Workshop targeted to Central and Eastern Europe

Budapest, Hungary
15 May 2014

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

http://www.mainline-project.eu
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Presenter/Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00</td>
<td>Welcome/coffee</td>
<td></td>
</tr>
<tr>
<td>09:30</td>
<td>Introduction</td>
<td>Björn Paulsson, UIC/Trafikverket</td>
</tr>
<tr>
<td>09:45</td>
<td>The role of LCAT in asset management</td>
<td>David Casto, Network Rail</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Justin LeBlanc, SKM</td>
</tr>
<tr>
<td>10:15</td>
<td>Asset degradation &amp; intervention strategies</td>
<td>Marios Chryssanthopoulos, University of Surrey</td>
</tr>
<tr>
<td>10:45</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>11:15</td>
<td>Methods to extend life of assets</td>
<td>Lennart Elfgran, Luleå University of Technology</td>
</tr>
<tr>
<td>12:00</td>
<td>Q&amp;A</td>
<td></td>
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<tr>
<td>12:15</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>13:15</td>
<td>Replacement of assets</td>
<td>Britta Schewe, Deutsche Bahn</td>
</tr>
<tr>
<td>13:45</td>
<td>Degradation monitoring: gaps &amp; opportunities Case study presentation</td>
<td>Polyvios Polvyiou, TWI Zoltán ORBÁN, University of Pecs</td>
</tr>
<tr>
<td>14:30</td>
<td>Demonstration of the LCAT</td>
<td>Justin LeBlanc, SKM</td>
</tr>
<tr>
<td>15:30</td>
<td>Q&amp;A</td>
<td></td>
</tr>
<tr>
<td>15:45</td>
<td>Feedback and conclusions</td>
<td>Björn Paulsson, UIC/Trafikverket</td>
</tr>
<tr>
<td>16:00</td>
<td>Break – end of workshop</td>
<td></td>
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<tr>
<td>16:30</td>
<td>Advisory Committee meeting</td>
<td>AC + EB members</td>
</tr>
<tr>
<td>18:00</td>
<td>End of meeting</td>
<td></td>
</tr>
</tbody>
</table>
Outline

• Background
• Refined assessment methods — 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
1955 25 ton
1998 30 ton
2015 32.5 - 35 ton?
114 bridges built 1900 - 2014

Iron Ore Line

Fatigue capacity tested at LTU 1995
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:
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 on Life Extension

Benchmark, D1.1
Assessment Methods, D1.2
Case Studies, D1.3
Guideline, D1.4

MAINLINE

MAIn tenance, 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

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

Grant Agreement number: 285121
Start date of project: 1 October 2011
Lead beneficiary of this deliverable:
Due date of deliverable: 30 June 2014

Draft version 0.1, 2014-05-08

Project co-funded by the European Commission within the 7th Framework Programme

Dissemination Level

Public
Four bridges to be tested/upgraded

- Rautasjokk
- Åby
- Haparanda
- Kiruna
Outline

• Background

• **Refined assessment methods** — 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

Performance index
(β, CI, Load ratio)

Advanced assessment (level 3)

Basic assessment (level 1)

Minimum Performance index

Time

$t_{ass}$
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

Åby älv
Reliability-based assessment: model and random variables

<table>
<thead>
<tr>
<th>Random variable</th>
<th>Unit</th>
<th>Mean</th>
<th>COV (%)</th>
<th>PDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield strength</td>
<td>MPa</td>
<td>220</td>
<td>10</td>
<td>Lognormal</td>
</tr>
<tr>
<td>Hardening modulus</td>
<td>MPa</td>
<td>1080</td>
<td>25</td>
<td>Lognormal</td>
</tr>
<tr>
<td>Self-weight</td>
<td>Kg/m³</td>
<td>7800</td>
<td>3</td>
<td>Normal</td>
</tr>
<tr>
<td>Railway traffic load (concentrated)</td>
<td>kN</td>
<td>103.5</td>
<td>10</td>
<td>Normal</td>
</tr>
<tr>
<td>(4 loads per rail)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railway traffic load (distributed)</td>
<td>kN/m</td>
<td>31.7/rail</td>
<td>10</td>
<td>Normal</td>
</tr>
<tr>
<td>Impact factor</td>
<td>-</td>
<td>1.10</td>
<td>25</td>
<td>Normal</td>
</tr>
</tbody>
</table>
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)

Assumed linear behavior

**LF**

**LF**

**LF**

**LF**

Intact system

Bridge Response

**LF**

**LF**

**LF**

**LF**

Ultimate capacity of intact system

Ultimate capacity of damaged system

Loss of functionality

First member failure

Load Factor

Damaged system

Actual behavior
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:
  \[ R_u = \frac{LF_u}{LF_1} \quad R_f = \frac{LF_f}{LF_1} \quad R_d = \frac{LF_d}{LF_1} \]
Damaged bridge
Results

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

<table>
<thead>
<tr>
<th>Analysis Case</th>
<th>LFu/LF1 Ultimate limit state of originally intact bridge</th>
<th>LFf/LF1 Functionality limit state of originally intact bridge</th>
<th>LFd/LF1 Redundancy ratio for damaged bridge scenarios</th>
<th>LF100/LF1 for damaged bridge scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULTM</td>
<td>1.35</td>
<td>1.29</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>CM01</td>
<td>-</td>
<td>0.30 (shaded)</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>CM02</td>
<td>-</td>
<td>0.57 (shaded)</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>CM03</td>
<td>-</td>
<td>0.67 (shaded)</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>VM01</td>
<td>-</td>
<td>1.35 (shaded)</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>VM02</td>
<td>-</td>
<td>1.35 (shaded)</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>VM03</td>
<td>-</td>
<td>1.30 (shaded)</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>VM04</td>
<td>-</td>
<td>1.27 (shaded)</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>DM01</td>
<td>-</td>
<td>1.23 (shaded)</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>DM02</td>
<td>-</td>
<td>1.37 (shaded)</td>
<td>1.35</td>
<td></td>
</tr>
<tr>
<td>DM03</td>
<td>-</td>
<td>1.41 (shaded)</td>
<td>1.40</td>
<td></td>
</tr>
</tbody>
</table>
Definition of robustness (II)

\[ R_d = \int_{d=0}^{d=1} f(x) \, dx \]
Robustness to corrosion
Robustness to corrosion

\[ C = A \cdot t^B \]

\[ R_d = 0.98 \]
Thank you!
Methods to Extend Life of Assets

Outline

• Background
• Refined assessment methods — Joan Casas
• **Strengthening methods**
• Track and Earthwork
• Case studies — Four bridges
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

<table>
<thead>
<tr>
<th>View</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="View Image" /></td>
<td><img src="diagram1.png" alt="Section Diagram" /></td>
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</tbody>
</table>

Photo(s)

<table>
<thead>
<tr>
<th>Photo(s)</th>
<th>Section</th>
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</thead>
<tbody>
<tr>
<td><img src="image2.jpg" alt="Photo Image" /></td>
<td><img src="diagram2.png" alt="Section Diagram" /></td>
</tr>
</tbody>
</table>

This is then related to method descriptions and 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

External prestressing

Thermography system

Mineral based CFRP strengthening
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

The Örnsköldsviks bridge
First the strengthening design was carried out

\[ M = \frac{x - d'_s}{h - x} \left( \varepsilon_f + \varepsilon_{uo} \right) A_s E_s \left( \beta x - d'_s \right) + A_{f_y} \left( d'_s - \beta x \right) + \varepsilon_f E_t A_t \left( h - \beta x \right) \]

Strain based design. Resulted in 9 bars (9x100mm²/beam). \( E_f = 250 \) GPa. Moment capacity of 11.6 kNm per beam
Sawing for Strengthening.
(Near Surface Mounted CFRP Rods)
The 15 x 15 mm slots were cleaned with high pressurised water, 150 bars.
Open time: ca 50 min
Final strengthening result
CFRP cut-off end
“Fish-bone pattern”
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

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
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

<table>
<thead>
<tr>
<th>Notation</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
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<tbody>
<tr>
<td>(b_f = b_{\text{eff}})</td>
<td>2610</td>
<td>mm</td>
<td>Effective flange (EC2 5.3.2.1)</td>
</tr>
<tr>
<td>(h_f)</td>
<td>180</td>
<td>mm</td>
<td>Heigth on flange</td>
</tr>
<tr>
<td>(h_w)</td>
<td>520</td>
<td>mm</td>
<td>Heigth on web</td>
</tr>
<tr>
<td>(h)</td>
<td>700</td>
<td>mm</td>
<td>Total heigth</td>
</tr>
<tr>
<td>(c)</td>
<td>30</td>
<td>mm</td>
<td>Concrete cover</td>
</tr>
<tr>
<td>(b_w)</td>
<td>250</td>
<td>mm</td>
<td>Width web</td>
</tr>
<tr>
<td>(A_c)</td>
<td>599800</td>
<td>mm(^2)</td>
<td>Cross sectional area concrete</td>
</tr>
<tr>
<td>(A_s)</td>
<td>1256.6</td>
<td>mm(^2)</td>
<td>Area steel reinforcement</td>
</tr>
<tr>
<td>(\phi_t)</td>
<td>20</td>
<td>mm</td>
<td>Diameter steel reinforcement</td>
</tr>
<tr>
<td>(d)</td>
<td>660</td>
<td>mm</td>
<td>Level arm</td>
</tr>
<tr>
<td>(L)</td>
<td>8000</td>
<td>mm</td>
<td>Distance between supports</td>
</tr>
<tr>
<td>(B)</td>
<td>5000</td>
<td>mm</td>
<td>Distance between beams</td>
</tr>
<tr>
<td>(A_{sw})</td>
<td>157.1</td>
<td>mm(^2)</td>
<td>Area of stirrups</td>
</tr>
<tr>
<td>(\phi_s)</td>
<td>10</td>
<td>mm</td>
<td>Area shear reinforcement</td>
</tr>
<tr>
<td>(s)</td>
<td>250</td>
<td>mm</td>
<td>Internal distance shear reinforcement</td>
</tr>
</tbody>
</table>

### Partial coefficient factors

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Steel</th>
<th>FRP</th>
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<tbody>
<tr>
<td>(\gamma_c = 1.5)</td>
<td>(\gamma_s = 1.15)</td>
<td>(\gamma_{\text{frp}} = 1.2)</td>
</tr>
<tr>
<td>(\alpha_{cc} = 0.85)</td>
<td>(\alpha_{ct} = 0.85)</td>
<td></td>
</tr>
<tr>
<td>(\varphi_{ef} = 2.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\gamma_{CE} = 1.2)</td>
<td></td>
<td></td>
</tr>
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</table>
Methods to Extend Life of Assets

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Geogrids – 5 year tests

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

Aggregate particles interlocking with geogrid apertures

Geogrid reinforcement of the ballast layer for maintenance reduction

Stanislav Lenart, ZAG, Slovenia, Smartrail
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

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Four bridges to be tested/upgraded

- Åby
- Rautasjokk
- Kiruna
- Haparanda
Increase axle load from 25 to 30 ton

Overuse:
- Flexure 1.25
- Shear 1.03

Prestress slab to increase shear capacity
Prestressing Haparanda Bridge

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

1) an anchoring nut
2) an anchoring plate and
3) load-distributing wedge
Södra Rautas
20 km NW Kiruna
1902, truss 1962

Åby Älv
50 km W Piteå
1894, truss 1957
Global view of the E11 strain of deformed Åby Bridge under 250 kN axle load (including self-weight)
Support strain – Abacus model
Eigenfrequencies

\[ f = 4.01 \text{ Hz (No.1)} \]

\[ f = 7.56 \text{ Hz (No.2)} \]
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

- Cut out due to overpressure in the jacks
- Load scenario
- Load scenario with settlements taken into consideration
- Expected results from simulation
Test of the Kiruna Mine Bridge
Preliminary Program 2014-05-10

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

- 121.5 m prestressed concrete bridge
- Continuous 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
  - Conditions 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 reinforcement (NSMR)
- Laminates
- Prestressed

Maintain track, S&C and Earth work
End of Presentation

• Thank you for your kind attention!
• Questions?