Erfarenheter från EU-projektet Sustainable Bridges

Lennart Elfgren
Luleå tekniska universitet

CIR-dagen den 1 februari 2011 - Göteborg Convention Centre
Järnvägsteknik för långsiktig hållbar utveckling

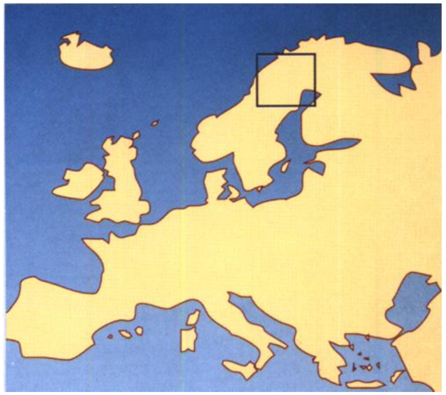
Disposition

- Bakgrund
- Målsättning
- Resultat
- Erfarenheter
- Fortsatt arbete

LULEÅ UNIVERSITY OF TECHNOLOGY


Luleå

Background

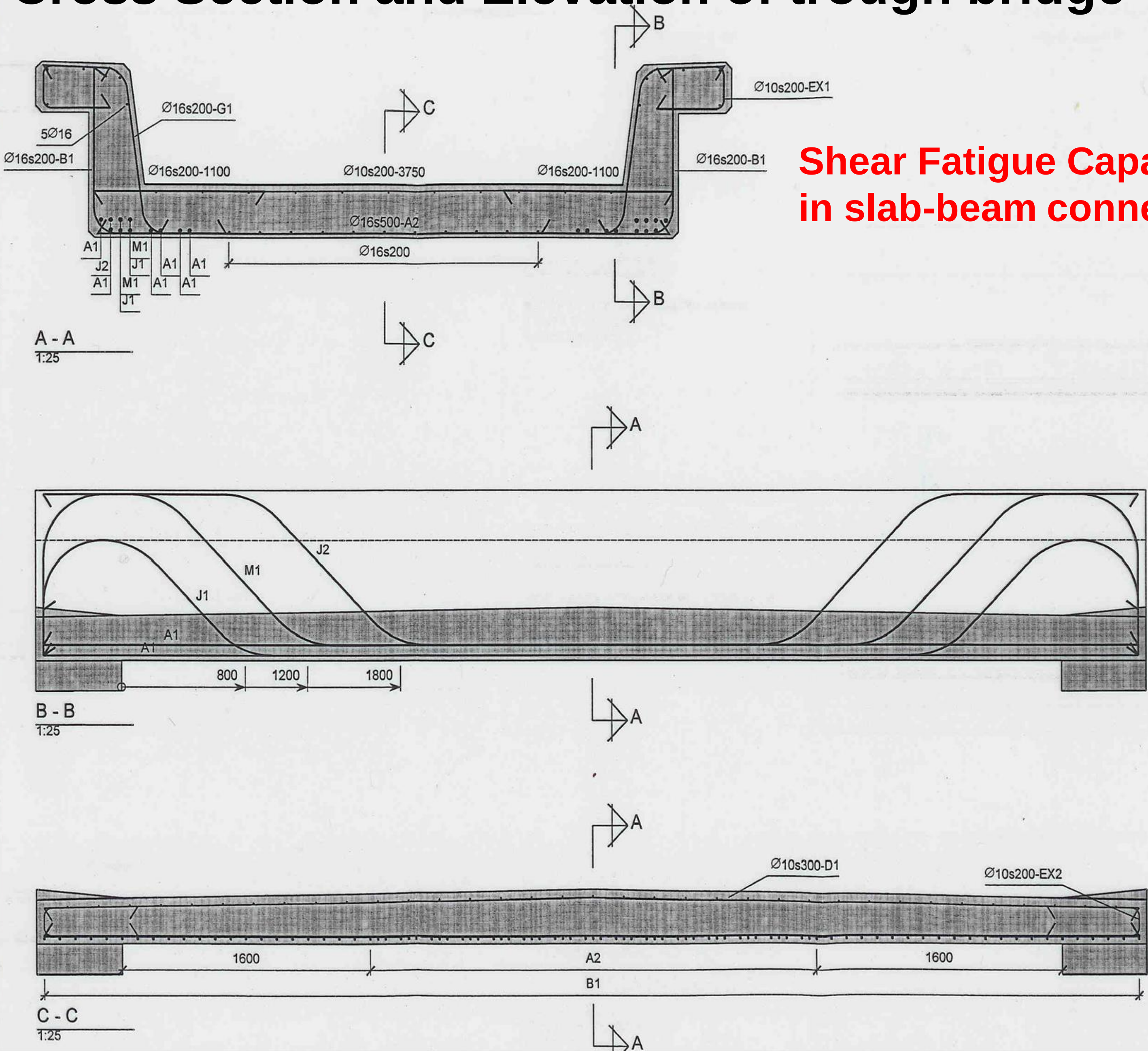


Malmbanan was built around 1900, has a length of about 500 km and has more than 100 bridges, the oldest from the time when the line was built.

The iron ore producer, LKAB, wanted to minimize its cost for transportation of the ore to the harbours in the Atlantic (Narvik) and the Baltic (Luleå)?

Axle load 25 -> 30 ton ?

Cross Section and Elevation of trough bridge



Shear Fatigue Capacity in slab-beam connection ?

FÖRKLARINGAR

BETECKNING	ARMERING TYP
A1	6+6 Ø25-7100
J1	2+2 Ø25
J2	1+1 Ø25
M1	2+2 Ø25

FÖRESKRIFTER

BETONG I, STD K40, KONSTRUKTIONS-GRUPP B VATTENTÄT.
ARMERING KS40.

HÄNVISNINGAR

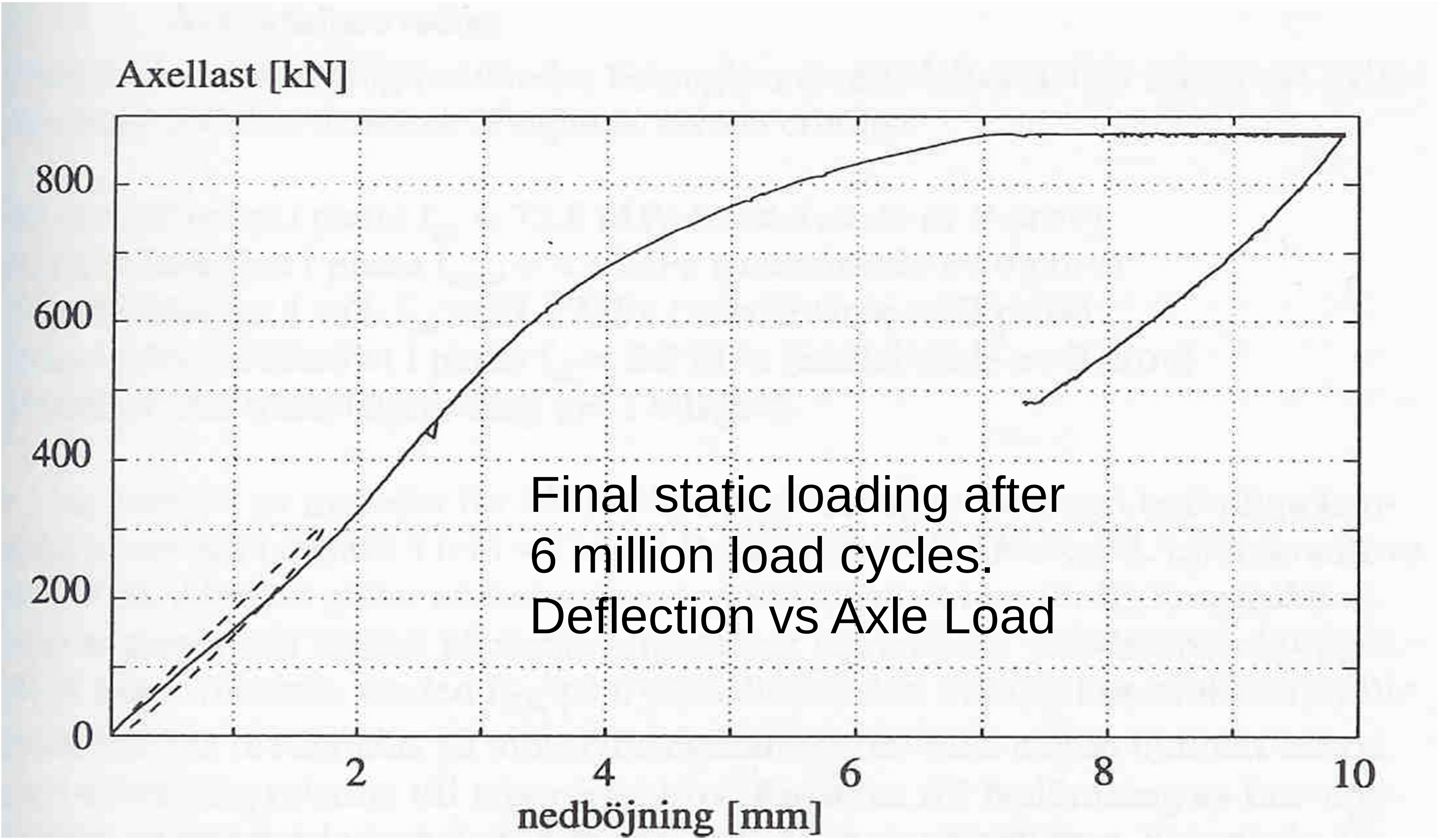
VIDSTÅENDE RITNING ÄR ETT UTDRAG UR BANVERKETS BETONGDÄCK ENLIGT STANDARDRITNING B 2447-12 AV ÅR 1972, REV 1974 OCH 1976-12-16.

TRÅGBROAR LÄNGS MALMBANAN

TVÄR- OCH LÄNGDSNITT: ARMERING

We tested a 20 year old bridge. The test showed that we had no shear fatigue problems.

Load-Deformation Graph



Final static loading after
6 million load cycles.
Deflection vs Axle Load

Sustainable Bridges

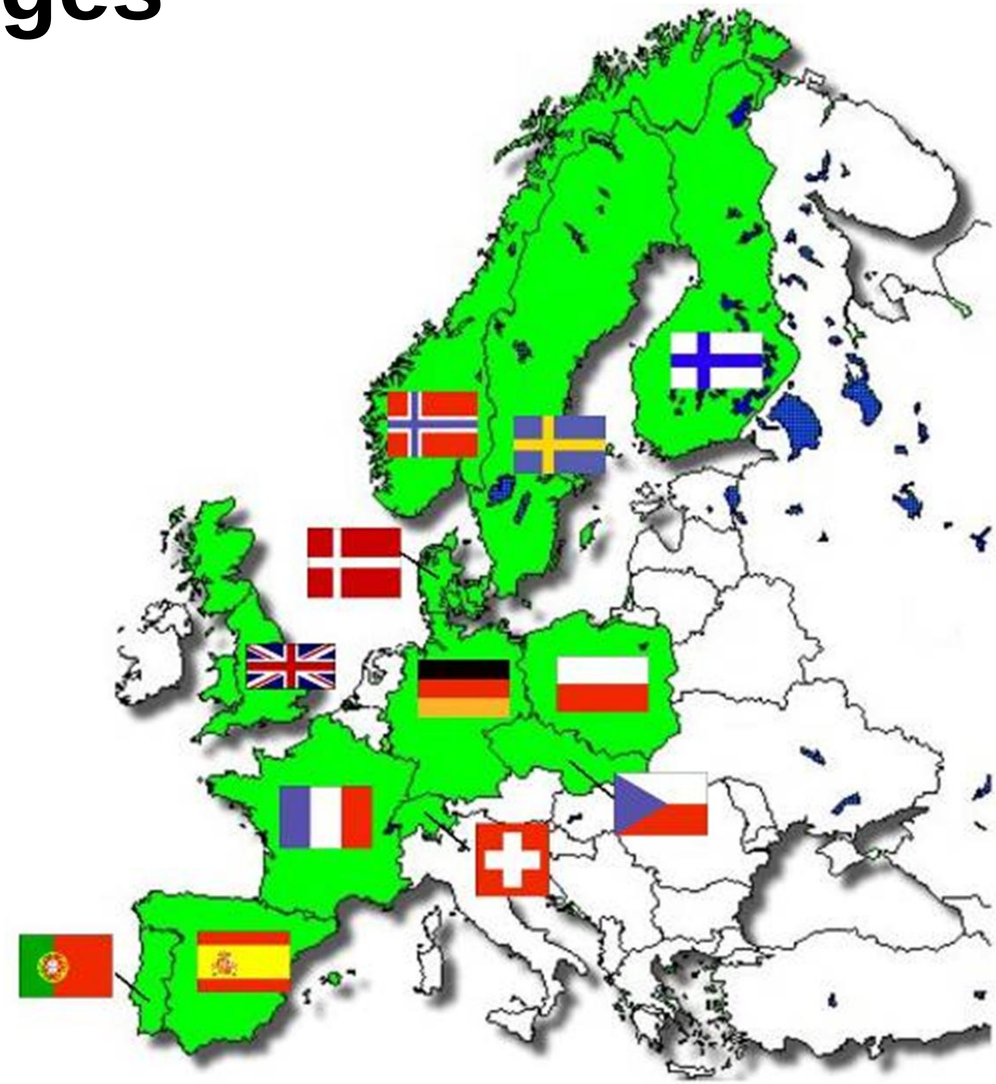
EC project within FP6

Started on December 1, 2003
Ended on November 30, 2007

Total budget (official)
10,2 million € of which
6,9 million € as EC contribution

Jan Olofsson, Skanska
Coordinator

Lennart Elfgren, LTU
Scientific Leader



SUSTAINABLE BRIDGES

Objectives

- **Increase the transport capacity** of existing bridges
  by allowing higher axle loads (up to 33 tons)
  or by allowing higher speeds (up to 350 km/hour)

- **Increase the residual service lives** of existing bridges with up to 25 %

- **Enhance management, strengthening, and repair systems**.

SUSTAINABLE BRIDGES

WP1

Railways top 10 priority research areas, WP1

1. Better assessment tools
2. Non-disruptive maintenance methods
3. Verification of theoretical dynamic factors for both design and assessment
4. Use of new materials
5. System for diagnosis & maintenance needs selection
6. Ageing/deterioration of concrete bridges
7. Indirect inspection and monitoring dynamics for evaluation/crack detection in metallic bridges
8. Repair and waterproofing of concrete
9. Better testing methods for existing bridges
10. Serviceability of arches

The *proportion of bridge types was found to be:*

Arches of masonry, stone or concrete

41 %

Concrete bridges

23 %

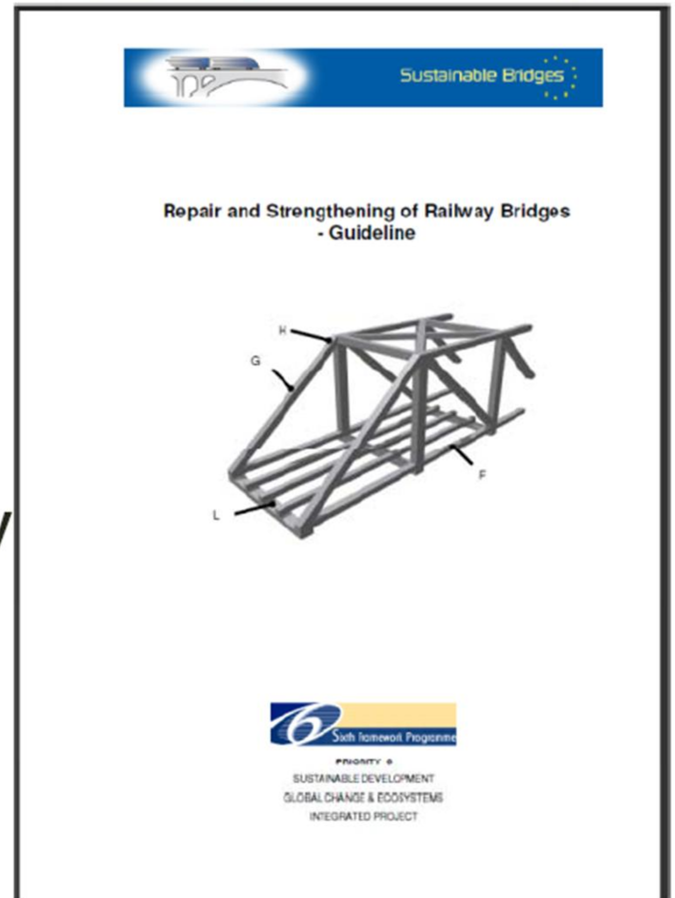
Steel beam bridges

22 %

Steel/concrete composite bridges

14 %

- **Guideline and NDT toolbox:** "Inspection and Condition Assessment of Railway Bridges"
- **Guideline :** "Load and Resistance Assessment of Railway Bridges"
- **Guideline :** "Monitoring of Railway Bridges"
- **Guideline :** " Repair and Strengthening of Railway Bridges"



Sustainable Bridges
www.sustainablebridges.net

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- BackgroundDocs
- Guideline_ICA
- Guideline_LRA
- Guideline_MON
- Guideline_STR

Work Packages

- WP 1 Start up and Classification
- WP 2 Guidance and Review
- WP 3 Condition Assessment and Inspectio
- WP 4 Loads, Capacity and Resistance
- WP 5 Monitoring
- WP 6 Repair and Strengthening
- WP 7 Demonstration. Field Testing of Bridges
- WP 8 Demonstration. Monitoring on Bridges
- WP 9 Training and Dissemination

Project Coordinator and Scientific Leader

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Finnish Road Administration
University of Oulu

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Societé National de Chemin des Fers (SNCF)

Germany
Deutsche Bahn AG
Fed Inst f Materials Res. and Testing (BAM)
Rheinisch-Westfälische Tech Hochschule
Universität Stuttgart

Norway
NORUT Technology

Poland
PKP Polish Railway Lines
Wroclaw University of Technology

Portugal
Universidade do Minho Portugal

Spain
Universitat Politècnica de Catalunya

Sweden
Banverket
Chalmers University of Technology
Designtech Projektsamverkan AB
Luleå University of Technology

Sustainable Bridges

Guideline for Load and Resistance Assessment of Existing European Railway Bridges

Advices on the use of advanced methods

Sixth Framework Programme

PRIORITY 6

SUSTAINABLE DEVELOPMENT

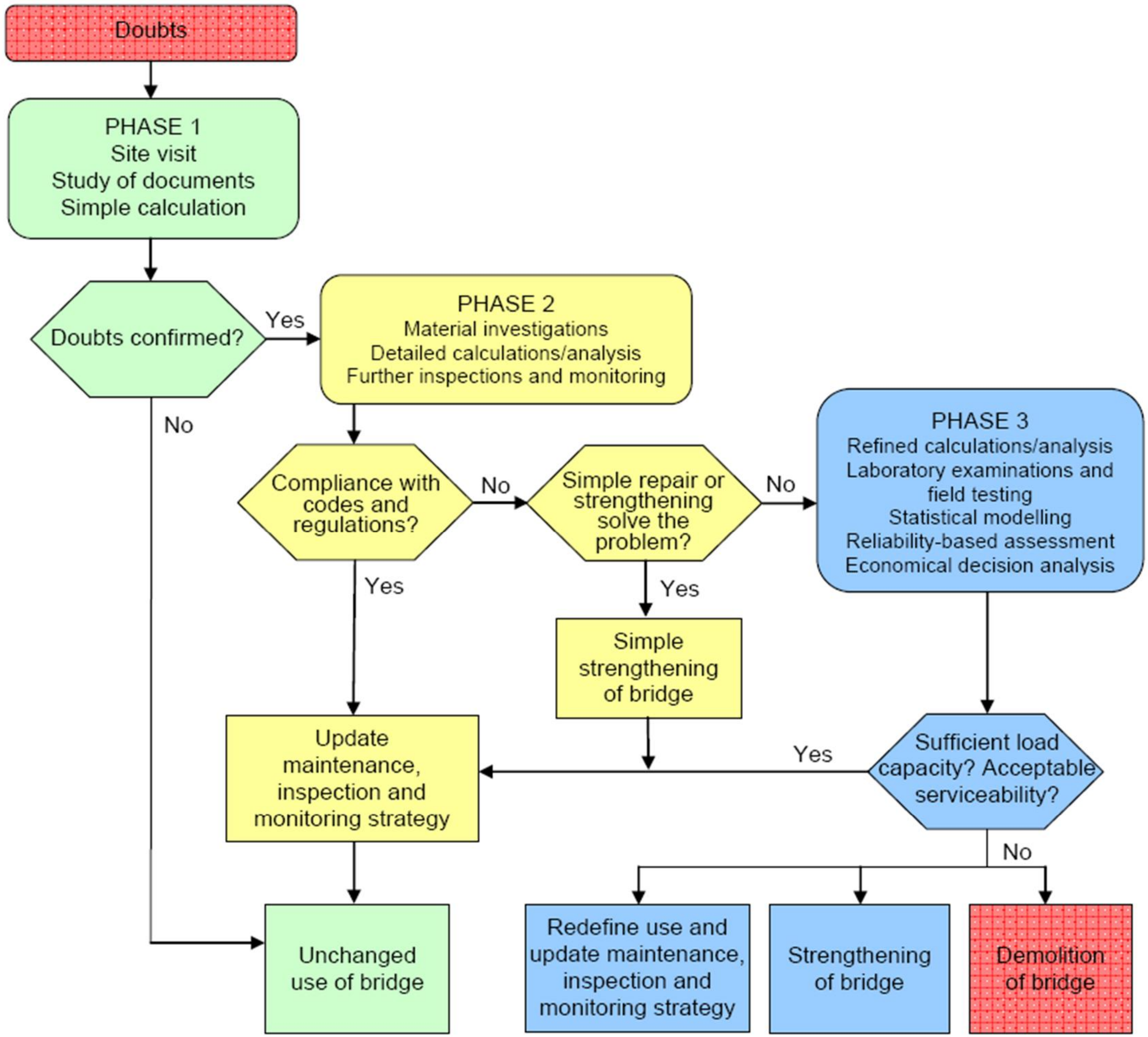
GLOBAL CHANGE & ECOSYSTEMS

INTEGRATED PROJECT

Theory
Limit States
Dynamics
Bridges made of
- **Metal**
- **Masonry**
- **Concrete**

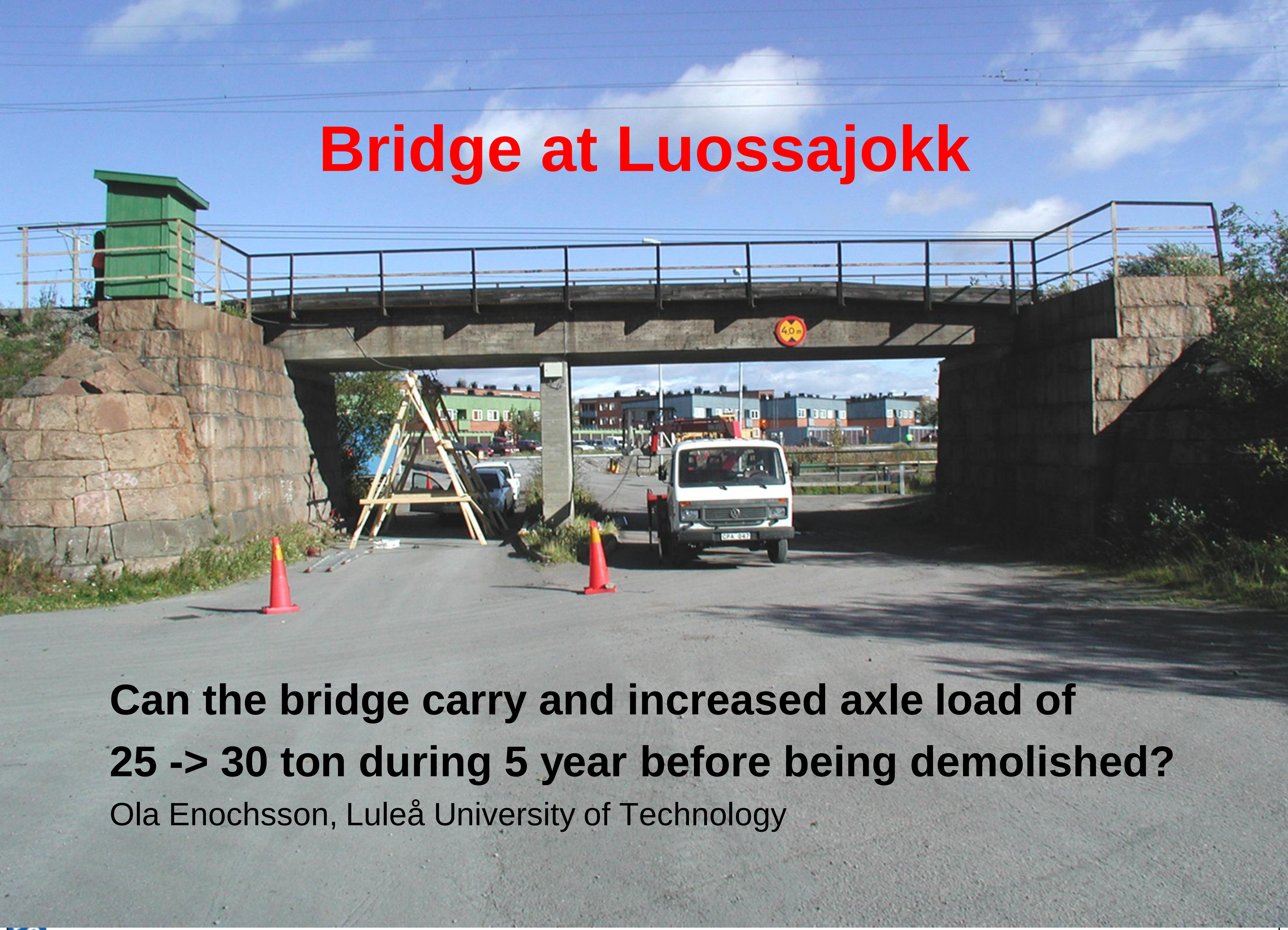
Examples
Background Documents

428 pp



Sustainable Bridges

Bridge at Luossajokk

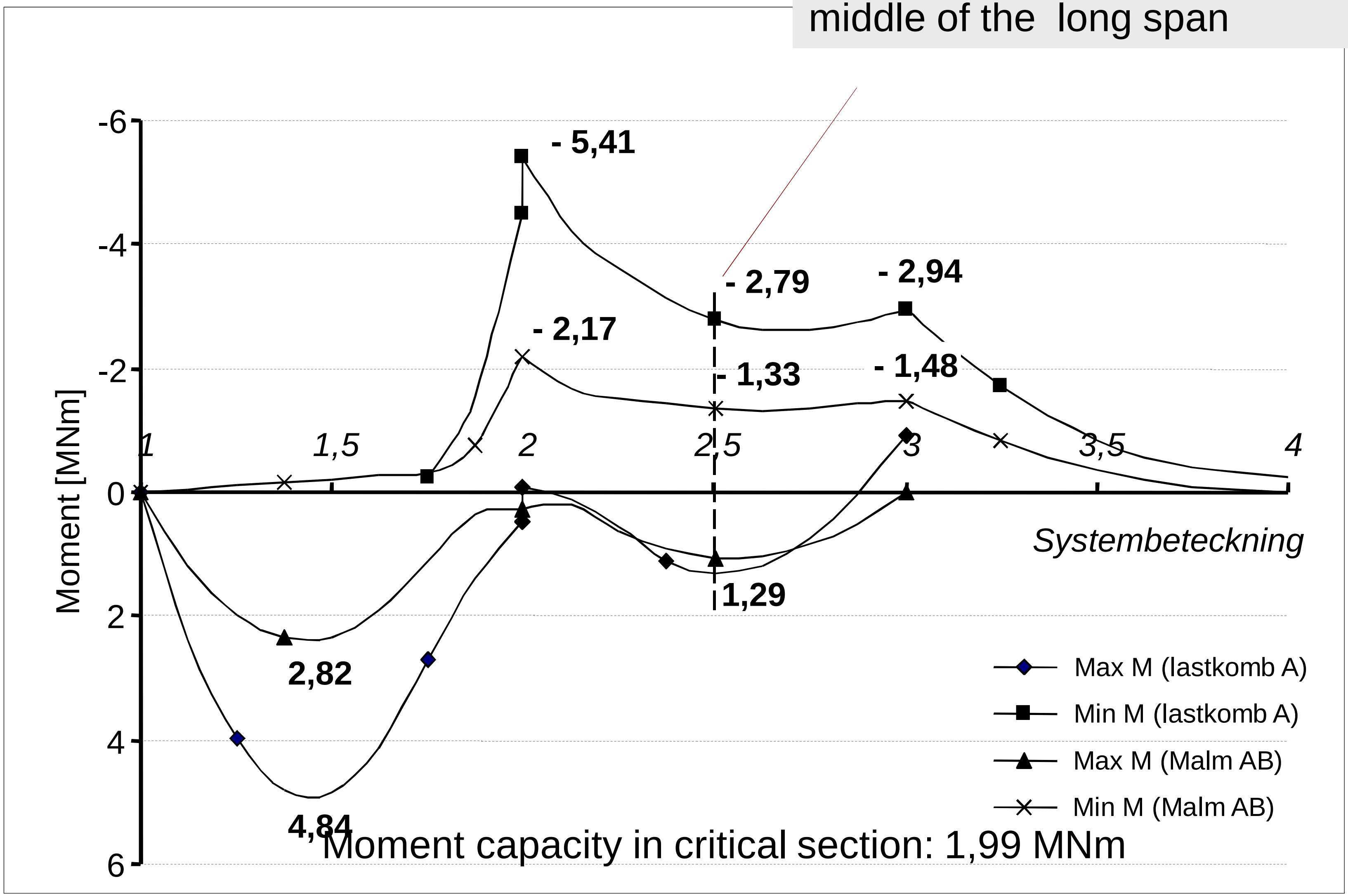


Can the bridge carry and increased axle load of 25 -> 30 ton during 5 year before being demolished?

Ola Enochsson, Luleå University of Technology

Luossajokk Assessment 1996

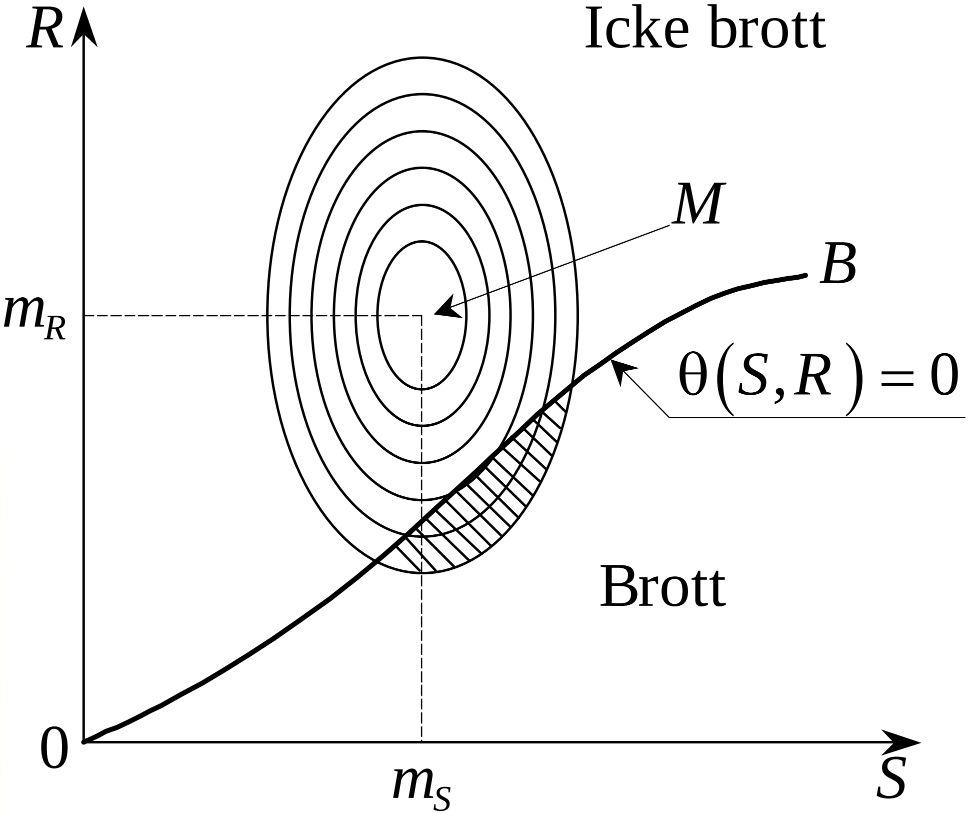
Critical section: top beam in middle of the long span

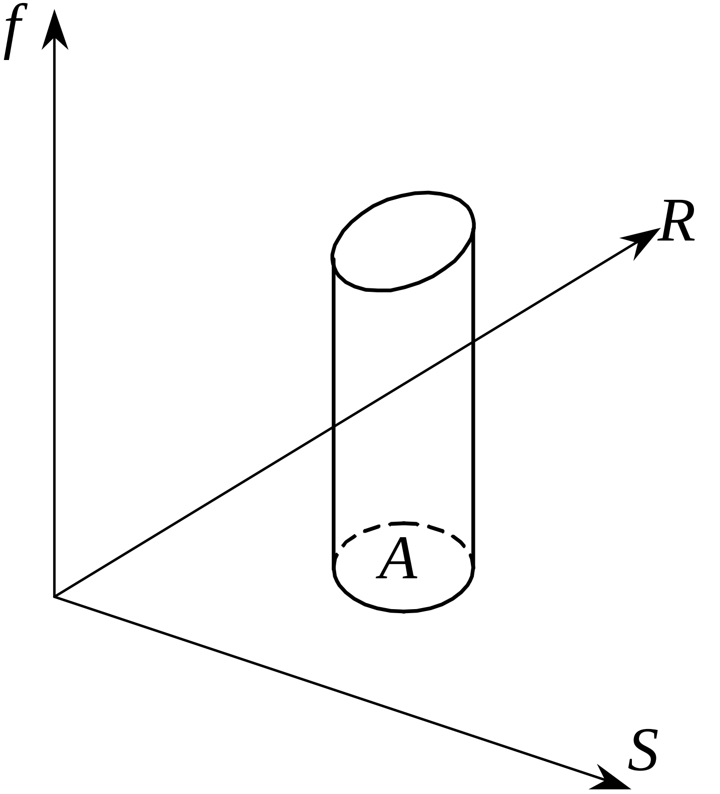


Moment capacity in critical section: 1,99 MNm

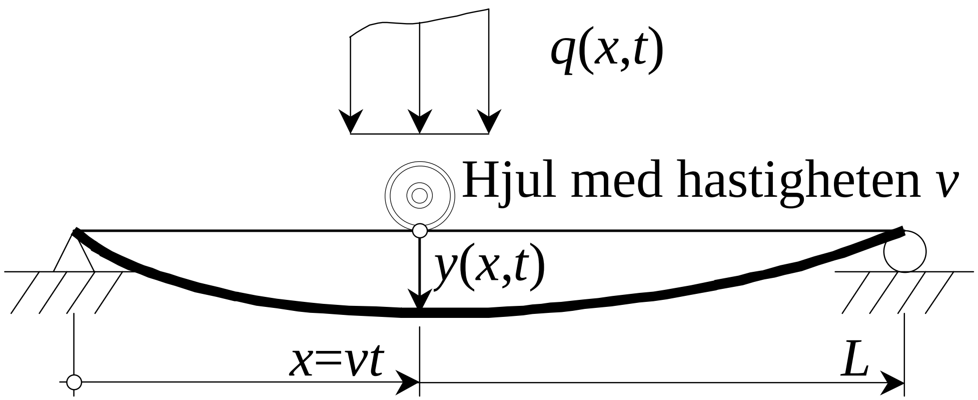
SUSTAINABLE BRIDGES

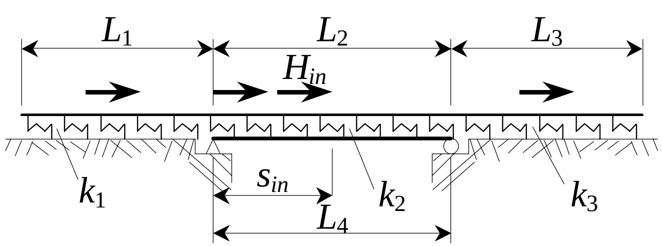
Probabilistic Methods



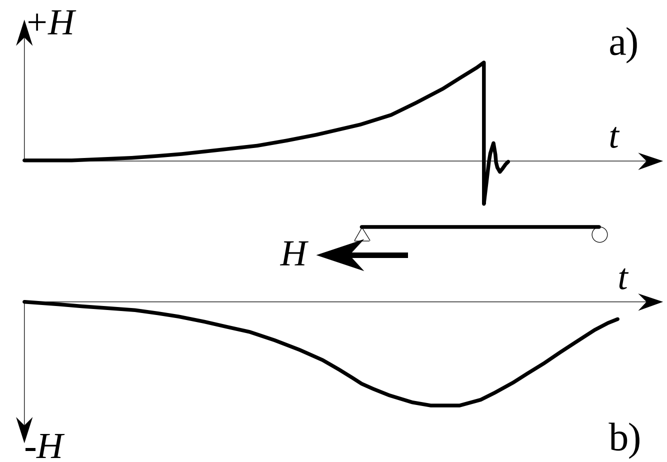


Dynamics



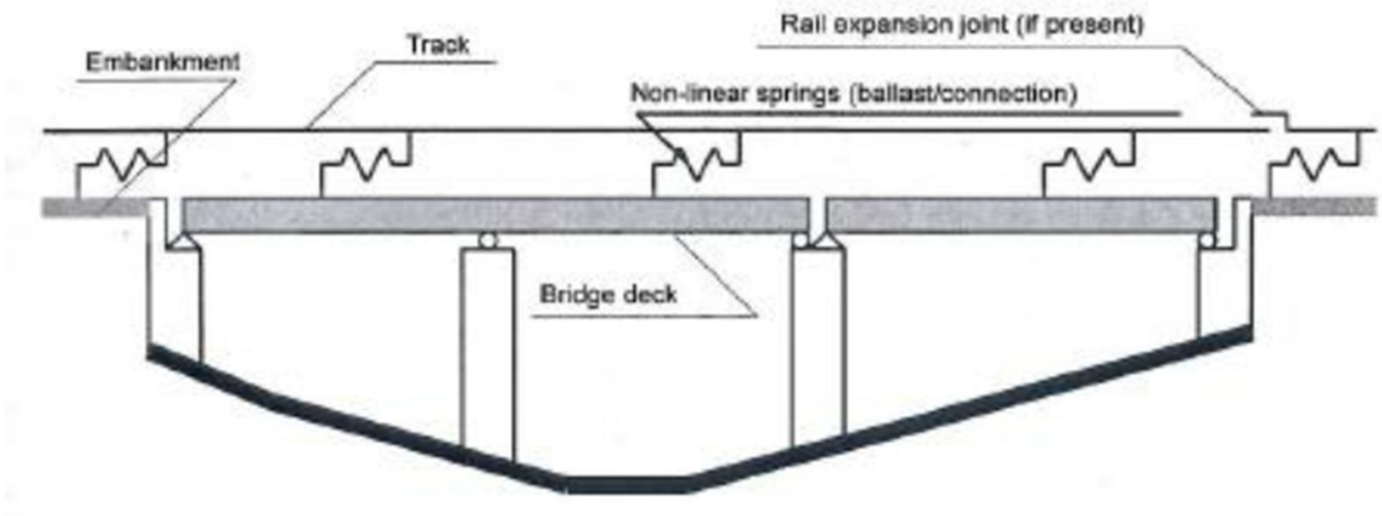


Deceleration



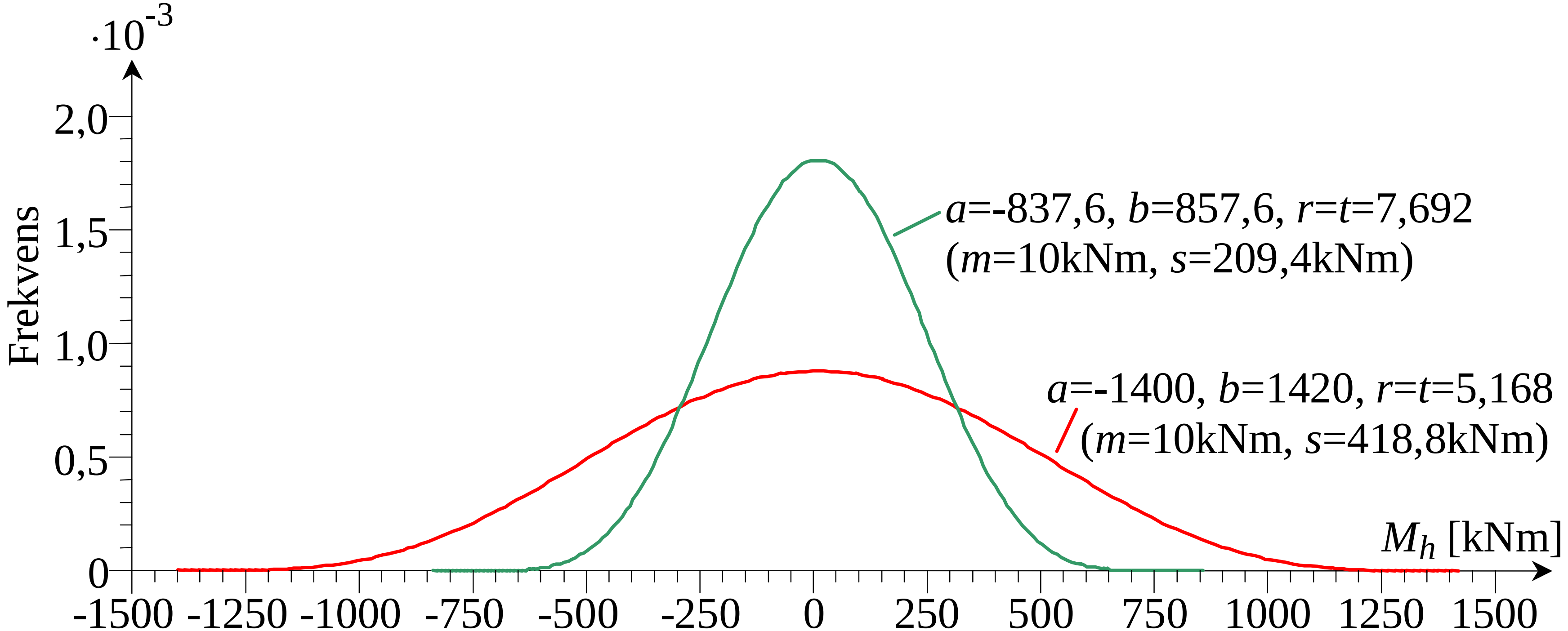
Acceleration

Niklas Bagge:
Accelerations- och bromskrafter för järnvägsbroar.
Examensarbete, LTU 2010



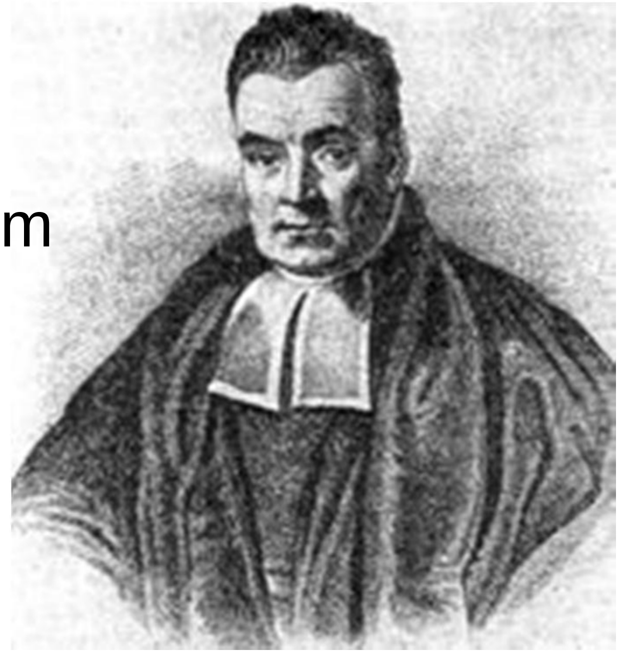
http://pure.ltu.se/portal/files/32449797/LTU-EX-2010-32441330.pdf

Frequency functions



Concrete Strength

Bayesian updating
Compare strengths from tested drilled out cores to the values from other series from the same site in order to adjust standard variations

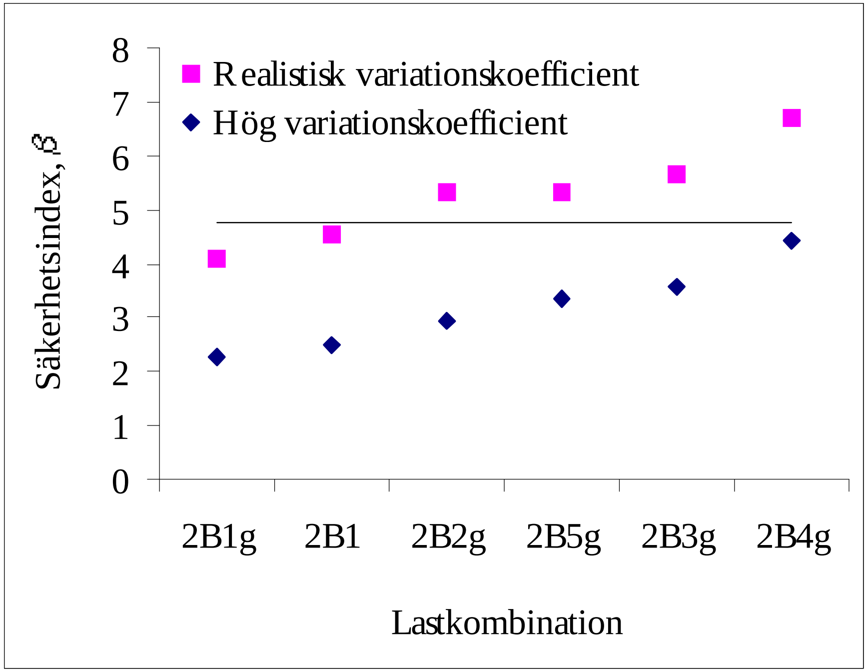


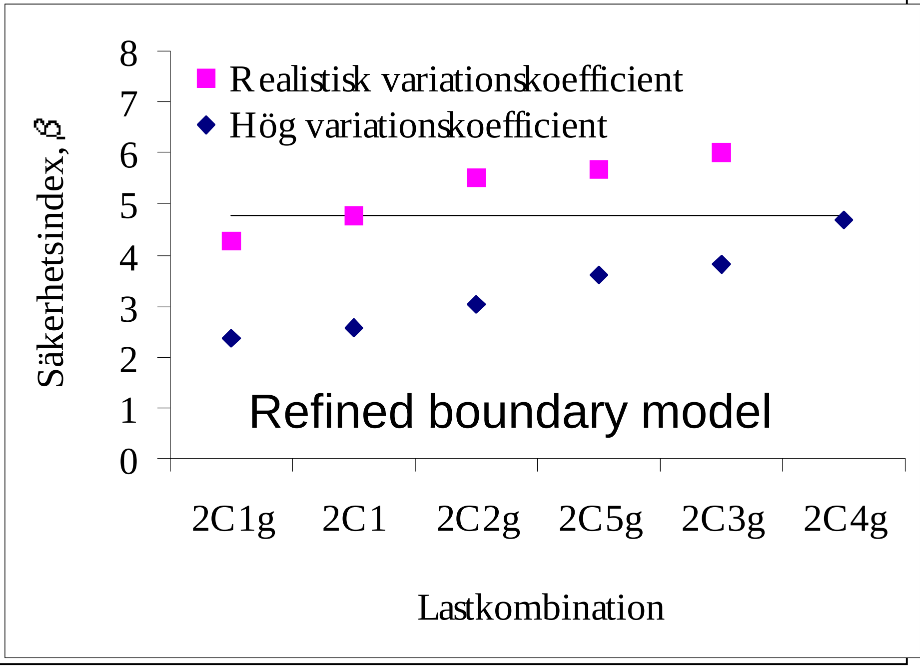
Thomas Bayes, 1702-1761, a Brittish mathematician and Presbyterian minister, known for having formulated Bayes' theorem, which now often is used to update results in statistical evaluations of data

Safety Index Metod

$G = R - S$ = Resistance – Load action

$$G = R - S = A_s f_{st} d \left(1 - \frac{A_s f_{st}}{2bdf_{cc}}\right) - M_g - M_{gb} - M_j - M_q(1+D) - M_h - M_t$$





Sustainable Bridges

Sustainable Bridges

Guideline for Inspection and Condition Assessment of Existing European Railway Bridges

Including advices on the use of non-destructive testing

Sixth Framework Programme

PRIORITY 6

SUSTAINABLE DEVELOPMENT

GLOBAL CHANGE & ECOSYSTEMS

INTEGRATED PROJECT

259 pp

Main deliverable

NDT Toolbox

More than 40 methods described with usage and limitations. Paper and electronic versions available.

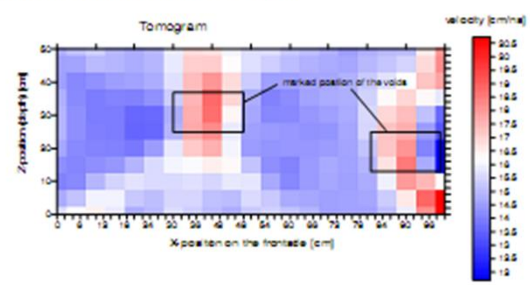
Impulse radar Tomography/ M

Sustainable Bridges

2.3.1.1 Field of application	Imaging the inner structure of masonry elements (velocity distribution/absorption) - to detect, localise and quantify inhomogeneities (voids, metal inclusions) - to determine the moisture content and distribution (limited)
Description	Radar tomography is a technique to map the interior of structural objects like pillars, columns and walls using reconstruction algorithms.
Physical principle	Tomography refers to the cross-sectional imaging of an object from either transmission or reflection data collected by radiating the object from many different directions. Either travel time (velocity tomography) or amplitude (attenuation tomography) information from many positions of transmitter-receiver pairs is used to reconstruct the hidden structure.
Limitation	Resolution strongly depends on the choice of transmitter-receiver pairs (ray coverage). Tomography is mainly applied to columns and pillars, where all sides are accessible. Applicable to walls, with only accessible opposite sites. There, with tomographic reconstruction it is not possible to map structures parallel to the surfaces.
Characterisation	
Physical principle	☐ Visual ☒ Electrical/Electromagnetic ☐ Acoustic ☐ Chemical ☐ Other
NDT/ destructive	☒ Non-Destructive ☐ Minor destructive ☐ Destructive
Type of test	☒ Single test ☐ Monitoring
Equipment Cost	☒ High ☐ Medium ☐ Low
Required education	☒ High ☐ Medium ☐ Low
Examination level	☐ Inspector alone ☐ Inspector + specialist ☒ Specialised laboratory
Accuracy	Strongly dependence of the geometry of the measurement and the material inhomogeneities, not established and not validated
Equipment	Radar system with 2 separated antennas, data processing software
Advantages	Information about the velocity/absorption distribution of the inner structure and the shape of constructional element or material inhomogeneities are given.
Disadvantages	Time consuming measurements, the resulting image is of limited resolution only.
Time consumption	For a 2D measurement of 1m scans with transmitter distance 5 cm approx. 1h; data quality check and preparation and inversion in the office: 1 day
2.3.1.2 Comments	Capability for application in bridge engineering is in research, not yet validated
Standardisation	Not available

Typical application:

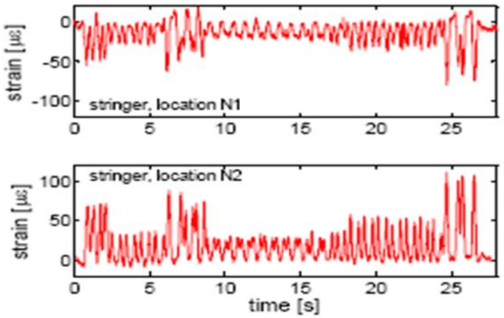
Typical result: (Image/ Graph)



Sustainable Bridges

Sustainable Bridges

Monitoring Guidelines for Railway Bridges



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GLOBAL CHANGE & ECOSYSTEMS

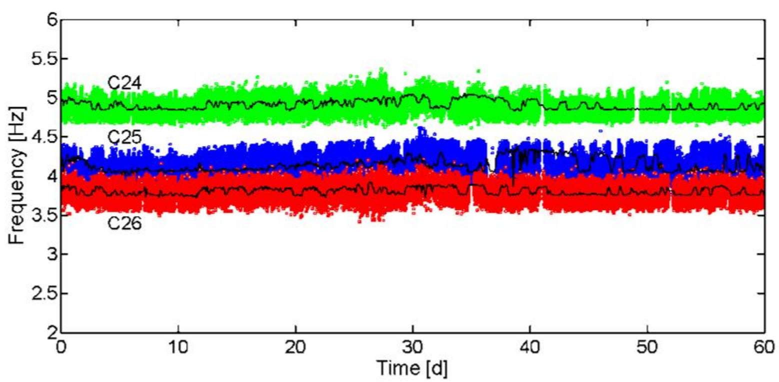
INTEGRATED PROJECT

93 pp

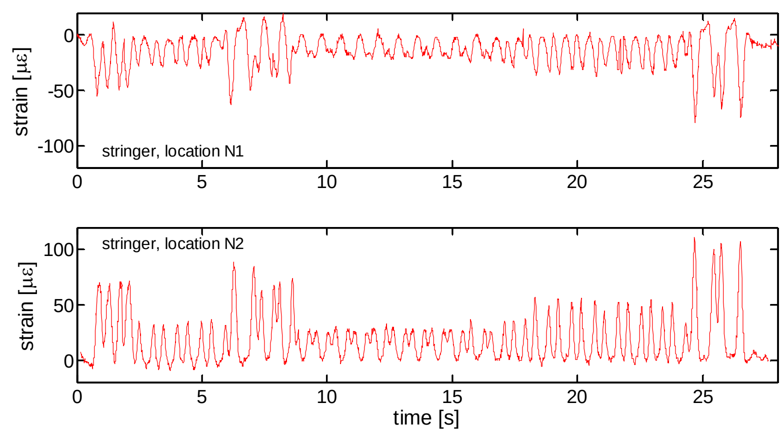
SUSTAINABLE BRIDGES

WP5

One year monitoring at the Stork Bridge



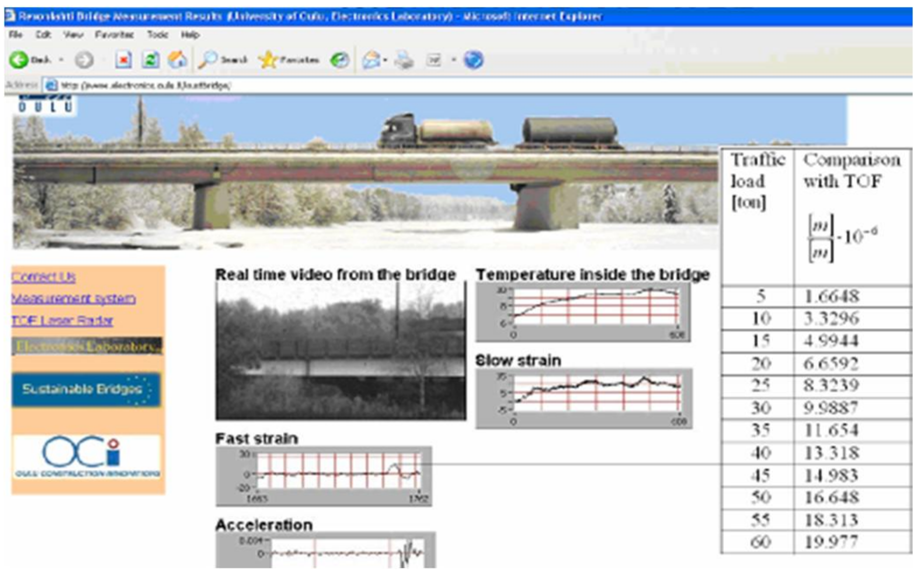
Strain monitoring at the Keraesjokk Bridge



SUSTAINABLE BRIDGES

Prototypes were developed:

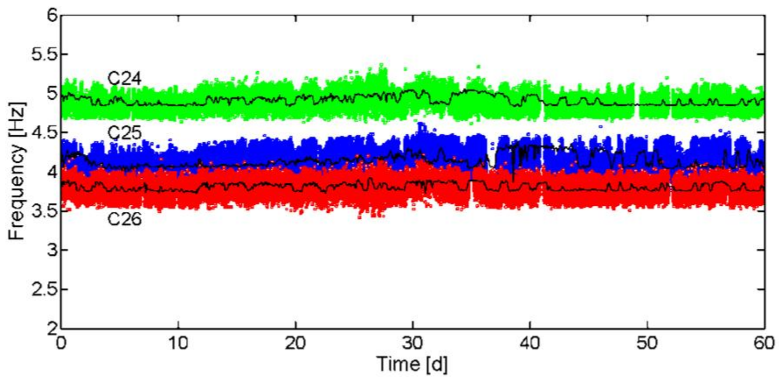
- Crack sensor
- Bragg grating sensor
- Time of flight sensor, tested at Revonlahti Bridge
- Wireless sensor network
- Dynamic exciter



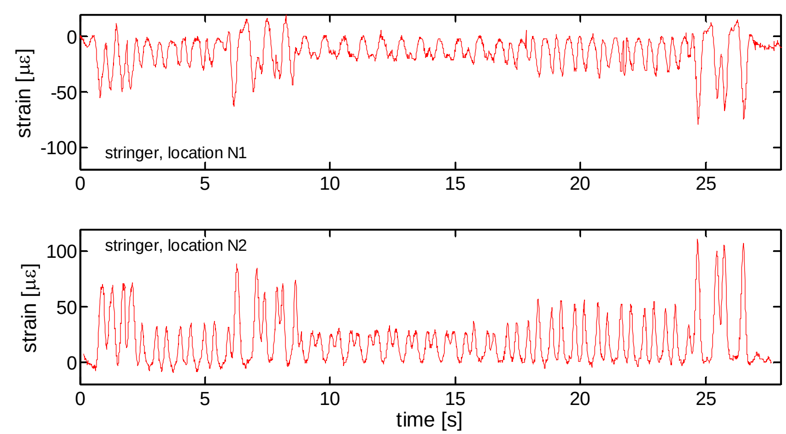
Online: www.electronics.oulu.fi/sustbridge

WP5

One year monitoring at the Stork Bridge



Strain monitoring at the Keraesjokk Bridge

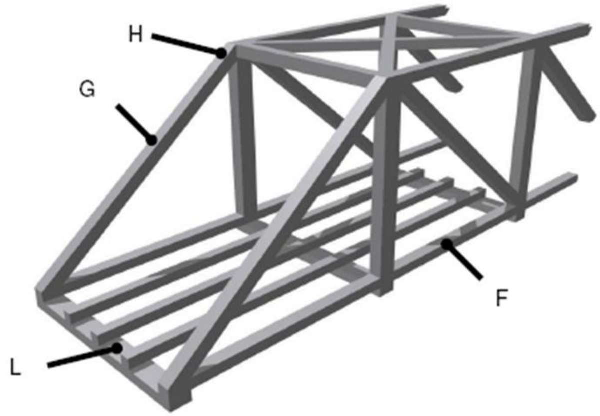


Sustainable Bridges

Sustainable Bridges

ice
Institution of Civil Engineers

Repair and Strengthening of Railway Bridges - Guideline



Visual Guideline
137 pp

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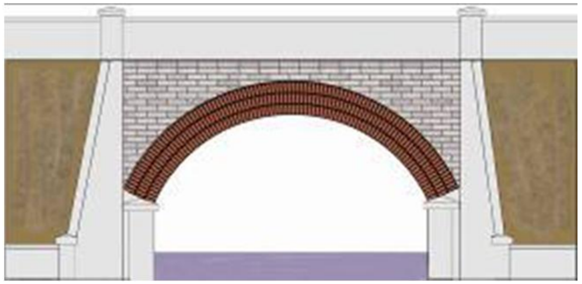
First step: Selection of Materials

WP6

Concrete

Metallic

Masonry



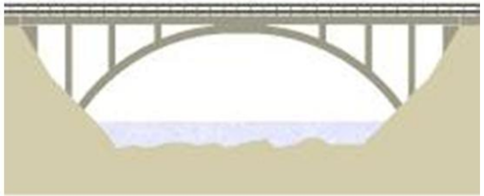
Second step: Selection of bridge type e.g. of r. c.

Box girder

Trough

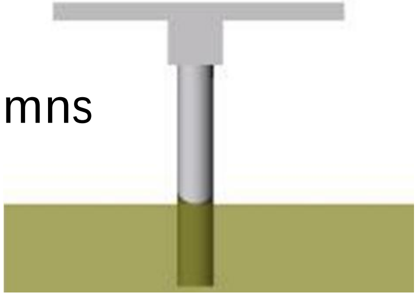
Beam/Slab

Arch

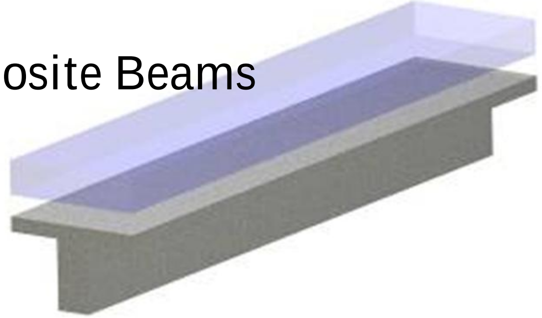


Or/and structural elements

Columns



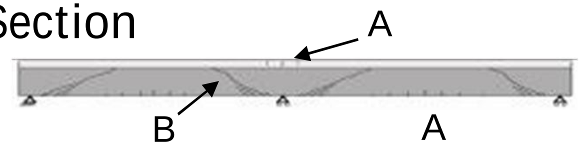
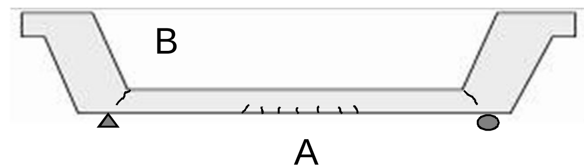
Composite Beams



SUSTAINABLE BRIDGES

Third step: Strengthening needs – a detailed description

WP6

View 	Section 
Photo(s) 	Section 

This is then related to method descriptions and case studies

Method Descriptions

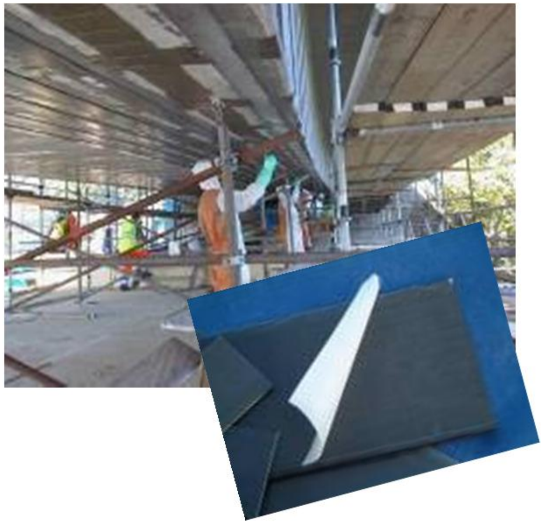
Case Studies

Easy to add-on

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

Different CFRP strengthening systems

Plates



Sheets

Rods
- Prestressed
- Non prestressed

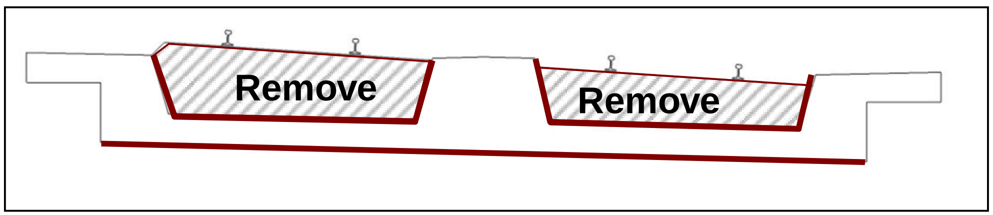
Grids, Mineral Based Strengthening Systems

Strengthening of the Frövi Bridge

Anders Bennitz, Björn Täljsten, Luleå University of Technology

Choice of strengthening

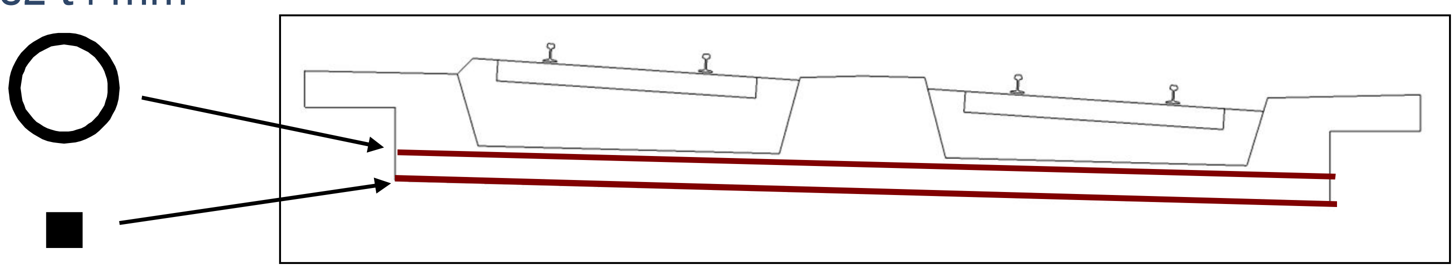
Traditional technique



Laboratory test

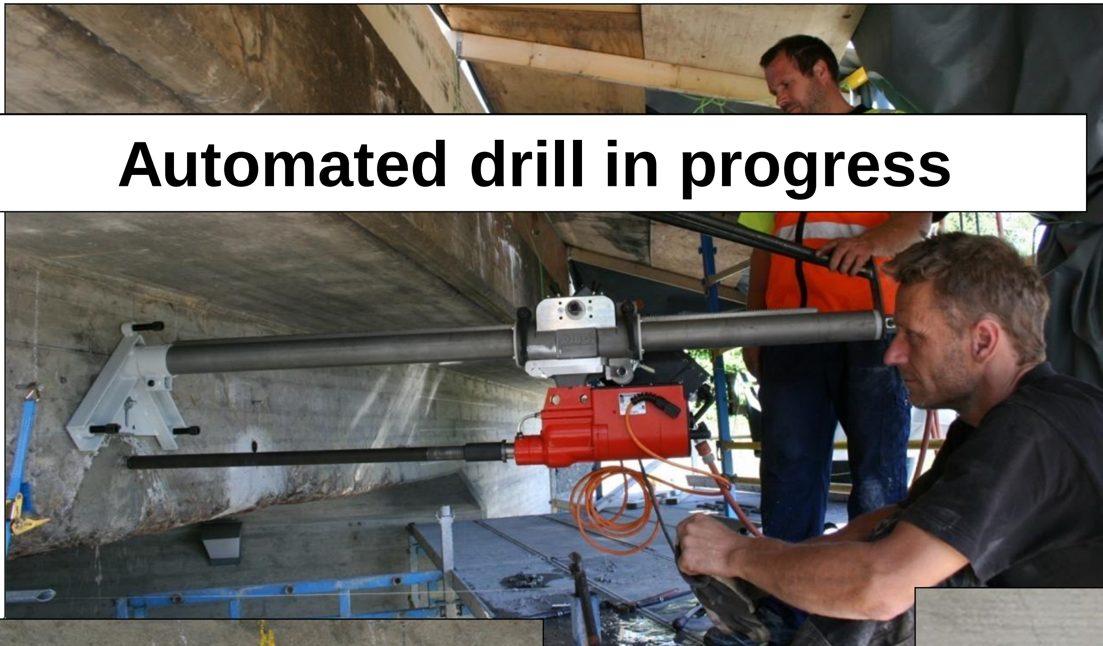
New technique

CFRP tube Ø32 t4 mm



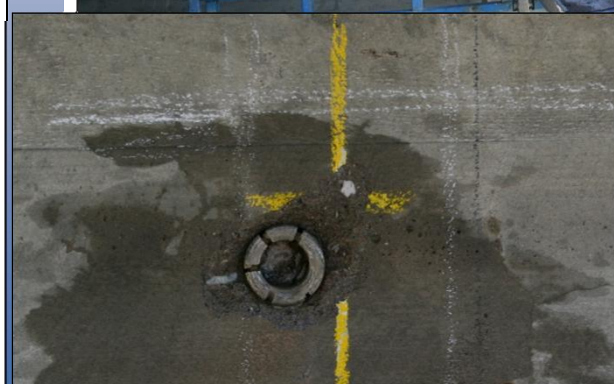
NSM bar 10x10 mm

Insertion of tubes

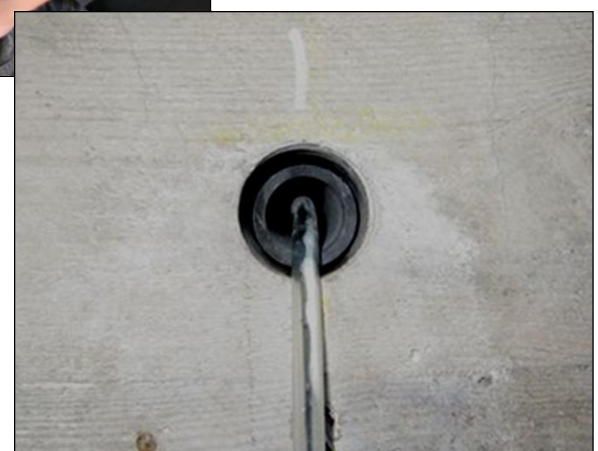


Automated drill in progress

11 holes
9 m long
1.3º vertical angle
± 15 mm vert.
± 85 mm hor.

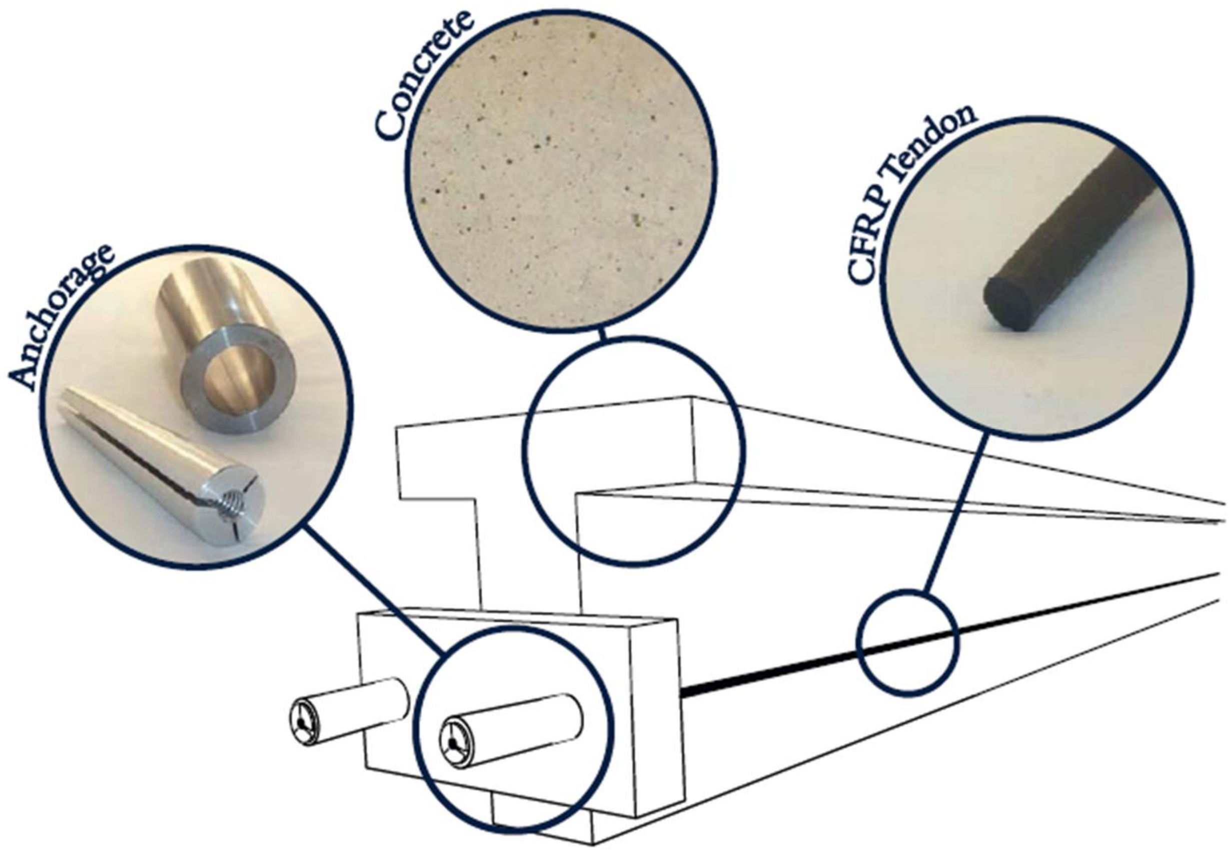


Exit of drillhead



Inserted tube ready for sealing and vacuum injection

Förspänd kolfiberarmering



Anders Bennitz, Disputation18 Feb 2011:
Externally Unbonded Post-Tensioned CFRP Tendons – A System Solution
http://pure.ltu.se/portal/files/32469379/Anders_Bennitz.Doc2011.pdf

Field Tests

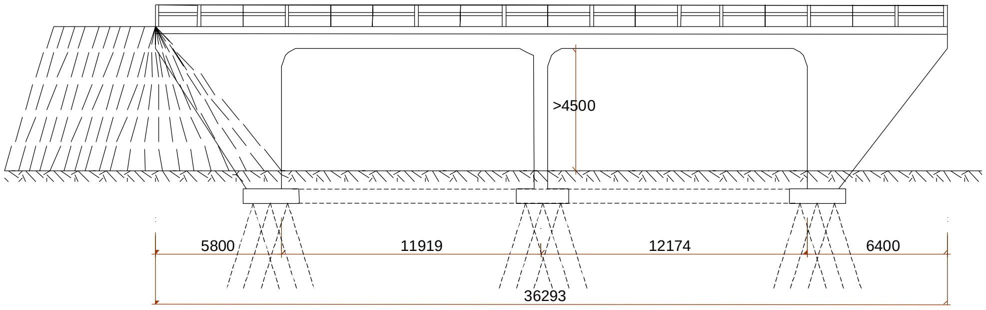
Bridge 1, **Riveted steel bridge**
– Avesnes, France

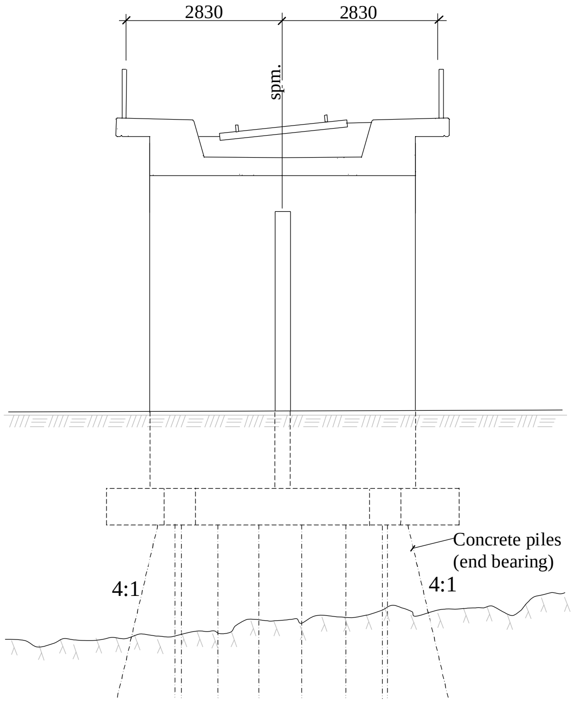
Bridge 2, **Concrete bridge**
– Örnsköldsvik, Sweden

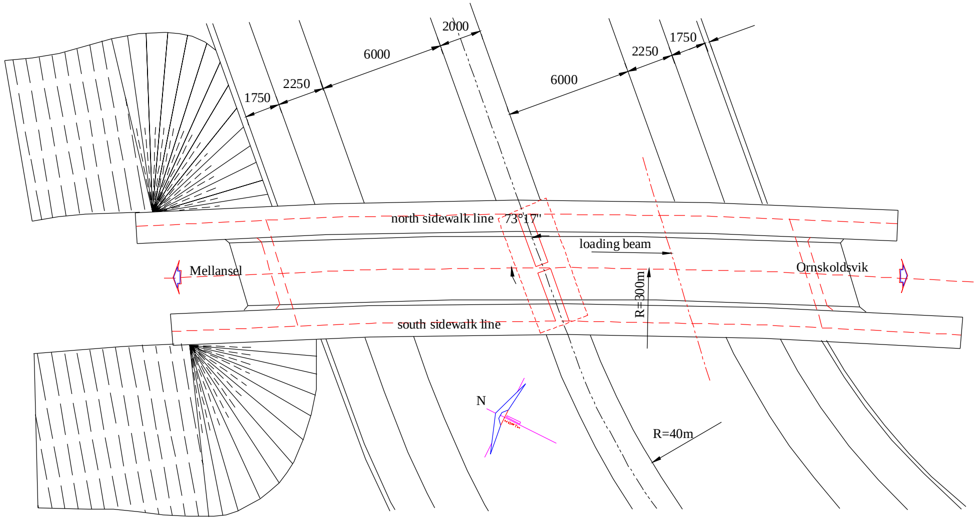
Bridge 3, **Masonry arch bridge**
– Olesnica, Poland

Testing of a strengthened R C Bridge 2006 in Örnsköldsvik

Overview – Boundary Conditions







Built 1955

Axle Load 250 kN

The bridge was strengthened in bending in order to get a shear failure

We are all optimists

Material Properties

Stage	Type of value	Concrete				Steel		
		f_c MPa	E_c GPa	f_t MPa	G_F Nm/m	$f_{sy} = R_{eh}$ MPa	$f_{su} = R_m$ MPa	E_s GPa
Initial properties from original drawings	Charac-teristic	31	32	1.8	-	ϕ16: 410	ϕ16: 500	ϕ16: 200
						ϕ25: 390	ϕ25: 500	ϕ25: 200
	Design ULS	17.2	25.4	1.0	-	ϕ16: 297.1	ϕ16: 362	ϕ16: 158.7
						ϕ25: 282.6	ϕ25: 362	ϕ25: 158.7
Mean properties based on tests (Standard deviations)	Mean	68.5 (8)	25.4 (1.7) ten-sion	2.2 (0.5) uni-axial	154 (82)	ϕ16: 441 (12)	ϕ16: 738 (2.4)	ϕ16: 192.1 (23.3)
						ϕ25: 411 (8.2)	ϕ25: 706 (22.6)	ϕ25: 198.3 (31.5)

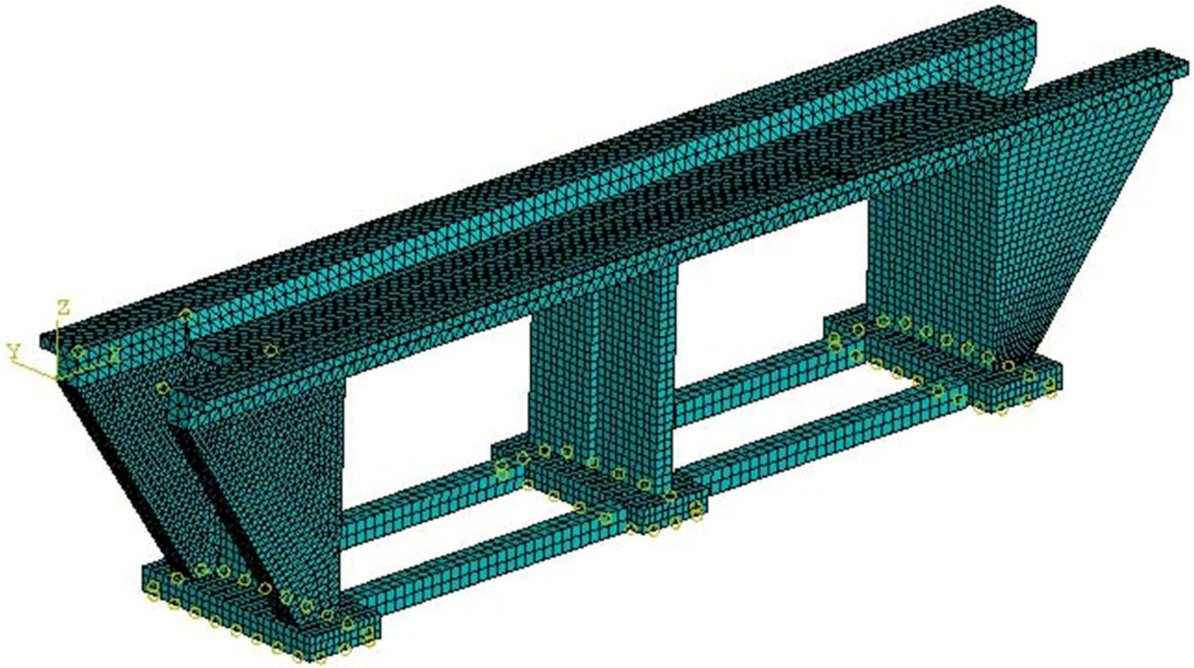
Eurocode 2 / BBK04

$V_{Rd,s} = A_{sw} f_{ywd} (z \cot \theta)/s$

where:

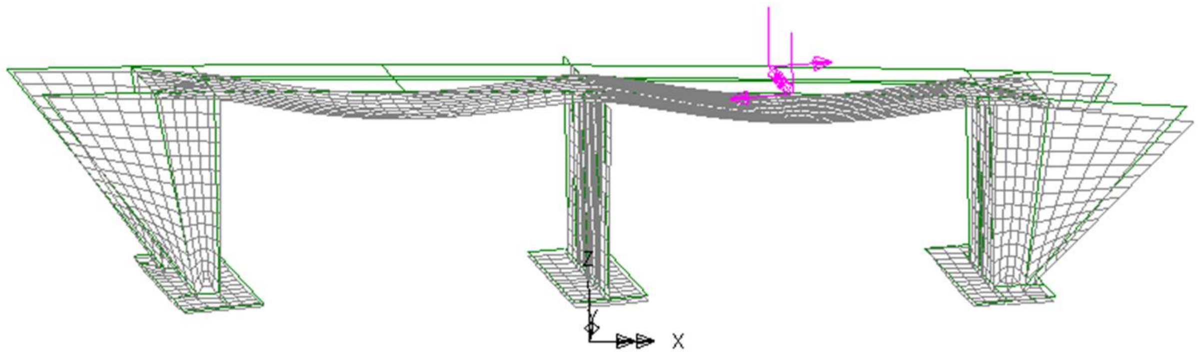
- A_{sw} is the cross sectional area of the reinforcement (804 mm^2, 4 Ø16, two hoops)
- f_{ywd} is the design yield strength of the shear reinforcement
- z is the inner level arm (900 mm = 0,9 d)
- θ is the angle between the concrete compression strut and the beam axis (min 21.8^o)
- s is the spacing of the stirrups (300 mm)

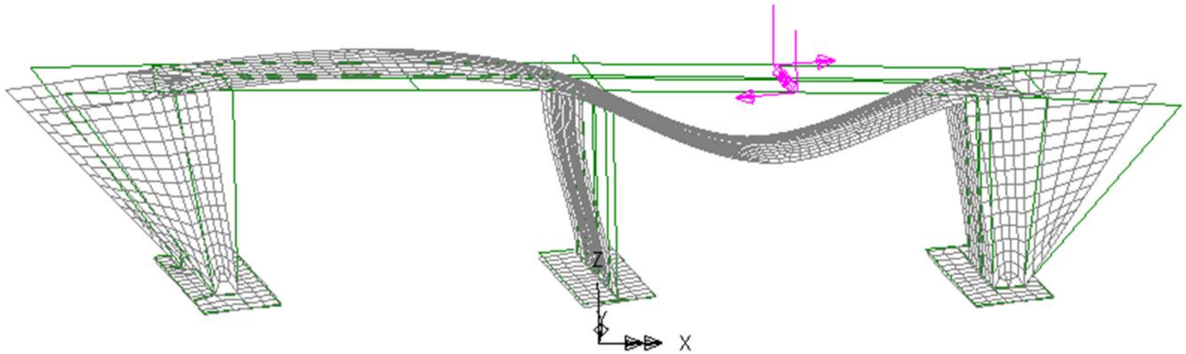
Linear and nonlinear 3D FEM Model
Brigade and French Code



Arto Puurula, LTU/ Savonia Univ.
Benjamin Richard & Christian Cremona, LCPC, Paris

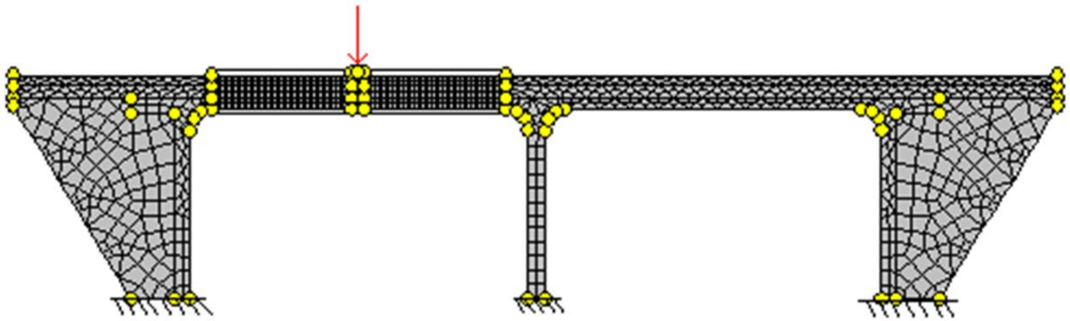
Linear 3D FEM Analysis with Lusas

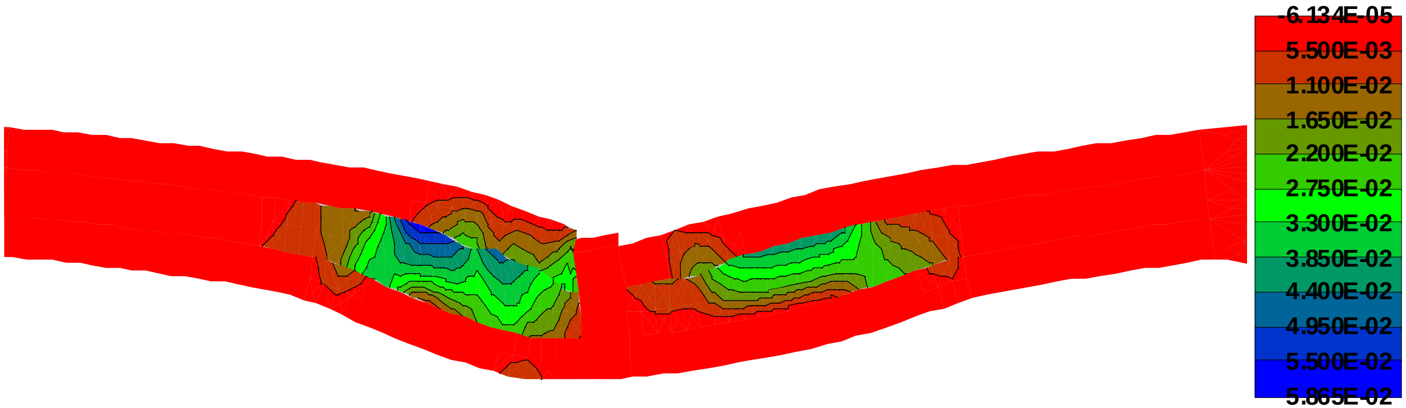




Deflections due to permanent loads and to a point load.
Jan Olofsson et al, Skanska

Non-linear 2D FEM-model with Atena

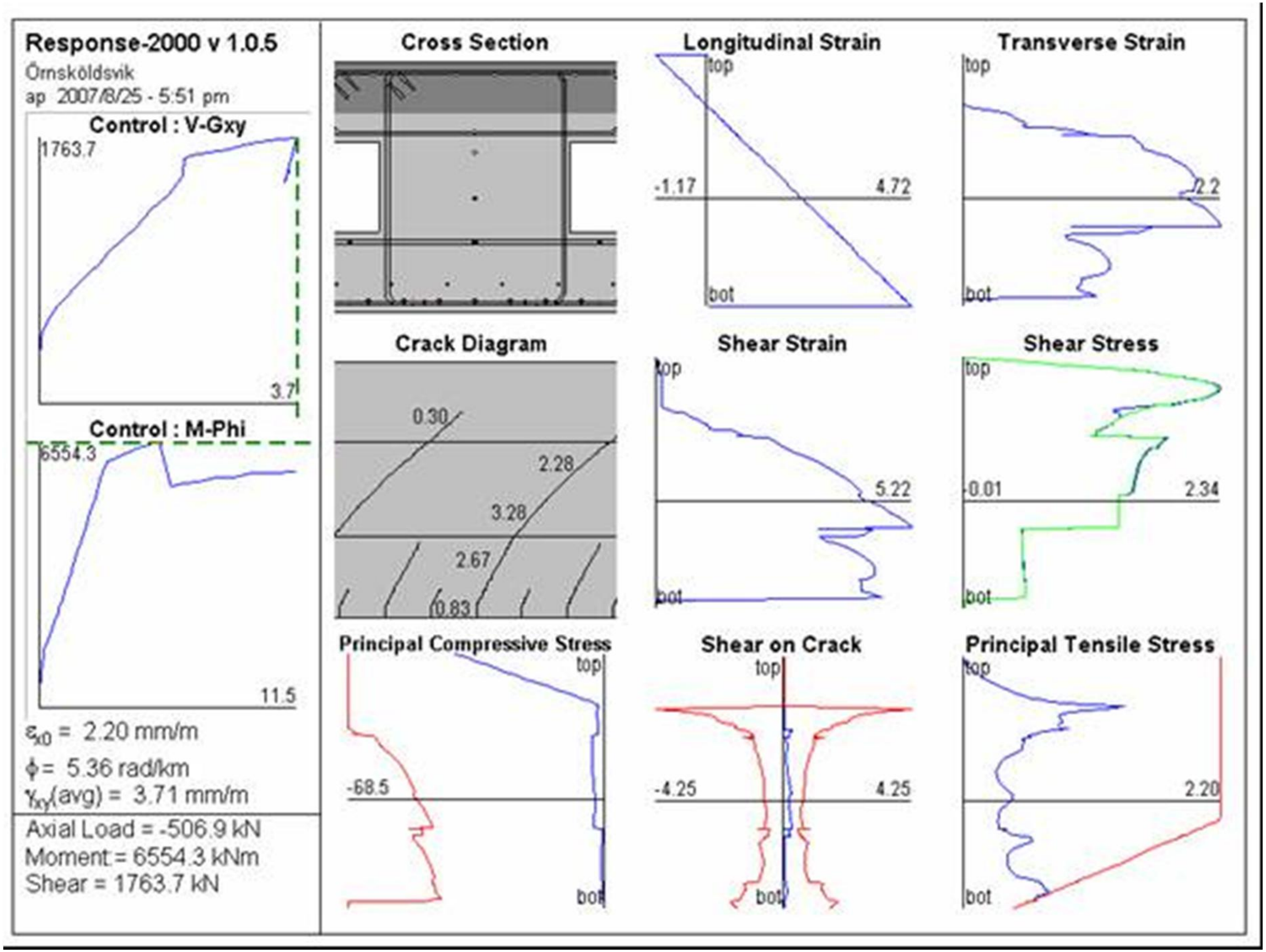




Max. Principal Strain showing Damage Localization

Jan Cervenka, Prague, Javier Quesada and Gabriel Sas LTU

Modified Compression Field Theory, Mike Collins et al



Midnight at test site

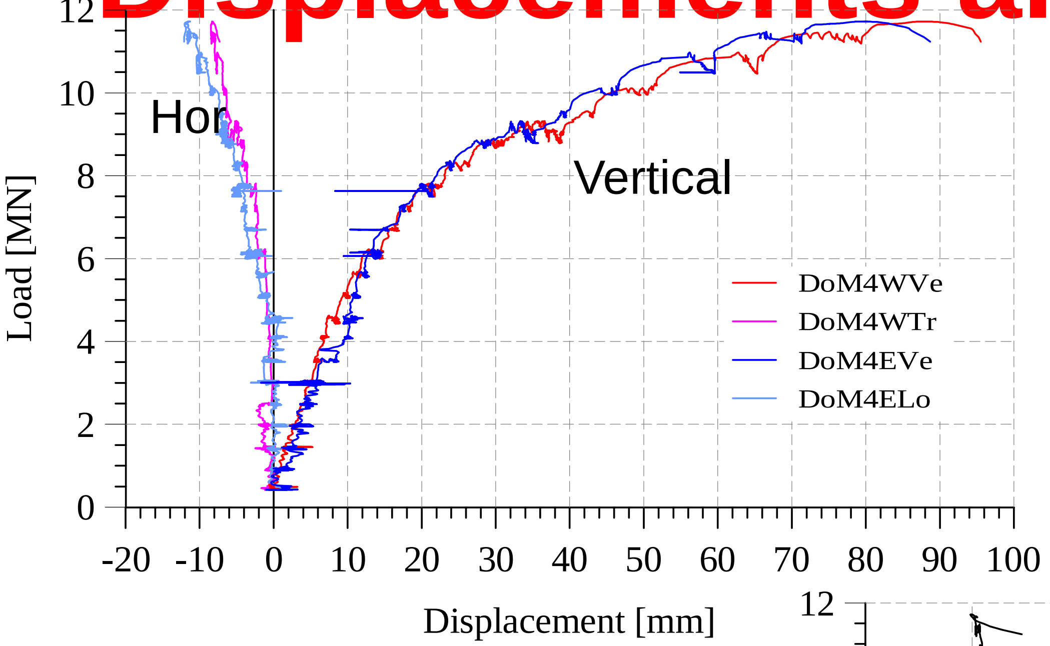
Sawing for Strengthening with Near Surface Mounted CFRP Rods

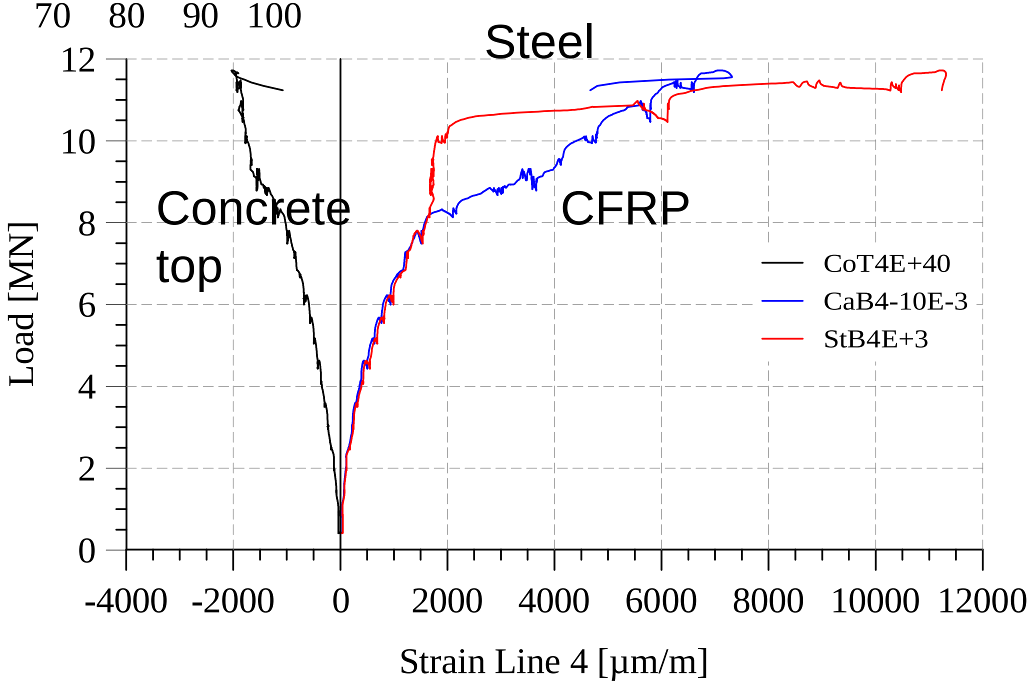
Strengthening procedure
Björn Täljsten et al

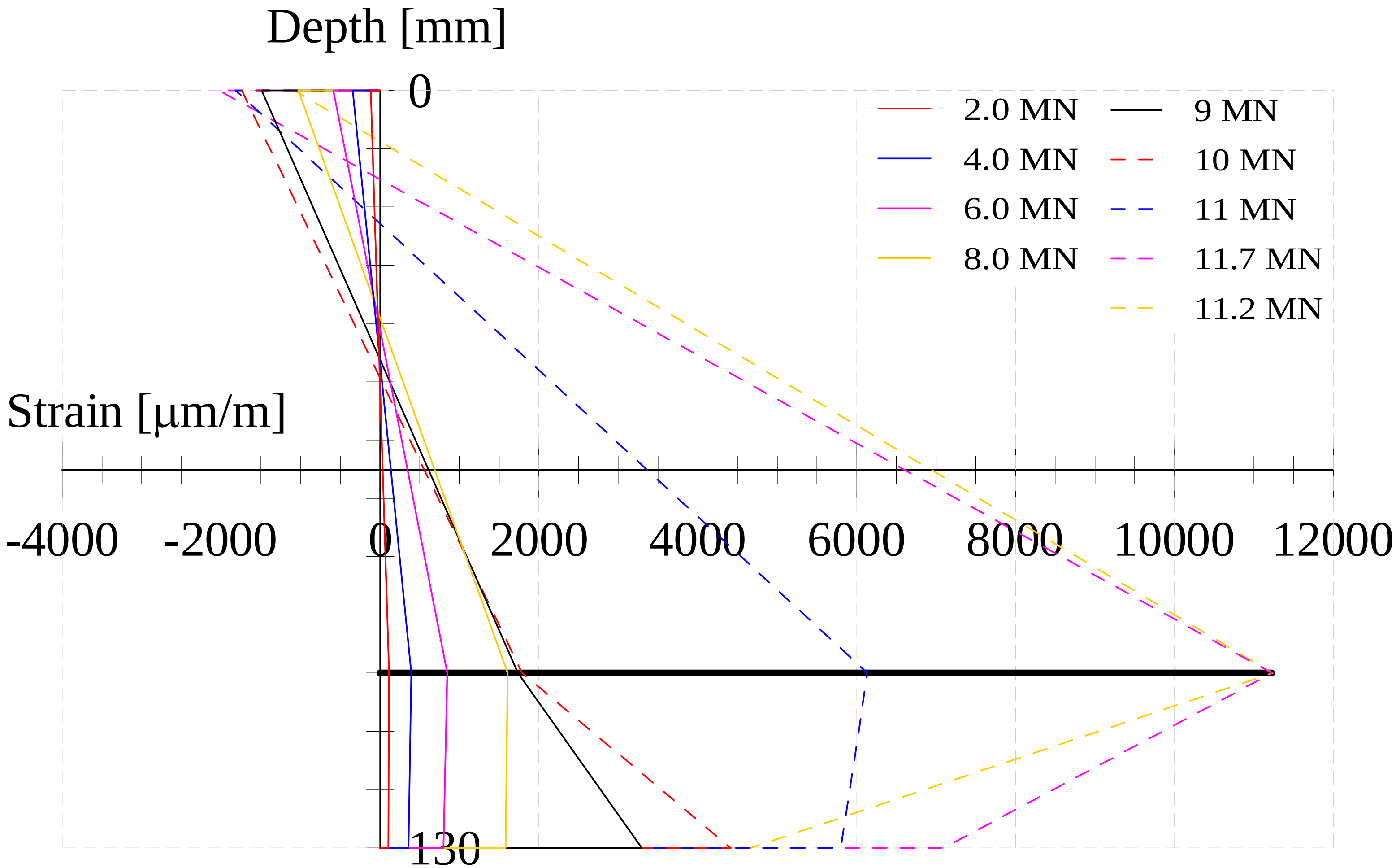

Final test
July 6, 2006


506
505
504

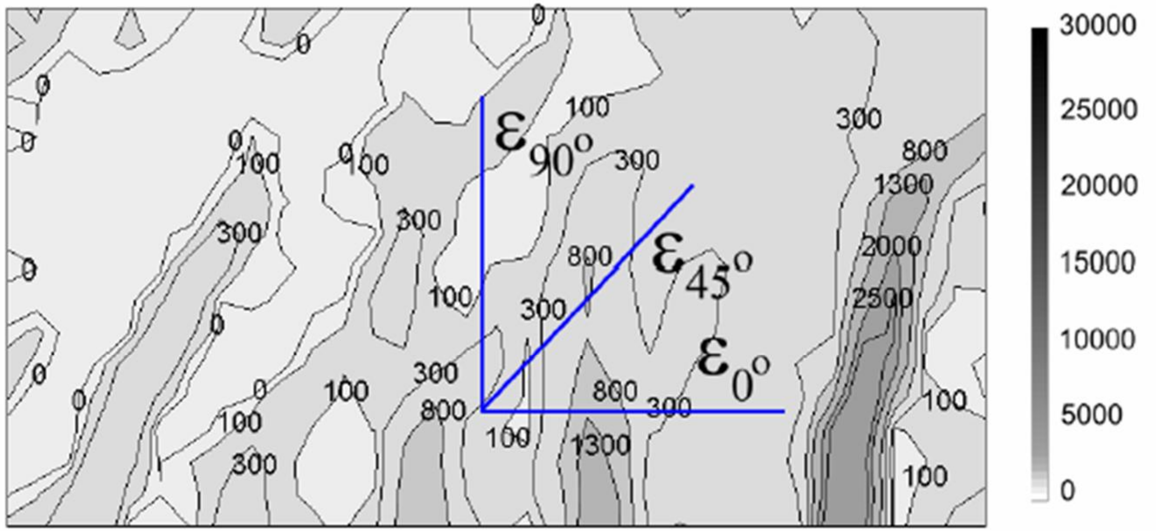
Displacements and Strains



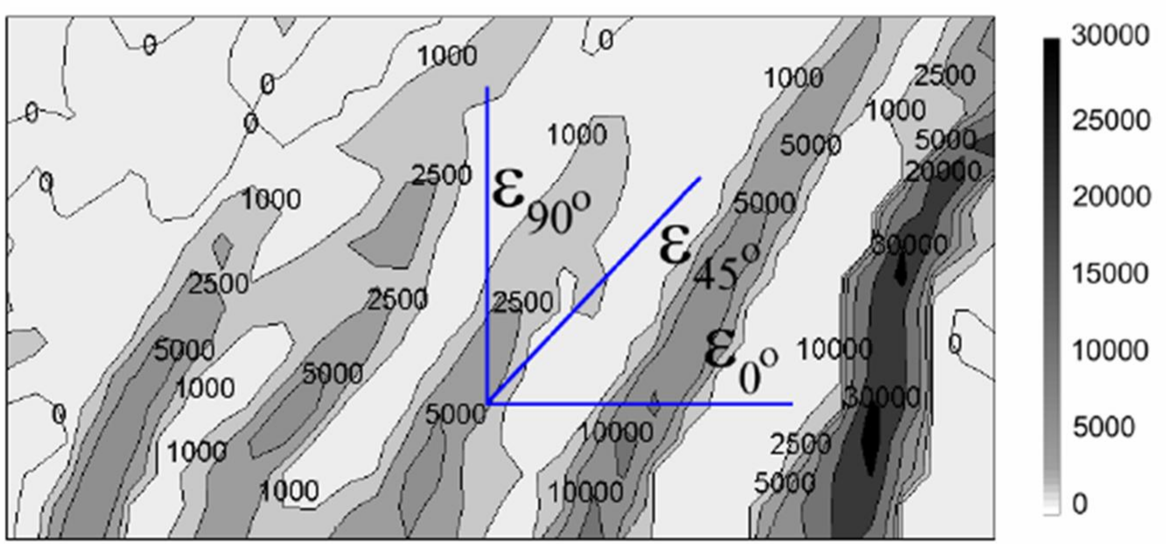




Strain profile in the east beam under the load at line 4.
Compressive concrete strains in the top.
Tensile strains in the steel and carbon fibre reinforcement in the lower part.


ε90o
ε45o
ε0o
30000
25000
20000
15000
10000
5000
0

6 MN


ε90o
ε45o
ε0o
30000
25000
20000
15000
10000
5000
0

10 MN


11. 07. 2006

Stirrup rupture after yielding

SUSTAINABLE BRIDGES

Video clip

Predicted Load-Carrying Capacity

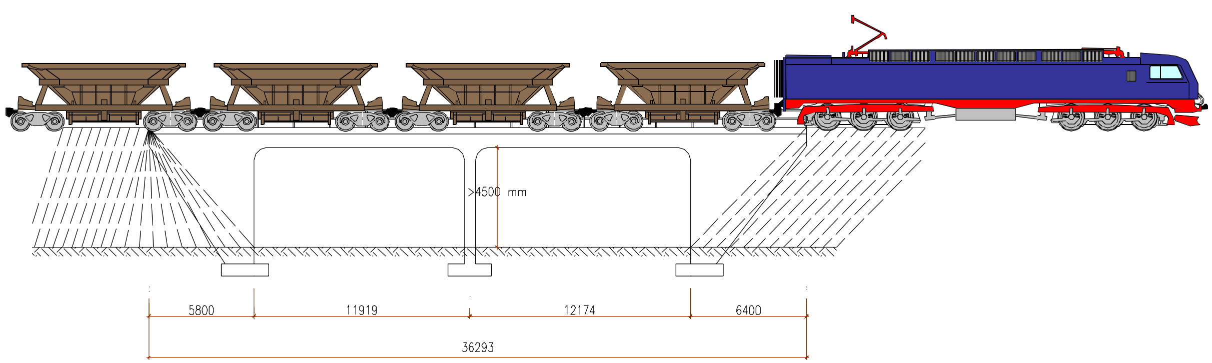
- Eurocode 2, $\theta = 30^o$ $P = 6{,}1$ MN
- Eurocode 2, $\theta = 22^o$ $P = 8{,}8$ MN
- MCFT, Response, $\theta \approx 30^o$ $P = 8{,}7$ MN
- 2D Non-lin, Atena, $\theta \approx 30^o$ $P = 10{,}8$ MN
- Test, $\theta \approx 30^o$ $P = 11{,}7$ MN

Reserve Capacity

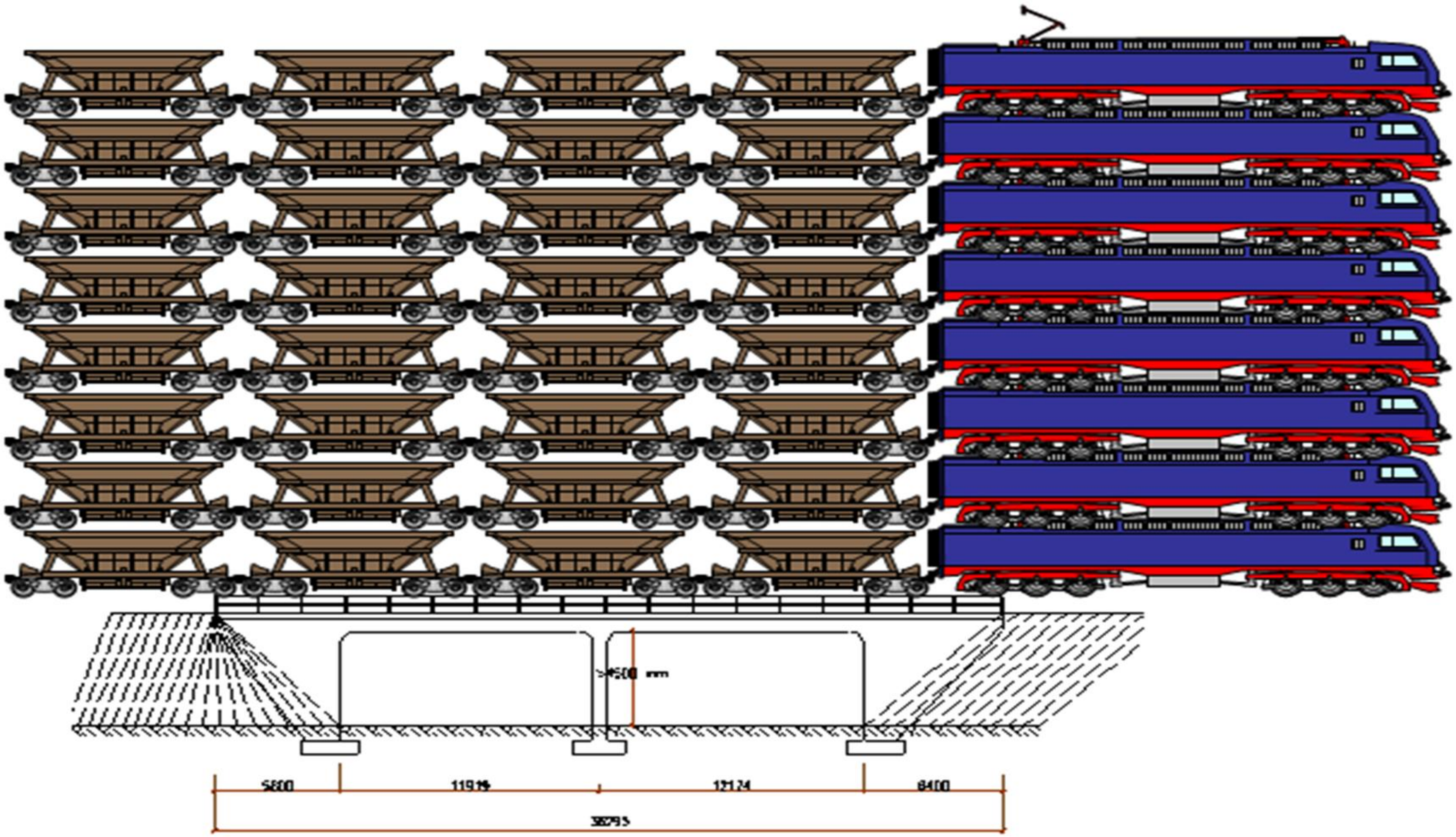
The failure load 1170 ton corresponds to
1170 ton / 25 ton ≈ 47 axles

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



Conclusions – Bridge Test

- SB methods have been successfully tested for
  - inspection and condition assessment,
  - load carrying capacity predictions,
  - strengthening and monitoring

  of a 50 year old reinforced concrete trough bridge.
- A failure in combined shear, bending and torsion was reached for P = 11,7 MN.
- The failure was initiated by rupture of a stirrup after yielding in stirrups and longitudinal reinforcement.
- The failure load was close to predictions with SB methods and 20 to 50 % higher than common methods.
- The test verifies that the anticipated failure mechanism was correct. This is sometimes not the case.

Top row: Arto Puurula, Jean-Christophe Collin, Kevin and Ola Enochsson, Rolando Estrada, James Leighton, Håkan Nordin, Abraham Diaz de Leon Benard, Otto Norling, Georg Danielsson and Stig Johansson. Front row: Lukasz Topczewski, Lennart Elfgren, Björn Täljsten, Ahti Hallikainen, Gabriel Sas, Bradley Pease, Anders Johansson and Håkan Johansson. Inserted: Ulf Ohlsson, Anders Carolin and Fateh Abdel Kerrouche.

Acknowledgements

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- **Banverket** (Björn Paulsson, Valle Jansen, Anders Kers, Katarina Kieksi, Anders Kronborg, Björn Töyrä)
- **BAM** (Ernst Niederleithinger, Jens Wöstmann, Ralph Bäßler, Boris Milmann, Markus Stoppel, Matthias Behrens)
- **CityU** (Bradley Pease, Fateh Abdel Kerrouche, W.J.O. Boyle)
- **Cervenka Consulting** (Jan Cervenka, Vladimir Cervenka)
- **COWI** (Tomas Frølund, Torben Pedersen, Mette Sloth)
- **LTU** (Anders Carolin, Georg Danielsson, Lennart Elfgren, Kevin Enochsson, Ola Enochsson, Håkan Johansson, Håkan Nordin, Ulf Ohlsson, Arto Puurula, Gabriel Sas, Håkan Thun, Björn Täljsten)
- **LCPC** (Christian Cremona)
- **SKANSKA** (In Göteborg: Anna Björklund, Marcus Davidson, Per Kettil and Jan Olofsson; In Örnsköldsvik: Hans-Erik Forslars, Jan-Arle Karlsson, Sten Lundgren)
- **STO** (Otto Norling)
- **University of Uminho** (Paulo Cruz, Rolando Estrada, Abraham Diaz de Leon Benar, Lukasz Topczewski, Dawid Wisniewski)

The following companies and institutions outside the project have also contributed:

- **Botniabanan AB** (Sören Backlund, Jan Jonsson, Jörgen Mosesson)
- **Denmark University of Technology** (DTU), (James Leighton, Björn Täljsten)
- **Jernhusen** (Leif Aker)
- **Nordisk Spännarmering** (Karl-Erik Nilsson, Stig Johansson, Anders Jansson, Rune Olsson)
- **Saviona University, Finland** (Jean-Christophe Collin, Arto Puurula, Ahti Hallikainen)
- **WSP** (Thorbjörn Sundén)
- **Ågrens Tryckeri** (Arne Eklund)
- **Örnsköldsviks kommun** (Hans Andersson, Ann-Charlotte Edholm, Ove Sedin, Elvy Söderström)

Dissemination

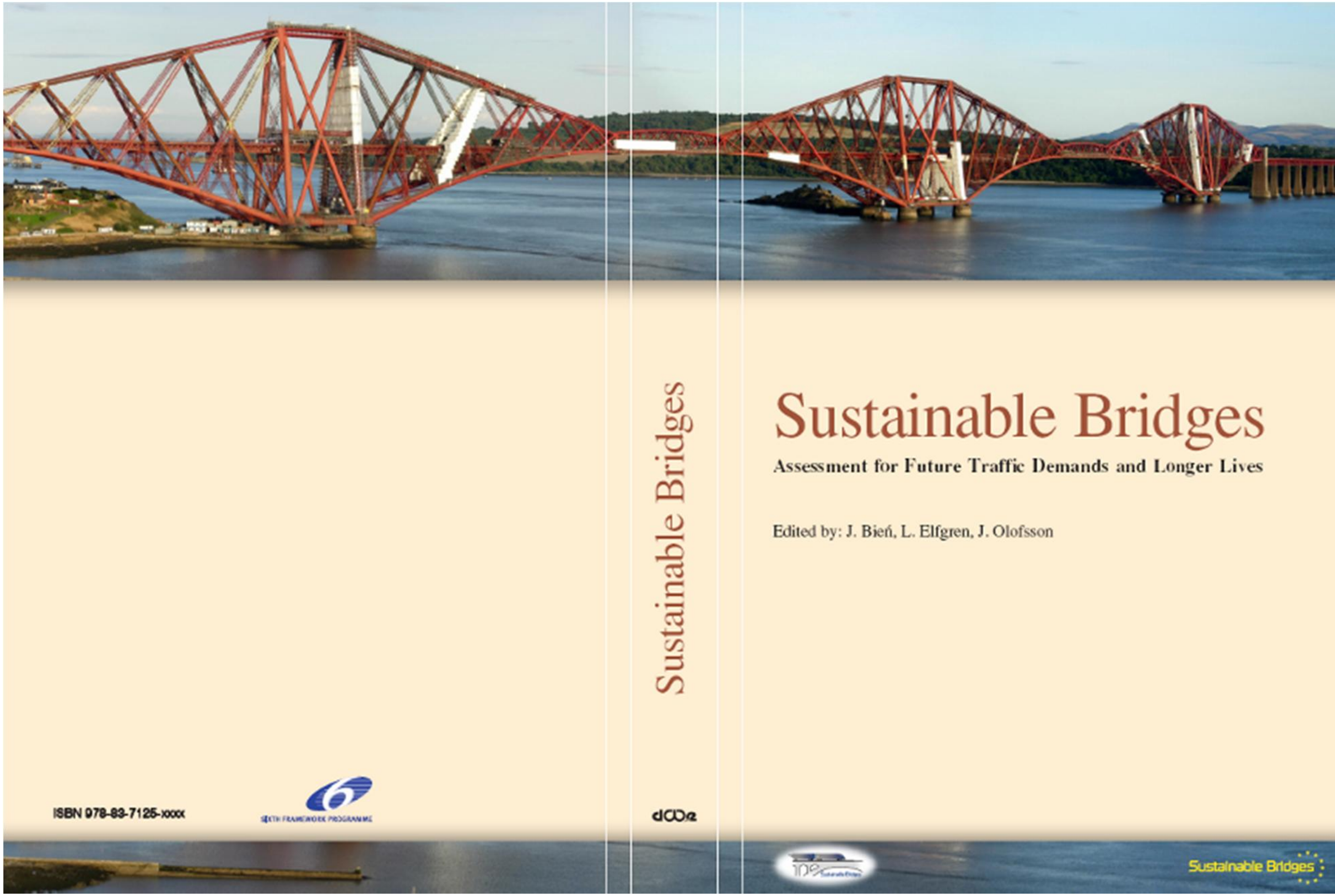
- **Workshop 1: "Inspection and Condition Assessment of Railway Bridges"**
  BAM, Berlin, 23-24.10.2006

- **Workshop 2: "Repair and Strengthening of Railway Bridges"**
  LTU, Luleå, 26-27.03.2007

- **Workshop 3: "Load and Resistance Assessment of Railway Bridges"**
  COWI, Copenhagen, 21-22.05.2007

- **Workshop 4: "Monitoring of Railway Bridges"**
  EMPA, Zurich, 25-26.06.2007

- **Final Conference**
  Wroclaw, Poland, 10-11.10.2007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Assessment for Future Traffic Demands and Longer Lives
Edited by: J. Bień, L. Elfgren, J. Olofsson
Sustainable Bridges
ISBN 978-83-7125-xxxx
SIXTH FRAMEWORK PROGRAMME
Sustainable Bridges

Management

Different backgrounds and interests, for example

Academic world ⟺ *Owners* ⟺ *Industry*

But taking into consideration different views in a good way is a Strength!

Cost saving

Replacement of a bridge in the UK of 100 m² is 1.4 M€

Two lane railway bridge	14 k€/m²
One lane railway	20 k€/m²
Road bridge	7 k€/m²

The cost to repair a typical bridge is 3 k€/m²

A typical 100 m² bridge costs 0,3 M€.

For every bridge we “save”, we earn about 1,1 M€.

Estimate in Proposal:

- 200 000 railway bridges in Europe á 0,25M€ = 50 G€ (Billions)
- 2 % savings gives 1 G€ (Billion)

Present Estimate:

- 300 000 railway bridges in Europe á 0,5 M€ = 150 G€
- 1000 bridges gives 1 G€ (Billion)

2009:189 CIV

MASTER'S THESIS

Improving Transportation Investment Decisions Through Life-Cycle Cost Analysis

Comparative LCCA of Bridges

Marco Ditrani

MASTER OF SCIENCE PROGRAMME
Civil and Mining Engineering

Luleå University of Technology
Department of Civil, Mining and Environmental Engineering
Division of Structural Engineering

2009:189 CIV • ISSN: 1402 - 1617 • ISRN: LTU - EX - - 09/189 - - SE

En jämförelse mellan

- 12 befintliga betongbroar i Norrbotten
- 3 projekterade limträbroar
- 3 projekterade rörbroar

Table 5.2 - Summary of Life Cycle cost for studied bridges. Maximum costs are indicated with **bold blue** and minimum costs with ***bold red italics***.

Bridge	**Lenth**	**Width**	**Area**	**Life length**	**Traffic 2009**	**Annuity Cost**	**Annuity/area**	**Annuity/(area*traffic)**
No/BaTMan Code	m	m	m2	years	vehicles/day	kkr	kkr/m2	kr/(m2*veh/day)
1/24-1790-1	26	7.3	189.8	120	200	11 752	62	310
2/24-1861-1	19	7	133	120	20	***6 777***	***51***	**2 548**
3/24-1497-1	26	7	182	100	370	12 033	66	179
4/24-1753-1	18	7	126	120	2 800	11 712	93	33
5/24-1876-1	20	15.2	304	120	**5 000**	27 170	89	***18***
6/24-417-1	23	7.9	181.7	90	1 900	20 371	112	59
7/24-471-1	19	6.9	131.1	100	105	15 971	122	1 160
8/25-1432-1	19	7.9	150.1	100	720	12 643	84	117
9/25-1674-1	22	9	198	80	1 410	30 361	153	109
10/25-1888-1	16	15.1	241.6	100	4 300	**38 999**	**161**	38
11/25-780-1	17	7.4	125.8	100	300	9 260	74	245
Glulam 1	20	7	140	80	100	10 005	71	715
Glulam 2	20	7	140	80	500	10 698	76	153
Glulam 3	20	7	140	80	**5 000**	18 946	135	27
Soil-steel 1	20	7	140	80	100	9 150	65	654
Soil-steel 2	20	7	140	80	500	9 497	68	136
Soil-steel 3	20	7	140	80	**5 000**	17 096	122	24

Implementing of results from Sustainable Bridges

- **Course in Non-Destructive Testing (NDT) and monitoring, 14-15 May 2008 in Ängelholm**
- **Workshop on Repair and Strengthening, 26-27 May 2009 in Paris**
- **Two workshops on assessment of existing bridges:**

  - Paris 7-8 September 2010

  - Frankfurt 2-3 November 2010
- **UIC Code 778-4 Inspection of Bridges**
- **UIC Code 778-2 Steel Bridge Assessment (Planned)**

Conclusions

- We should further investigate the **hidden strengths** and **weaknesses** of structures. **Full scale tests to failure** is one approach.
- Good assessment methods are available but we need more data on **deterioration** and **environmental impact** to be able to make reliable **whole life assessments.**
- By **monitoring and strengthening** we can **extend life length** - up to a limit. We must also **start to exchange old structures**.

Current and Future Needs

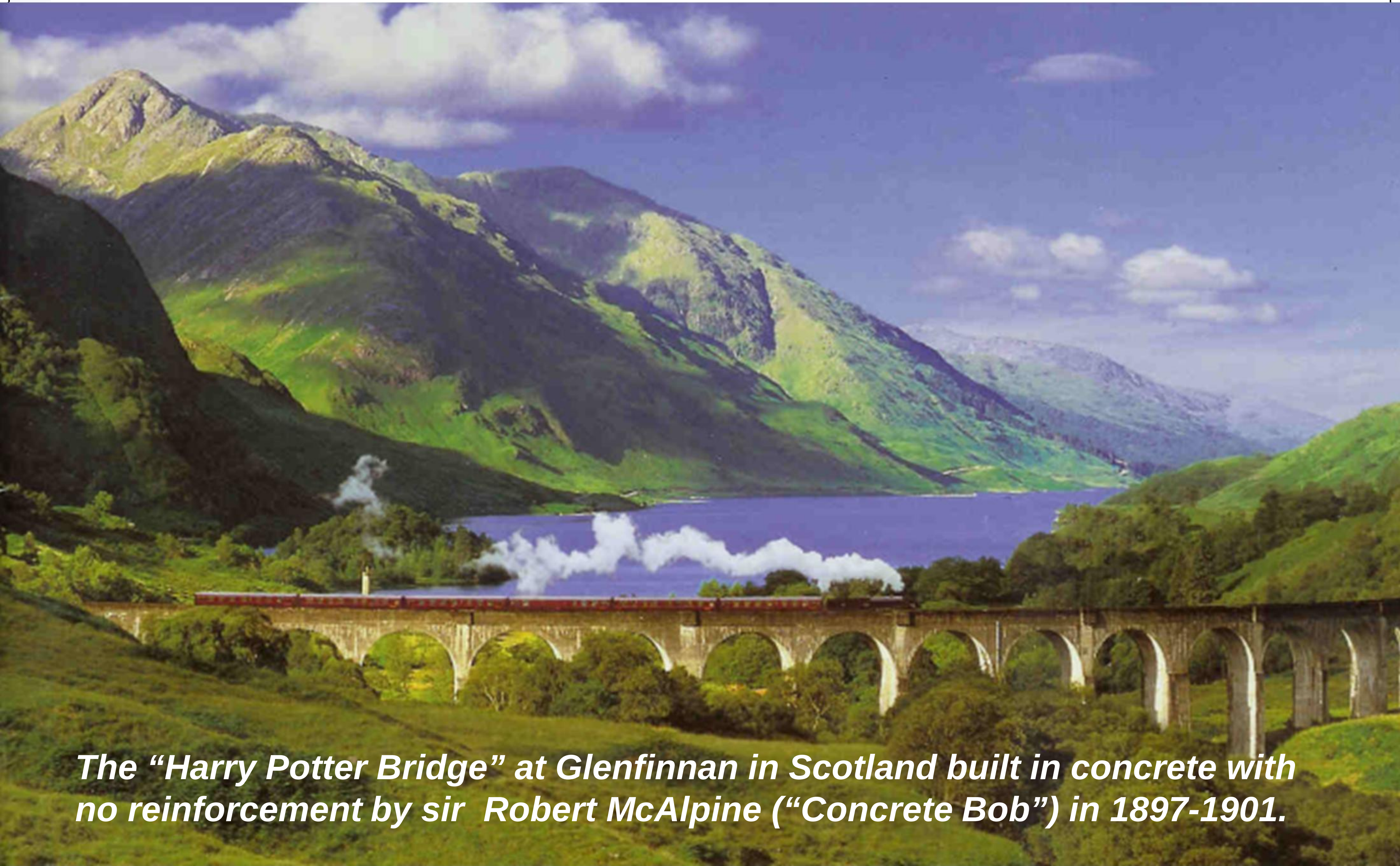
- There a significant "hidden strength" in the majority of the European bridge stock
- We must now repair and strengthen more bridges instead of replacing
- The result from Sustainable Bridges shows it is possible in most cases
- The most difficult question is that it takes so long time to implement results from R&D

Thanks for your kind attention!

Acknowledgements to colleagues in Sustainable Bridges Final Review with EC Experts in Wroclaw, October 2007

Patrik van Honacker, Adam Grotzicki, Dwight O´Dwyer, EC; Jan Olofsson, Skanska, Mgr, Lennart Elfgren, LTU, Scientific Leader; Brian Bell, Network Rail, WP1; Björn Paulsson, Banverket, WP2; Ernst Nieder-leithinger, Rosemarie Helmerich, BAM, WP3; Jens Sandager Jensen, COWI, WP4; Glauco Feltrin, EMPA, WP5; Björn Täljsten, LTU, WP6; Christian Cremona, LCPC, WP7; Risto Kiviluoma, WSP, WP8; Jan Bien, WUT, WP9; Britta Schewe, DB.

Thank you for your kind attention



The "Harry Potter Bridge" at Glenfinnan in Scotland built in concrete with no reinforcement by sir Robert McAlpine ("Concrete Bob") in 1897-1901.

Erfarenheter från EU-projektet Sustainable Bridges

Lennart Elfgren
Byggkonstruktion
Luleå tekniska universitet

CIR-dagen den 1 februari 2011
Göteborg Convention Centre
Järnvägsteknik för långsiktig hållbar utveckling

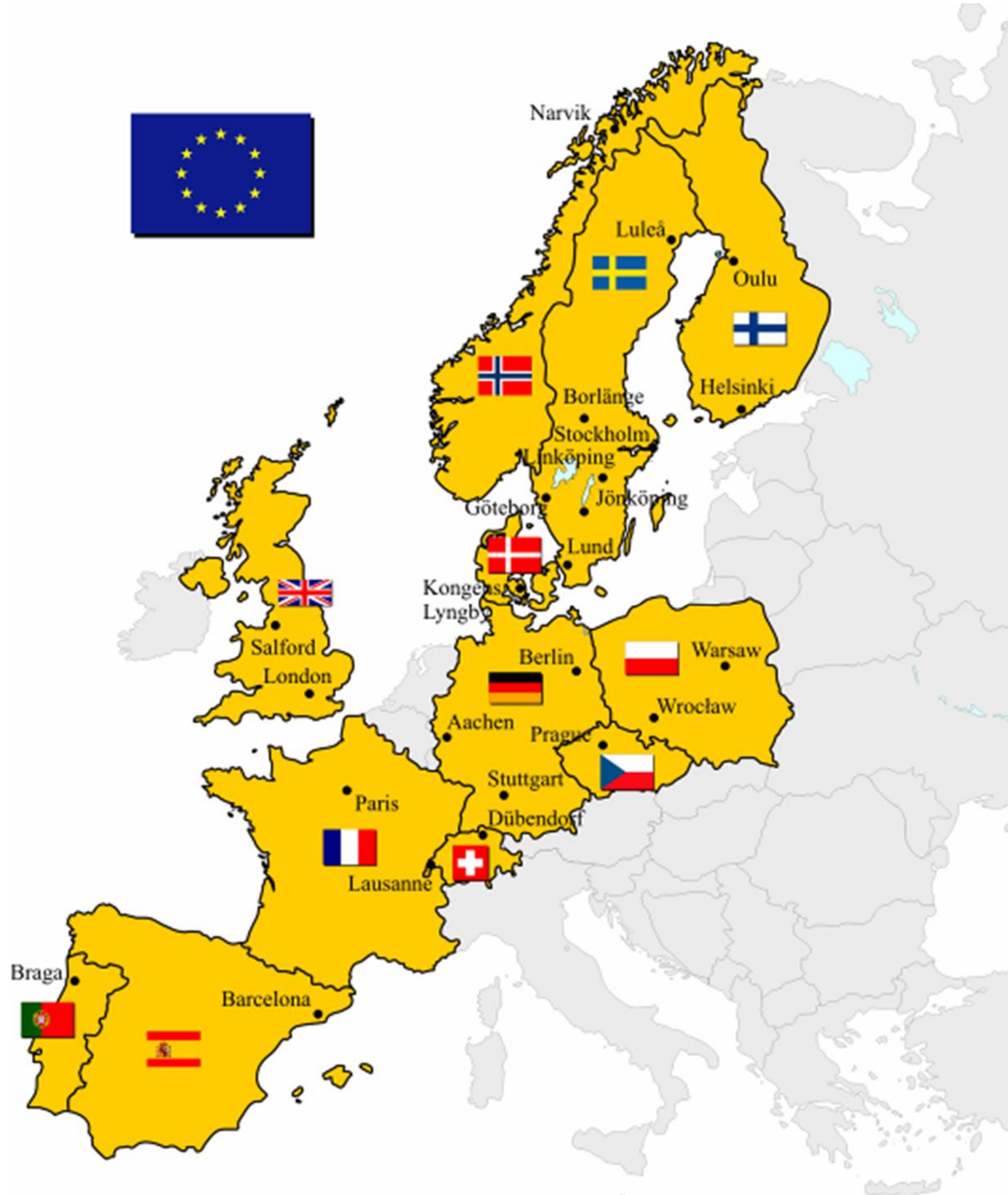
LULEÅ UNIVERSITY OF TECHNOLOGY

Project Consortium with
32 partners
from 12 countries

6 railway partners:
Banverket, RHK, NR,
DB, SNCF and PLK

3 UK Partners:
Network Rail
City University
Salford University

www.sustainablebridges.net



SUSTAINABLE BRIDGES

In conclusion, all the three specific goals for the project have been met!

Achievements

Increased load-carrying capacity by better assessment, monitoring and repair & strengthening methods;

The results have been tested and demonstrated on several bridges in order to promote better engineering solutions which will produce savings throughout Europe.

Further work

Management Systems;

Life Cycle Costs

Failure – mechanisms - More Full Scale Testing