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Assessment of European railway bridges for future traffic demands and longer lives – EC project "Sustainable Bridges"

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A European Integrated Research Project has recently been started within the 6th Framework Program of the European Commission. The project aims at improved methods for the upgrading of existing railway bridges within the European railway network. The main objectives of the project are to increase the transport capacity by allowing higher axle loads and by increasing the maximum speeds. Other objectives are to increase the residual lifetime of existing bridges and to enhance management, strengthening and repair systems. The overall goal is to enable the delivery of improved capacity without compromising the safety and economy of the working railway. A consortium consisting of railway bridge owners, consultants, contractors, research institutes and universities will carry out the project, having a gross budget of more than 10 million Euros. Funding from the European Commission covers a major portion of the four-year project costs.

Keywords: Railway bridges; Assessment; Monitoring; Strengthening; Residual lifetime

1. Introduction

In order to meet present and future demands on improved capacities for the passenger and freight traffic on the European railway network, it is of vital importance to upgrade the existing railway bridges and ensure that they will behave properly under increased loads and higher speeds.

The needs in this respect are similar throughout Europe even though the bridges themselves can be quite different. The resources in each country are, however, too small for these kinds of activities. Integrated activities are needed for effectiveness and competitiveness. For these reasons, an Integrated European Research Project was started in December 2003 with the aim of providing guidelines for assessment and strengthening of railway bridges across Europe.

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2. Main project objectives

The overall goal is to facilitate the delivery of improved capacity without compromising the safety and economy of the working railway. The main objectives of the project are to:

- increase the carrying capacity of existing bridges by allowing axle loads up to 33 tonnes for freight traffic with moderate speeds;
- increase the capacity for passenger traffic with low axle loads by increasing the maximum speeds to up to 350 km/hour;
- increase the residual lifetime of existing bridges by up to 25%;
- enhance strengthening and repair systems.

The activities within the project will focus on the functional requirements for railway bridges in order to achieve increased capacities, increased residual service life and enhanced management, strengthening and repair systems. Further, the activities will address efficient condition monitoring systems. The objectives are in line with ERRAC 2002 (European Rail Research Advisory Council).

2.1 *Increased allowable loads and speeds*

There is a need for European railway bridges to carry increased loads and allow higher speeds thus enabling larger capacities for passenger and freight traffic. This demand can in many cases be met through better structural assessment, determination of the true behaviour of the structure, strengthening of certain sections of it or by monitoring of its critical properties. Using a probabilistic approach for loads and resistance is one example of a new generation of methods that can be developed and applied.

Codes for the design of bridges have been developed gradually and are formed to consider all the uncertainties that are present in the construction phase of a structure. These codes are also often used for the evaluation of existing bridges. However, far better information on material and structural properties is available for an existing structure than for one not yet built. Still, the same factors of safety are often applied to existing structures as to the ones being constructed. Many bridges can be allowed to carry greater loads and faster trains if improved codes and methods for assessment are used.

One example is the Iron Ore Line ‘‘Malmbanan’’, which is a line for transportation of iron ore from northern Sweden to the coast of Norway. Here the axle load was increased from 25 to 30 tonnes after a thorough assessment procedure. Some bridges could carry the increased load in their existing states while others had to be strengthened, see Paulsson *et al.* (1997, 1998), Lunden (1998). A great potential for improvement in the form of better methods and procedures for assessment was recognized. In figures 1 and 2 examples are given from the assessment and testing procedure.

Figure 1. Freight train carrying iron ore over the Luossajokk bridge in Kiruna in the northern parts of Sweden. The bridge is going through an assessment procedure to check its capacity to carry axle loads of 300 kN instead of the present 250 kN.

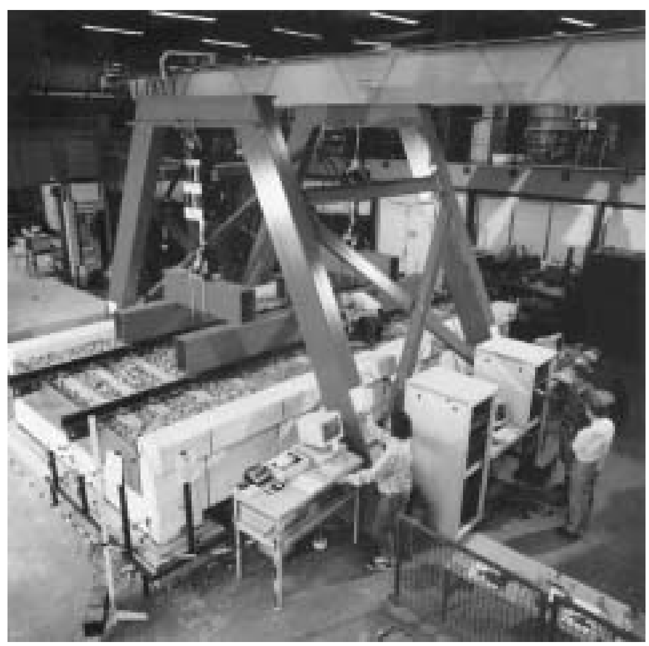

Figure 2. Concrete trough bridge with a span length of 7m being loaded in fatigue to assess its capacity to carry higher axle loads.

Expected achievements:

- new methods for the structural assessment of existing bridges will be developed in order to obtain better approximations of the real structural capacity;
- these new methods will be used to assess existing bridges in order to verify their validity and to demonstrate how they may be used;
- guidance and background material for a guideline for assessment will be developed.

2.2 *Increased residual service life*

Deterioration is an unavoidable part of the ageing process of all structures. This is not a problem, however, if the rate of deterioration is kept at an acceptably low level. Many factors affect this rate, some of which can be controlled or eliminated even after the structure has been built. For example, heavy traffic or an aggressive environment can accelerate deterioration processes. The deterioration may result in the need for repairs and even a reduced load-carrying capacity. Many modern structures are more prone to chemical degradation and suffer from higher rates of deterioration than their older counterparts. The effects of alkali–silica reaction, chloride ingress and carbonation exacerbated by low concrete cover and poor quality materials also result in increased rates of deterioration.

However, further information is required on techniques for quantifying the condition of a structure, determining the rate of deterioration, and development of monitoring and strengthening strategies.

Non-destructive testing (NDT) methods are widely used in many industries. Aircraft, nuclear facilities, chemical plants and other safety critical installations are tested regularly and their operation depends very much on the results of such non-destructive tests. Also, as an integral part of quality assurance and quality control implementations, NDT is an indispensable tool.

The maintenance of existing structures can best be planned on the basis of objective information about their current state. As infrastructure is the largest asset in developed countries, budget planning must be done well in advance to maintain the existing structures and to ensure the safety of the many people using it. In most countries, visual inspection is the preferred NDT method for the rating of the structures, best exemplified by bridges, which are a major part of any infrastructure.

In this project, echo methods (impulse radar, ultrasonic echo, impact echo), laser spectroscopy, electrochemical methods and active IR-thermography will be advanced for automated large area measurement. Now, the time has come to integrate these NDT methods together with MDT (minor destructive testing) sensors for monitoring as well as conventional testing for the application on site and quality assurance. In figure 3 an example is given of a health monitoring system.

Expected achievements:

- scanning application and combination of echo methods will be developed for condition assessment of concrete bridges;
- easy-to-handle systems will be developed for quality assurance of repair and strengthening;

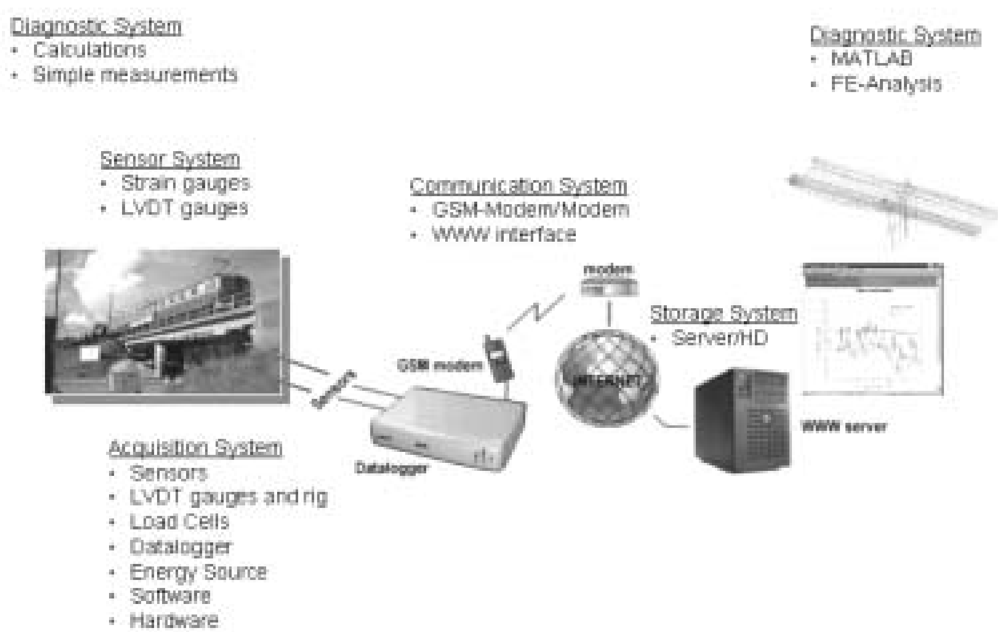

Figure 3. Suggestion for a structural health diagnostic (SHD) system.

- pile integrity testing and soil profile investigation under traffic will be developed;
- models for the progressive development of reinforcement corrosion will be elaborated;
- new research results will be verified by application to real structures;
- the verified results will be presented in a manual for railway bridges.

2.3 *Enhanced management, strengthening, and repair systems*

The number of bridges in the European railway network and the increasing proportion that require rehabilitation means that the direct cost of the engineering work necessary to maintain the network at a satisfactory level is high. Hence there is a need for rational methods for deciding how maintenance budgets should be allocated and repair methods chosen in order to ensure cost effectiveness. Determining the most appropriate maintenance strategy for a stock of bridges is a complex matter since there is a large number of factors that determine the most economic strategy. These include:

- condition of the structure and its load-carrying capacity;
- maintenance measures available and their effectiveness, cost, and disruptive effect on traffic using the structure;
- access to the structure;
- traffic management costs and traffic flow rates;
- time available for maintenance activities;
- costs accruing from improvements such as strengthening or bridge widening;
- implications for safety and traffic flow (if the work is postponed);
- sensitivity of the local environment;
- subsoil and support.

By taking all these factors into account it will be possible to establish a program for the maintenance work, optimized to achieve a standard condition at a minimum whole life cost.

Expected achievements: a management framework for the assessment and strengthening of bridges in the European railway network, developed in order to meet the future traffic demands, and definitive guidelines on the most appropriate engineering solutions to typical bridge problems.

3. Railway owners' preliminary priority list

A survey carried out by the railway owners has indicated that the more than 220,000 railway bridges in Europe are of four main type categories:

- concrete beam bridges (23% of the bridges)
- steel beam bridges (22% of the bridges)
- steel/concrete composite bridges (14% of the bridges)
- arches (41% of the bridges).

More than 35% of the bridges are more than 100 years old, while only 11% are less than 10 years old. Small span bridges are dominating with 62% of the bridges being shorter than 10 m, while only 5% have spans larger than 40 m.

The railway owners listed the following top 10 priority research areas:

- better assessment tools;
- non-disruptive maintenance methods;
- verification of theoretical dynamic factors for both design and assessment;
- use of new materials;
- system for diagnosis and maintenance needs selection;
- ageing/deterioration of concrete bridges;
- indirect inspection and monitoring dynamics for evaluation/crack detection in metallic bridges;
- repair and waterproofing of concrete;
- better testing methods for existing bridges;
- serviceability of arches.

Figure 4. Work Package structure and interactions.

4. Work Packages and activities

The work will be implemented through the following work packages, see figure 4 and a presentation of the different Work Packages below (with Work Package leader within brackets).

4.1 *Work Package 1. Start-up and Classification (Network Rail, United Kingdom)*

Work Package 1 will form the foundation for the project work. Information will be gathered from rail authorities in Europe and from railway organizations as the International Union of Railways (UIC) and the European Rail Research Advisory Council (ERRAC). The information gathered will guide the project regarding the direction of the main work.

4.2 *Work Package 2. Guidance and Review (Banverket, Sweden)*

Work Package 2 will guide the project regarding the direction of the main work and review and assess the results and progress towards the objectives, with input from the railway authorities playing an important role.

4.3 *Work Package 3. Condition Assessment and Inspection (BAM, Germany)*

The objectives of Work Package 3 are to identify the common types of deterioration, examine the behaviour of deteriorated bridges and to supply information on modern methods of assessing their condition. New reliable assessment models will enable a more efficient use of resources in bridge maintenance. For calculating the bearing capacity of a bridge or for deciding if it can be strengthened, information on the condition of the bridge has to be available.

Existing standard methods for bridges in different European countries are compared and new innovative techniques are developed and adapted for the needs of inspecting railway bridges.

4.4 *Work Package 4. Loads, Capacity and Resistance (COWI A/S, Denmark)*

Work Package 4 focuses on load assessment and capacity assessment of railway bridges. For the load assessment various loads on railway bridges both at present and in the foreseeable future will be studied. There are wide differences in the influence on a bridge from a freight train with heavy axle loads and a high-speed passenger train, and this will be a part of the study. The main effort is concentrated on the trainload. For example, probabilistic methods for assessing the actual load on the bridges will be developed and load requirements for interoperability of train traffic between different countries in Europe will be studied. The latter will consider both the load and the track width. The capacity assessment will be focused on the typical European railway bridge types and critical sections. This includes bridges made of steel or other metallic, concrete, masonry and composite materials. One of the most important issues for the capacity assessment is to include the actual state of the structure.

4.5 *Work Package 5. Monitoring (EMPA, Switzerland)*

Any cost-efficient assessment, maintenance and strengthening process requires specific information about the current condition state of a structure. Currently, this information is mainly provided by visual inspections. However, the ageing of the bridge population demands an increasing inspection effort producing considerable costs. Furthermore, most of the time, periodical visual inspections do not provide up-to-date information about the condition state of bridges. This yields an increasing demand for more rationalized, autonomous and continuous inspection technologies.

Continuous monitoring with physical sensors has the potential to provide up-to-date information. Furthermore, it furnishes information about processes which change in time, such as live loads, fatigue damage, vibrations, temperature, which are difficult to assess using other methods. However, to achieve this goal at reasonable prices, a significant effort is needed to standardize the monitoring process with regard to data acquisition, analysis and management. A key feature of any effective monitoring system is its ability to perform autonomously a diagnostic of the state of health of a bridge. This offers the potential to perform inspections on demand, reducing significantly the inspection costs.

The goal of continuous monitoring is not to supersede traditional inspection but to optimize the inspection process with modern smart tools. This allows increasing the reliability of the obtained information, to reduce the human intervention as far as possible and to improve the benefit costs ratio. Civil engineering structures are mainly large and complex physical systems consisting of many heterogeneous components. Monitoring all components with sensors is not feasible economically and technologically. Therefore, the monitoring process has to be restricted to a limited number of components. Identifying simple condition indicators and assessing these indicators by measurements can achieve this.

4.6 *Work Package 6. Repair and Strengthening (LTU, Sweden)*

The main objectives in Work Package 6 are to find technical, environmentally stable and financially justified repair and strengthening methods that are non-disturbing for the traffic on the existing railway structures. Here a "toolbox" with different repair and strengthening methods will be put together which will cover specifically the needs for railway bridges, embankments and transition zones.

For repair and strengthening of bridges, carbon fibre reinforced polymers (CFRP) can be used. For the efficient application of these systems a good bond has to be guaranteed between the CFRP material and the bridge structure. Here both non pre-stressed and pre-stressed systems will be developed and tested, for railway bridges in concrete as well as in steel. Use of monitoring systems, such as fibre optic sensors, together with advanced composites may provide systems that will be able to follow a repair or strengthening measure over time.

The project also deals with the foundation/geotechnical aspects of railways including the long-term subsoil behaviour below railway structures (embankments) and transition zones between an embankment and a bridge (in fact between sections with a difference in stiffness).

4.7 *Work Package 7. Field testing of Old Bridges (LNPC, France)*

A major way to demonstrate the real capacity of a bridge is to load it to failure. Very few such tests have been performed due to the high costs involved. However, on the occasions where tests to failure have been carried out, a very high load capacity has been obtained. For example, on "Malmbanan", a railway line for iron ore transportation in northern Sweden, a concrete trough bridge reached three times its calculated ultimate limit state load before the bridge failed. Similar excess capacities are also expected to be found in other types of bridges.

In order to be able to use such kinds of hidden capacities, demonstrations on existing structures are needed. They will indicate what the real failure mechanisms are, what kinds of load redistributions are possible and how the theoretical models may predict this. Bridges, transition zones and embankments will be instrumented and loaded to failure.

Implementation of bridge monitoring systems comprises several multidisciplinary tasks. One of the main tasks is to build a system, which can withstand difficult environmental conditions for years of continuous operation and to find data communication systems, which serve a high-speed connection with reasonable overall costs and outstanding reliability. As conditions at the site could be dramatically worse than those under initial laboratory testing of the system, demonstration on real bridges is the necessary and best way to ensure the usefulness, reliability and accuracy of the system. Another important issue is the post-processing and correct interpretation of monitored data.

4.8 *Work Package 8. Monitoring of New Bridges (North Finnish Building Cluster, Finland)*

Within Work Package 8, the suggested monitoring system will be tested and evaluated. It will comprise standard components as well as new sensor technologies assessed mainly in Work Package 5. Wireless sensor and data communication systems will be of special interest. A custom software interface will be programmed for the specific needs of railway-bridges and automation of the decision making process. Within the project, the monitoring system will be installed on four actual bridges. The more widespread utilization of monitoring technologies is a target for the near future, and is one of the primary goals of the project provided that such technologies are found useful, reliable and affordable.

4.9 *Work Package 9. Training and Dissemination (Wroclaw University, Poland)*

Results of the project will be disseminated beyond the consortium. Owners, consultants, and contractors, especially small and medium enterprises, need to be trained with the new methods and procedures elaborated as results of the project.

The results of the project will be disseminated through publication in scientific and technical journals, presentations during conferences and seminars, the publication of books presenting selected results of the project, specialist training and education. All results of the project will be presented in international conferences at the end of the project period.

5. Participants and organization

A consortium consisting of railway bridge owners, consultants, contractors, research institutes and universities will carry out the project. The organization is based on quick, efficient decision-making and decentralized responsibility among the 10 core partners and 22 additional partners. The 32 members from all over Europe represent 12 countries. The members are bridge owners (25%), contractors (9%), consultants (9%), research institutes (19%) and universities (38%). They represent the whole chain from user to producer/designer/developer. The relatively high number of research institutes and universities reflects the fact that research on existing structures is often carried out at academic institutions in collaboration with owners. Contractors and consultants, on the other hand, have up until now often focused on the construction of new structures rather than on the maintenance of existing ones. However, some consultants, e.g. from Denmark and UK, are now involved in both construction of new structures and maintenance of existing structures. The project will demonstrate the economical potential in maintenance and upgrading of bridges, and hence why the interest from both contractors and consultants in this field will increase.

The consortium constitutes a broad experience of the different types of difficulties facing the European railways. In central Europe, flooding of large rivers crossing a flat landscape is a major problem, whereas frost-related problems are great in northern Europe and rapid changes due to fast running water occur in the Alps. There are also different needs of railway lines crossing in the wilderness of northern Sweden with intense and heavy traffic (iron ore) compared to the densely populated areas of central Europe and UK with intense passenger traffic and even more intense traffic on all the crossing roads. There are also differences in types of bridges with masonry, concrete and steel bridges.

The contractors in the consortium are Skanska, one of the major general contractors in Europe active in most EC countries, and BPE Systems, a small company specializing in bridge strengthening with carbon fibres.

Five companies represent consultants, from large companies like COWI A/S to small companies like NORUT Technology A/S.

The project participants are the following:

Czech Republic: Cervenka Consulting (Vladimir and Jan Cervenka)
Denmark: COWI A/S (Jens Sandager Jensen, Mette Sloth)
Finland: Finnish Road Administration (Timo Tirkkonen), Finnish Rail Administration (Harri Yli-Villamo), University of Oulu (Timo Aho), North Finnish Building Cluster (Risto Kiviluoma)
France: Societé National de Chemin des Fers (SNCF, Didier Martin, Benjamin Barbier), Laboratoire Central des Ponts et Chausées (LCPC, Alberto Patron, Christian Cremona)
Germany: Deutsche Bahn AG (Martin Muncke, Britta Schülke), Bundesanstalt für Materialprüfung (BAM, Ernst Niederleithinger), Universität Stuttgart (Christian Grosse, Markus Krüger), Rheinisch-Westfälische Technische Hochschule (Gerhard Sedlacek)
Norway: NORUT Technology A/S (Geir Horrigmoe)
Poland: PKP Polish Railway Lines (Maciej Sawicki), Wroclaw University of Technology (Jan Bien, Pawel Rawa)
Portugal: Universidade do Minho (Paulo Cruz)
Spain: Universitat Politècnica de Catalunya (Joan Ramon Casas)
Sweden: Skanska Teknik AB (Ingvar Olofsson, Coordinator; Björn Täljsten), Banverket (The Swedish Rail Administration, Björn Paulsson, Katarina Kieksi), Vägverket (The National Swedish Road Administration, Ebbe Rosell), Luleå University of Technology (Lennart Elfgren, Scientific Leader; Bernt Johansson, Thomas Olofsson) Chalmers University of Technology (Kent Gylltoft, Mario Plos, Mohammad Al-Emrani), Royal Institute of Technology (Håkan Sundquist, Ove Lagerqvist), Lund University of Technology (Sven Thelandersson), Swedish Geotechnical Institute (Göran Holm), BPE Systems AB (Otto Norling), Designtech Projektsamverkan AB (Pär Johansson, Patrik Svanerudh)
Switzerland: Eidgenössische Materialprüfungsanstalt (EMPA, Glauco Feltrin), Ecole Polytechnique Federal de Lausanne (EPFL, Eugene Brühwiler)
United Kingdom: Network Rail (Brian Bell), City University (William Boyle), University of Salford (Clive Melbourne, Adrienn Tomor).

5.1 *Cooperation with other projects*

As the number of arch bridges in Europe is quite considerable, cooperation with the UIC Project I/03/U/285 ''Assessment, Reliability and Maintenance of Masonry Arch Bridges'' has been initiated.

Co-operation with other UIC work streams will be provided by the active participation in the project of two members of the UIC Structures' Experts Panel. Other participants are members of the EU 5th Framework Networks SafRelNet (Safety and Reliability), SAMCO (Structural Assessment, Monitoring and Control) and ConRepNet (Concrete Repairs) and the UK based networks SIMoNet (Structural Integrity Monitoring), SMARTnet (Arch Bridges) and NGCC (Composites in Construction).

In addition, many of the partner railways are undertaking, or participating in, ongoing research in areas relevant to the project and, as far as they are able, will share the outputs of this work as they become available.

5.2 *Budget and financing*

The budget for the project exceeds 10 million euros for the full period of four years. The corresponding funding from The European Commission is 6.9 million euros. The budget is derived from an overall project Implementation Plan covering the four-year project period and a detailed Implementation Plan for the first 18 months. A large number of deliverables (reports, specifications, demonstration activities, etc.) and corresponding delivery dates have been specified for each one of the different Work Packages.

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