Extended Use of Existing Rail Infrastructure

Lennart Elfgren
Luleå University of Technology
Final Workshop
Paris, September 30, 2014
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.
Iron ore in Northern Scandinavia

The ore was first transported with reindeer.

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:
Four Reports on Life Extension

Benchmark, D1.1

Assessment Methods, D1.2

Development, 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

Dissemination Level

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

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

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

PHASE 1 - INITIAL
Site visit
Study of documents
Simple calculation

Doubts confirmed?
Yes

PHASE 2 - INTERMEDIATE
Material investigations
Detailed calculations/analysis
Further inspections and monitoring

No

PHASE 3 - ENHANCED
Refined calculations/analysis
Laboratory examinations and field testing
Statistical modelling
Reliability-based assessment
Economical decision analysis
Four case studies

Åby

Kiruna

Haparanda
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
Loading to failure
Loading to failure – Abacus model

- Max load: 12.08 cm, 12.32 MN
- Yield point: 7.97 cm, 8815 kN
- 400 kN Axle Load x 4 + Gravity: 2.14 cm
- 330 kN Axle Load x 4 + Gravity: 1.85 cm
- 250 kN Axle Load x 4 + Gravity: 1.5 cm
- Gravity: 0.50 cm

http://www.mainline-project.eu
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 3

Element type 2

Element type 4

<table>
<thead>
<tr>
<th>Element type</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>320 x 415</td>
</tr>
<tr>
<td>2</td>
<td>300 x 402</td>
</tr>
<tr>
<td>3</td>
<td>435 x 336</td>
</tr>
<tr>
<td>4</td>
<td>373 x 250</td>
</tr>
</tbody>
</table>
Tunnels

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

- Rolling Stock
- Transport Volume
- Speed
- Alignment
- Superstructure
- Ballast
- Sub-Layer
- Drainage
- Sub Grade
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

<table>
<thead>
<tr>
<th>View</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>![View Image]</td>
<td>A</td>
</tr>
<tr>
<td>![Section A]</td>
<td>B</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

Method Descriptions

Case Studies

http://www.mainline-project.eu
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
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
First the strengthening design was carried out

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

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
Outline

• Background
• Assessment - Examples
• Strengthening - Examples
• Conclusions – Open questions
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 reinforcement (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
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 of Strengthened Bridge

- Pre-loading – similar as for unstrengthened bridge (16 load cases)
- Loading to failure – moment-shear resistance
Bridge being 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*
MTBF
Mean Time Between Failures

Reliability

Failure

MTTR
Mean Time To Repair

Maintainability

MWT 1
Mean Waiting Time 1

Supportability

MWT 2
Mean Waiting Time 2

Restored function

Availability = MTBF / Total Time
RAMS

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)
- Reliability
- Availability
- Maintainability
- Safety

RAM4S

Safety
Security
Sustainability
Supportability

Maintenance terminology
(SS-EN_13306_2010)

Reliability
Availability
Maintainability
Supportability

http://www.mainline-project.eu
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 (level 3)
- Basic assessment (level 1)
- Minimum Performance index
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)

Assumed linear behavior

$\text{LF}_d$  
$\text{LF}_1$  
$\text{LF}_u$

Bridge Response

Load Factor

Intact system

Damaged system

Ultimate capacity of intact system

Ultimate capacity of damaged system

Loss of functionality

First member failure
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
Eigenfrequencies

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

\[ f = 7.56 \text{ Hz (No.2)} \]
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 (4 loads per rail)</td>
<td>10</td>
<td>Normal</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>

[Diagram of a steel bridge]
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

External prestressing

Thermography system

Mineral based CFRP strengthening
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