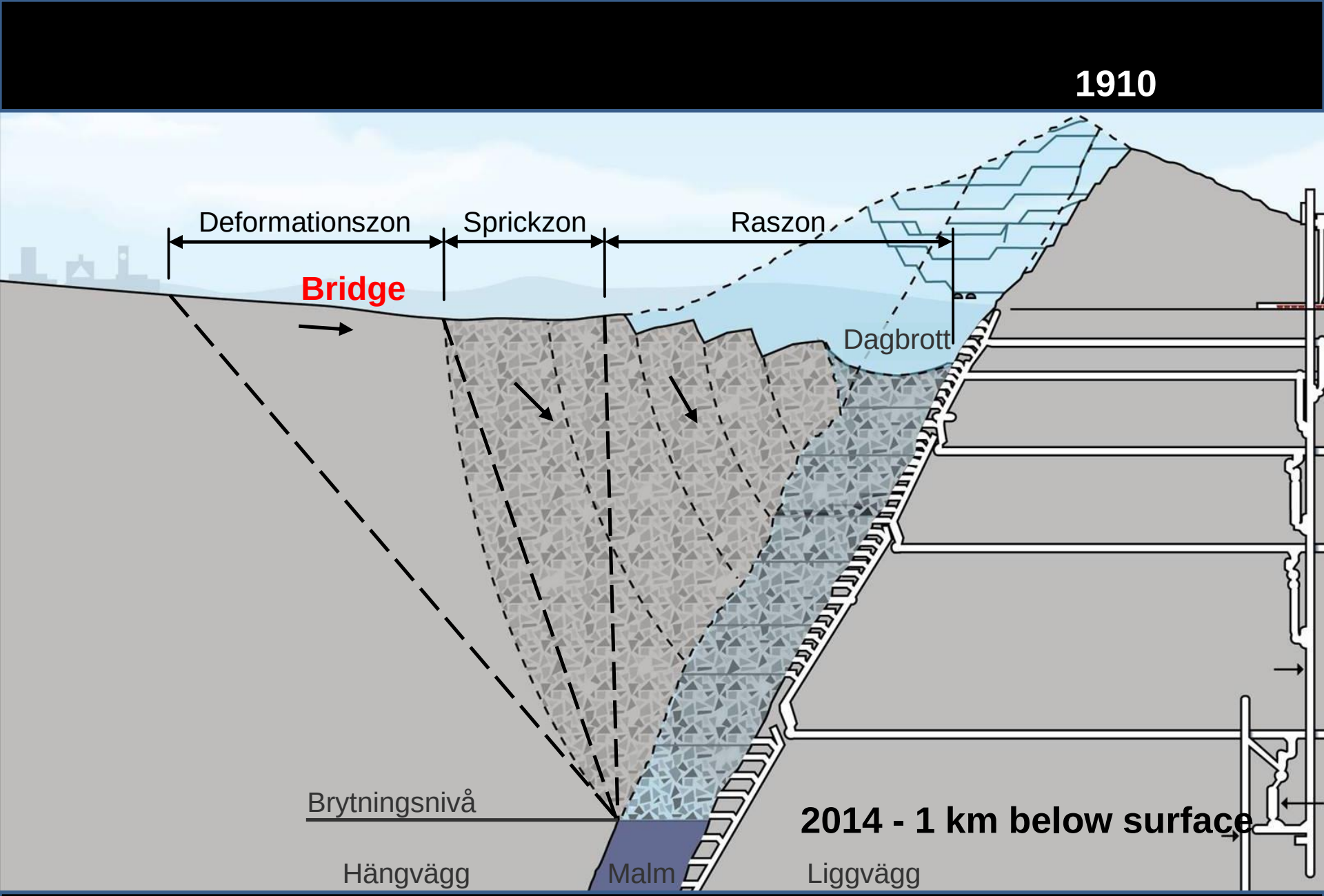
Test of the Kiruna Mine Bridge

Preliminary Program 2014-05-10

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

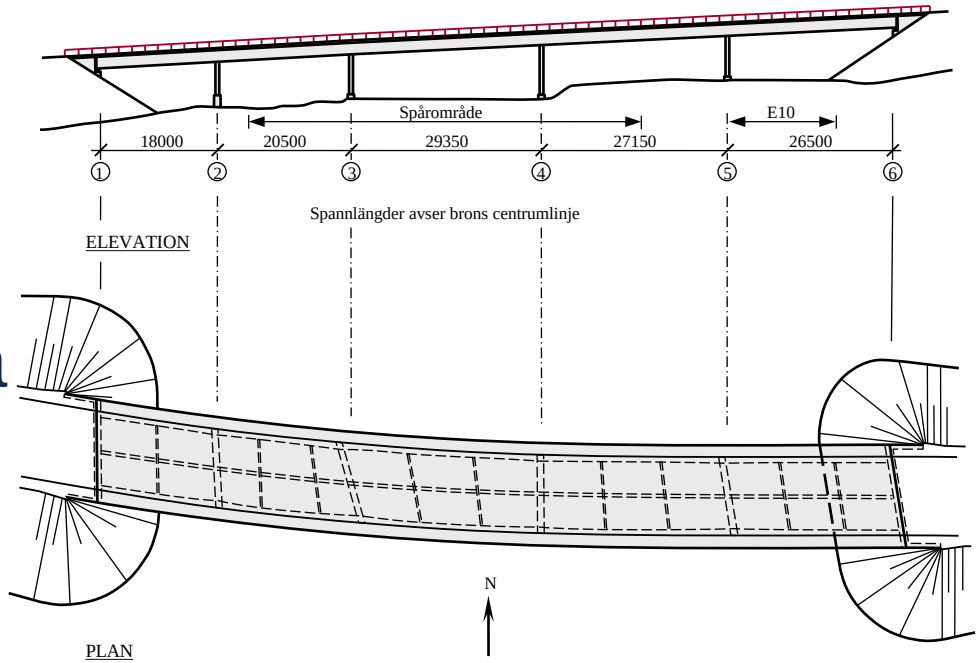




LULEÅ
UNIVERSITY
OF TECHNOLOGY

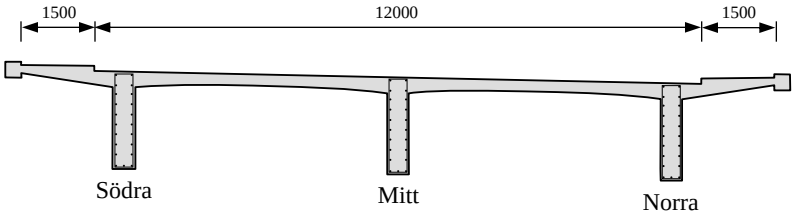

1910
Deformationszon
Sprickzon
Raszon
Bridge
Dagbrott
Brytningsnivå
2014 - 1 km below surface
Hängvägg
Malm
Liggvägg

Geometry & Materials

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

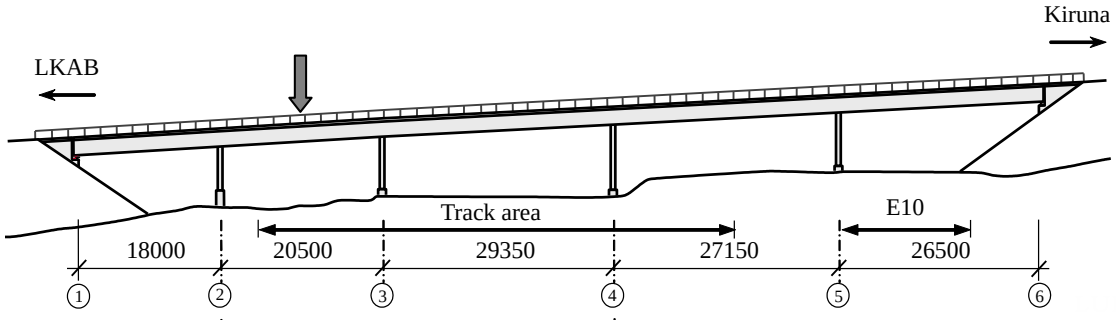


- Concrete 30.40 MPa
- Rebar 400 & 600 MPa
- BBRV St1450/1700



Test Program – June 2014

- Test material properties
- Check remaining force in prestressed cables:
  - Non-destructive testing
  - Destructive testing
  - Conditons of cables
- Strengthen to increase capacity and test:
  - CFRP: NSMR-bars + prestressed laminate on beams
  - Test moment-shear capacity of beams
  - Test shear capacity of bridge slab



Conclusions – Life Extension

Use Refined Assessment Methods:

- Check robustness
- Use Probabilistic Methods
- Proof load

Strengthen with CFRP; Carbon Fibre Reinforced Polymers:

- Near surface mounted reinforcment (NSMR)
- Laminates
- Prestressed

Maintain track, S&C and Earth work

End of Presentation

- Thank you for your kind attention!
- Questions?