Extend the life of existing railway bridges – Results from EU FP7 project MAINLINE

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Abstract

There is a need to extend the life and capacity of many existing bridges. One of the objects of the EU FP7 Project MAINLINE, 2011-2014, was to facilitate this. Guidelines for assessment and strengthening methods are presented as well as case studies in which existing bridges are studied in order to extend their life length.

One example is the prestressing of the slab in a one-span concrete trough bridge in order to increase its load-carrying capacity. Horizontal holes were drilled trough the slab and in them steel bars were placed and post-tensioned. In this way a compressive stress was introduced into the concrete section so that it’s bending and shear capacity was increased.

In another study a metal truss bridge was monitored in order to check strain and stress ranges in critical connections to enable an enhanced evaluation of the remaining fatigue resistance. The studied bridge was then replaced and loaded to failure to study its robustness and the reliability of applied assessment methods. The results could then be applied to prolong the life of an identical twin bridge located in the northern part of Sweden.

A Life Cycle Assessment Tool (LCAT) has been developed to enable Infrastructure Managers to choose optimal maintenance strategies.

Keywords: Assessment methods, Strengthening, Bridges, Prestressing, Guidelines, Modelling, Repair, Structural Design, Testing, Life Cycle Assessment

1 Introduction

1.1 Background

Growth in demand for rail transportation across Europe is predicted to continue. Much of this growth will have to be accommodated on existing lines that contain old infrastructure. This demand will increase both the rate of deterioration of these elderly assets and the need for shorter line closures for maintenance or renewal interventions. The impact of these interventions must be minimized and will also need to take into account the need for lower economic and environmental impacts. New interventions will need to be developed along with additional tools to inform decision makers about the economic and environmental consequences of different intervention options being considered.

1.2 MAINLUINE – A project within EU FP7

The project MAINLINE [1] addressed the issues above and targeted a reduced environmental footprint in terms of embodied carbon and other environmental benefits by

- Applying new technologies to extend the life of elderly infrastructure (WP 1, Deliverables D1.1 – D1.4 in [1]).
- Improving degradation and structural models to develop more realistic life cycle cost and safety models (WP 2, D2.1-2.4 in [1]).
- Investigating new construction methods for the replacement of obsolete infrastructure (WP 3, D3.1-D3.4 in [1]).
- Investigating monitoring techniques to complement or replace existing examination techniques (WP4, D4.1-D4.4 in [1]).
- Developing management tools to assess whole life environmental and economic impact (WP 5, D5.1- D5.7 in [1]).

The project consortium included leading railways, contractors, consultants and researchers from across Europe, including members from both Eastern Europe and the emerging economies. Partners also brought experience on approaches used in other industry sectors which have relevance to the rail sector. Project benefits come from keeping existing infrastructure in service through the application of technologies and interventions based on life cycle considerations. Although MAINLINE focused on certain asset types, the management tools developed are applicable across a broader asset base.

2 Assessment, Strengthening and Renewal

2.1 Estimate of bridges in need of action

Eleven Infrastructure Managers responded to a questionnaire. If the results are extrapolated from the about 125 000 km of network and the about 150 000 railway bridges that these Infrastructure Managers oversee to the full European network, which is about 230 000 km, a rough estimate may be obtained of the needs. Such an extrapolation suggests that in the next ten years we may expect to strengthen some 1 500 bridges, to replace some 4 500 bridges and to replace the deck of some 3 000 bridges. Some of the bridges that are planned to be replaced may instead be upgraded/strengthened, if the new technologies presented in the project would be used.

2.2 Assessment methods

Methods for assessment of structures are a key activity that was investigated already in an earlier project, Sustainable Bridges [2]. It has now been further developed and applied in case studies. The basic idea is a step-wise procedure of (I) Initial, (II) Intermediate and (III) Enhanced assessment levels with increasing accuracy:

(I) The **initial** low-cost step includes a site visit, study of documents and simple calculations.

(II) The slightly more costly **intermediate** step may include material investigations, detailed calculations/analyses and further inspection and monitoring.

(III) The third more time-consuming step with **enhanced** methods may include refined calculations/analyses, laboratory examinations and field testing, statistical modelling, reliability based assessment and economical decision analysis.

In the MAINLINE project work was concentrated on improving and exemplifying methods in the third enhanced step in order to make it easier to apply. A case study is presented in section 3 below.

2.3 Strengthening and Renewal methods

Methods for strengthening with prestressing was studied and applied on a concrete trough bridge built in 1959 in Haparanda, Sweden, see Figure 1, Nilimaa [3]. The bridge was upgraded to carry maximum axle loads of 300 kN instead of 250 kN. The bridge was strengthened in the summer of 2012 using eight internal, unbonded steel bars, installed in holes drilled through the slab. Each bar was prestressed up to 430 kN. A reference train with 215 kN axle loads was used for loading and the response was monitored before and after strengthening. The tensile strains in the bridge slab were completely counteracted for the test load.

The method with Near Surface Mounted Reinforcement (NSMR) glued into grooves grinded into the bottom slab of a bridge was earlier tested on another concrete trough bridge in Örnsköldsvik, see Figure 2. It has recently been demonstrated by Puurula et al [4], [5] that the bridge, after strengthening the deck slab with CFRP bars, would have failed under a load 6.5 times the current maximum axle load of 330 kN, whilst the unstrengthened bridge would have failed under a load 4.7 times the axle load of 330 kN and approximately 6.2 times the originally designed-for axle load of 250 kN. This demonstrates a high hidden capacity in this kind of bridges. The demonstration of the strengthening method was successful. However, the bridge was strong enough even without it.

Strengthening and renewal methods are further exemplified in a Guideline D1.4 in [1] and in Täljsten et al [6].

3 Test to failure of a truss bridge

3.1 General

There may be considerable reserve strength also in metallic bridges. One example is a 55 year old bridge that was tested in the MAINLINE Project, see Figure 3. The bridge had a length of 33 m and originally crossed the Åby River some 50 km East of Piteå in northern Sweden. The regulated

Figure 1. A concrete trough bridge strengthened with post-stressed bars installed in holes drilled through the slab (insert left). The two tracks on the top of bridge are also shown (insert right), Nilimaa [3]

Figure 2. Near Surface Mounted Reinforcement (NSMR) are placed in groves grinded in the bottom of a slab (left, middle). Carbon Fibre Reinforced Polymer (CFRP) bars (right) can then be glued into the groves.

axle load on the route (25 tons) was exceeded approximately 4 times before having a non-linear behavior for the deflection in mid span and almost 6 times for the ultimate load. Further, the structural behavior remained ductile with a nondramatic failure without excessive deformations, unwanted hinges or any joint breaking down.

The final failure mode was buckling of the top frame beam, see Figure 3 (insert), MAINLINE D1.3 [1], Häggström and Blanksvärd [7].

Estimations made before testing by the Finite Element Software Abacus with nominal material properties indicated that the global failure would occur at approximately at 9MN and that it would be buckling of the top frame in the main truss. Before buckling of the frame there would be some yielding and redistribution of forces in the structure. In Figure 4 the expected results from the simulation are displayed together with the measured results.

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Figure 3. Test of a metallic bridge. Overview of test site with two jacks anchored in the bed rock in the centre (left) and final buckling failure of top girder beam (right), Häggström and Blanksvärd [6].

Looking at the diagram, one can conclude that the simulation corresponds well to the measured results regarding global deformation within the linear elastic range. However, once yielding starts the results differs to some extent. Figure 4 also shows the magnitude of what live load that the tested load correspond to, ca 3 MN for 32,5 ton axle load (without safety factors) and ca 5 MN for UIC LM71 with 25 ton axle load with safety factors.

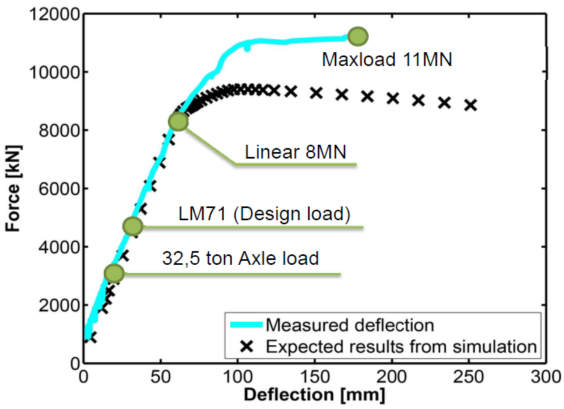

Figure 4. Deflection at mid span. The figure also shows the expected outcome based of the simulation, Häggström and Blanksvärd [7].

3.2 Robustness

A robustness indicator R_d is defined in MAINLINE D1.2 [1] for all levels of damage as:

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

where f is the normalized performance, given by the ratio between the structural performance on the intact and damage states, and d is the normalized damage, given by the ratio between actual and maximum possible damage.

This equation is based on the assumption that robustness is defined by the area under the normalized performance profile for the damage levels between 0 (intact) to 1 (total damage). In this sense, a structure for which any damage causes a complete loss of performance is considered not robust (curve A in Figure 5), as a structure for which no reduction in performance occurs for any damage level corresponds to full robustness (curve E in Figure 5).

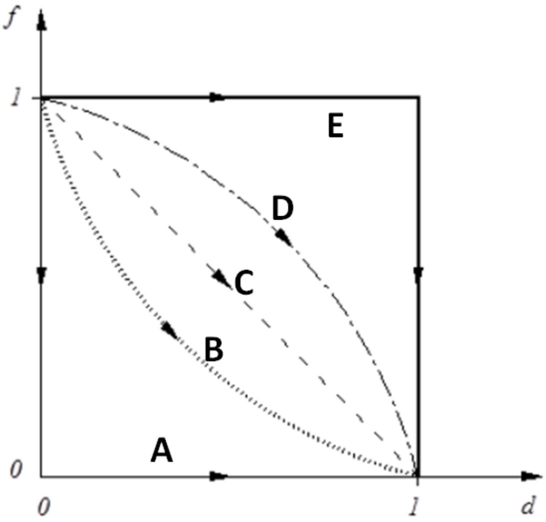

Figure 5. Levels of robustness as function of performance f and damage d, MAINLINE D1.2, D1.3 [1].

A real structure will correspond to situations between these two extremes (curves B, C and D) and the geometry of the curve will show the susceptibility of the structure to deterioration. According to equation (1), to evaluate the robustness index, it is necessary to obtain the bridge performance for different levels of corrosion degradation, from 0 (intact bridge) to 1 (maximum corrosion after 100 years of exposure without coating). In this case, a deterministic approach is adopted, defining the bridge performance in terms of the load factor. The load factor is defined as the number of times the live load has to be increased to reach the maximum failure load.

To evaluate the load factor a model presented in MAINLINE D1.2 [1] was used, based on a FEM model. Different corrosion scenarios were been considered, as corrosion effecting only one single element (U1-4, D1-4, O1-4, V1-5 and T1-5, see Figure 6. T denotes transverse girders not indicated in the figure) or corrosion affecting all elements (CGEN). In the case of exposure class C2, the results shown in Figure 6 are obtained.

According to ISO 9223, the C2 exposure corresponds to low corrosivity: Temperate zone, atmospheric environment with low pollution (SO_2 < 5 µg/m3), e.g. rural areas, small towns. Dry or cold zone, atmospheric environment with short time of wetness, e.g. deserts, subarctic areas. The C5 exposure is defined as very high corrosivity: Temperate and subtropical zone, atmospheric environment with very high pollution (SO_2: 90 µg/m3 to 250 µg/m3) and/or significant effect of chlorides, e.g. industrial areas, coastal areas, sheltered positions on coastline.

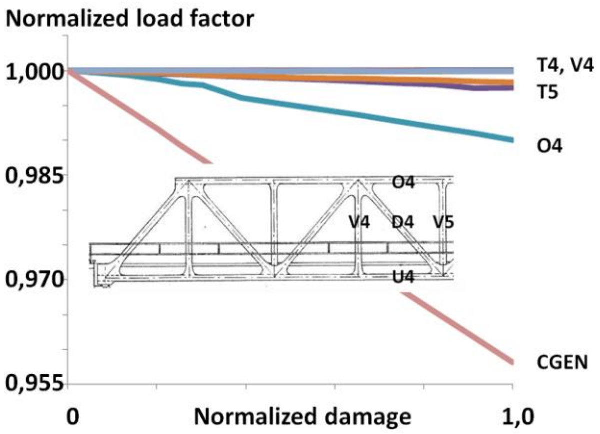

Figure 6. Normalized damage for corrosion in Åby Bridge, Casas et al in MAINLINE D1.3 [1].

As expected, the most sensitive member to corrosion is the upper chord (O4), as the failure is due to buckling of this element. The bridge is almost non-sensitive to the corrosion in other key members such as diagonals (D) and tension chord. However, even for the case of corrosion in all members of the bridge (CGEN), the load capacity only decreases around 4 % for the maximum service life. The robustness index obtained in this case is $R_d = 0.98$.

The high value of robustness obtained indicates that the bridge is able to maintain the required safety level without any maintenance, or, in other words, the bridge has the ability to accommodate to degradation and can wait to maintenance interventions. This is of great interest from a life-cycle management perspective.

Robustness of a prestressed concrete bridge has recently been studied by Bagge [8].

3.3 Fatigue

Fatigue is often an issue for old metallic bridges. However, for the Åby Bridge no fatigue problems could be found although an initial assessment had indicated that several joints had passed their fatigue life length. The problem with fatigue is also of importance in reinforced concrete bridges. Also here the standard codes are often very conservative and a refined assessment can increase the life length considerably, MAINLINE D1.3, Elfgren [9] and Mahal [10].

4 Life Cycle Costs (LCC), Life Cycle Analysis (LCA) and Life Cycle Assessment Tool (LCAT)

Many Infrastructure Managers currently do not yet use Life Cycle Costing (i.e. financial) and/or Life Cycle Assessment (i.e. environmental) in the planning of maintenance and repair of their rail infrastructure. There is a lack of data and methods and here the MAINLINE project gives some guidance. Some data on different types of bridges in northern Sweden are given in Ditrani [11].

There is also often a lack of economic resources for maintenance which may lead to a shorter life length and less sustainability than would otherwise be the case; results from the MAINLINE Project also gives advice that may help to improve this situation. A Life Cycle Assessment Tool (LCAT) was developed for (a) Metal Bridges, (b) Soil cuttings and (c) Track. It is based on spread sheets, which allow users to demonstrate optimum interventions and reduce capital expenditure, see Figure 7

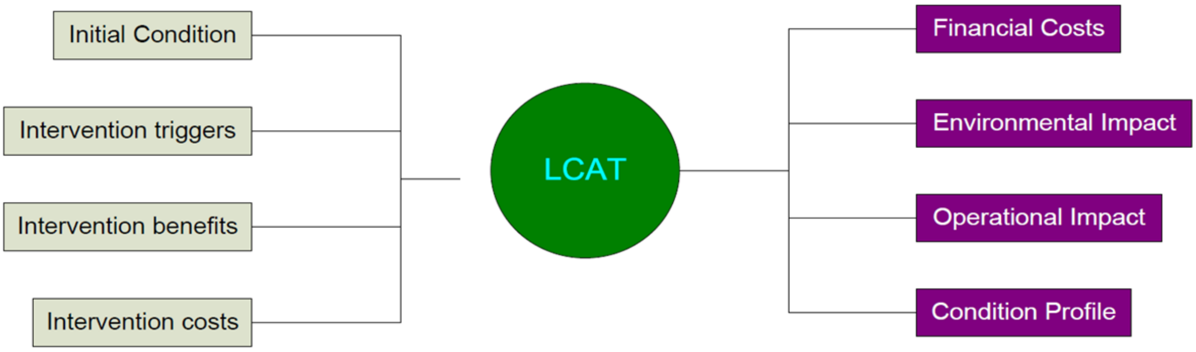

Figure 7. Life Cycle Assessment Tool (LCAT), MAINLINE D5.7 [1]

5 Possible Savings

The results from MAINLINE may facilitate longer service lives for existing railway infrastructure, which may bring about great savings for Infrastructure Managers. They provide methods to optimize replacement of obsolete structures which will further reduce costs. As an example, a modest 10 year increase in the service life of 2% of the bridges due to the results of MAINLINE means that the replacement of 10,000 bridges could be postponed for 10 years with notional cost savings calculated below.

- The average construction cost (K) of a new railway bridges is about 1M €
- With a low interest rate (p) of 2% the present value of the cost for rebuilding a bridge in 10 years will be $K/(1+p)^{10} = 0.820$ K
- Compared to rebuilding the bridge now the saving will then be K – 0.820 K = 0.180 K.
- Not replacing 1,000 bridges per year gives an annual saving of 1,000 x 0.180 x 1 M€ = 180 M€.

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