UIC Project on assessment, inspection and maintenance of masonry arch railway bridges

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ABSTRACT: Masonry arch bridges represent a large proportion of the railway bridge stock. Many of them belong to the civil engineering heritage of the railways, therefore their management require careful consideration. Maintenance strategies should promote solutions that are directed towards their preservation and restoration by relying on their existing structural capacity and give preference to stabilization rather than their substitution or replacement. The paper introduces the results of an international project entitled "Improving assessment, optimization of maintenance and development of database for masonry arch railway bridges". The project is organised by the International Union of Railways (UIC) with the participation of 14 railway administrations and many consultant institutions, spanning a period of 4 years. The principle objective of the project is to collect and develop tools that help optimising the life-cycle management of masonry arch bridges, help reducing their maintenance costs and promote an effective exchange of good practice between the railway administrations.

1 INTRODUCTION

1.1 General introduction

Masonry arch bridges form an integral part of the railway infrastructure. They are the oldest structure types in the railway bridge population with thousands still in service.

In order that the railways accommodate increased axle loads, train speeds and a greater volume of freight traffic, it is necessary to assess the load carrying capacity of existing masonry arch bridges. Assessment of masonry arch bridges is difficult as there is little knowledge or experience of design of these structures to modern standards, and much of the structure is hidden from view.

To provide confidence in the assessment result, reliable input parameters are required for their calculations. Accordingly effective inspection and measuring methods to establish the parameters are necessary. As well as the predominant use of visual inspections, and destructive investigation there is a tendency in recent years towards using non-destructive testing techniques.

The current condition of masonry arch bridges varies from good to very bad, although statistics show that there are a relatively large number of bridges in a medium or bad condition with a tendency for accelerated deterioration. Accordingly there is a potential doubt as to the adequacy of masonry bridges to withstand increased axle loads, train speeds and a greater volume of freight traffic.

Contrary to doubts masonry arch bridges are proving durability with life-cycle costs significantly more economical than for the majority of other structure types. In addition, they belong to the civil engineering heritage of the railways, and their substitution or refurbishment requires careful consideration with maintenance strategies adopted to promote solutions that preserve and restore these structures instead of their replacement.

1.2   Project description

A study group was set up in 2002 by the International Union of Railways (UIC) in order to establish information on the 'state-of-the-art' of masonry arch railway bridges. The work was initiated by the Hungarian Railways and during the preparatory stage 13 more railway organisations joined the project. Currently the following railway administrations are involved in the project: MAV (Hungary, task leader) DB (Germany), SNCF (France), NR (UK), ÖBB (Austria), SBB (Switzerland), JBV (Norway), CD (Czech Republic), REFER (Portugal), RENFE (Spain), RFI (Italy), JapanRail-RTRI (Japan), PKP (Poland), IR (India).

The work is carried out in close collaboration between the partaking railway administrations and consultant institutions from various countries such as: Obvis Ltd. (UK), University of Sheffield (UK), Ines Ingenieros Consultores (Spain), University of Genoa (Italy), Wroclaw University of Technology (Poland)**,** Ingenieurbüro A. Pauser (Austria), Hochschule Bremen (Germany), Brno University of Technology (Czech Republic), University of Pécs and Orisoft Engineering Consulting (Hungary).

The project has been divided into two phases. The preparatory phase the masonry arch bridge stock has been reviewed and the state-of-the-art practices of their assessment, inspection and maintenance summarised. It has been concluded that there were no internationally accepted tools available for the reliable assessment of the load carrying capacity of masonry arch bridges and that a lack of guidance has retarded the widespread application of up-to-date inspection and maintenance procedures.

The objectives and tasks of the follow-up phase have been put together according to the conclusions of this preparatory phase.

The following work packages have been identified in the programme:

WP1: Development of assessment tools for masonry arch bridges.

WP2: Optimised inspection and monitoring of masonry arch bridges.

WP3: Optimised maintenance and repair of masonry arch bridges.

WP4: Development of Information Database for masonry arch bridges.

The project is funded over a period of 4 years starting from January 2003. Guides have been developed for the assessment, inspection and maintenance of masonry arch bridges. An Information System & Database has been developed on the Internet to be a reservoir for knowledge on masonry arch bridges and to provide a platform for the railway administrations to consult and share information. The main deliverables of the project are summarized in Table 1.

Table 1 : Summary of work-packages and deliverables

WP1: Assessment	WP2: Inspection & Monitoring	WP3: Maintenance & Repair	WP4: Database
Revision of the MEXE method & development of new simple assessment tools	Guide to the testing of material properties by destructive methods	Expert tool for the degradation modelling of masonry arch bridges	Collection of masonry arch bridge related documents (codes, scientific papers, case studies, presentations)
Development of computerized module for arch assessment	Guide to Non-Destructive Testing Methods	Guide to the execution and control of repairs	Photo collection of railway masonry arch bridges
Guide to the high-level assessment of masonry arch bridges	Catalogue of masonry arch bridge damages	Testing new repair techniques	Glossary of terms
			Database of experts
Guide to the assessment of masonry arch bridges	Guide to the load test of masonry arch bridges		Discussion Forum & Mailing system

Revision of UIC Code 778-3R

2   INTRODUCTION OF THE MASONRY ARCH RAILWAY BRIDGE POPULATION

A survey has been carried out to give an overview on the number, characteristics and condition of masonry arch railway bridges in the participating railway administrations. The statistics were compiled about the total masonry arch bridge population of the railways including culverts with a span not exceeding 2m.

Some conclusions derived from these statistics are summarised as follows:

- The railways participating in the project possess more than 200,000 masonry arch bridges and culverts on their lines which is approximately 60%, a significant proportion, of their total bridge stock (*UIC Report, 2004)*. The highest numbers of arches inclusive of culverts have been reported from France (cca. 78,000 – 77% of total bridge stock), Italy (56,888 – 95%), Germany (cca. 35,000 – 39%), India (20,967 – 18%), UK (17,867 – 47%) and Portugal (11,746 – 90%).
- Bridges and culverts with short spans represent the majority of masonry arch structures (according to the survey approximately 60% of the bridge spans are under 2m, approximately 80% are under 5m and there are only 8,5% of arches exceeding 10m span).
- The majority of masonry arch bridges are single-span structures (approx. 85%).
- The majority of masonry arch bridges (approx. 70%) are between 100 and 150 years old. There is also a significant proportion (approx. 12%) of bridges more than 150 years old.
- The shapes of masonry arches are generally not recorded by the railway administrations. The limited information has prevented any conclusions being drawn with regard to the shape of arches, except that semi-circular deep arches are the most common type.
- The vast majority of masonry arch bridges are in good and medium condition (approximately 85%) but there is significant proportion in a poor or very poor condition.

3   WP1: ASSESSMENT OF MASONRY ARCH BRIDGES

3.1   General

Assessment of masonry arch bridges is a difficult task as there is no widely accepted and reliable structural assessment procedure. Structural behaviour of masonry arches depends on several parameters but there is little experience of the effect of changes in such parameters and masonry arches have internal elements that are extremely difficult to investigate.

Several methods are available for the assessment of masonry arch bridges. These include simple conservative methods (such as MEXE) and recently developed computerized methods (such as adaptations of the mechanism method and FEM systems). Besides their particular limitations, conservative methods often underestimate the load carrying capacity, which may result in uneconomical or unnecessary mitigation measures being taken to maintain or replace bridges. Conversely the use of sophisticated new methods is generally hindered by the difficulty in provision of input parameters or prolonged data processing.

The use of advanced computerised techniques in the analysis of masonry arch bridges is a relatively new concept. Several computational techniques have been developed for this purpose including 1D frame or 2D and 3D non-linear finite element (FE) models, discrete element-based (DE) models and combined finite element-discrete element models (FE/DE). These methods were developed to describe the complex nature of arch deformation, cracking processes and arch-backfill interaction phenomena. Assessment of serviceability is becoming more and more important with increasing traffic volumes on masonry arches. There is however no suitable method for the serviceability assessment of masonry arches nor any criteria against which such an assessment could be made. Other shortcomings of existing methods are their inability to (or complicatedly) describe the effects of structural defects and strengthening intervention.

The objective of WP1 was to develop simple, reliable and user-friendly new assessment methods for masonry arches, improve existing ones and provide guidance for assessor engineers to the application of these integrated methodologies. A multi-level assessment procedure has

been recommended starting from the most simple and conservative 'rule of thumb' approach towards high-level analysis tools.

3.2   Revision of the MEXE method

The method is based on elastic principles where a two-pinned, parabolic arch static system is assumed to have a limited compressive strength of 13 tons/per square foot (cca. 1.4N/mm^2). The load capacity is calculated using empirical formulas with the application of subjectively estimated modifying factors referring to the geometry and material condition of the bridge (UIC Code 778-3R). These modifying factors are determined principally by visual inspection of the bridge.

The equations involved in the MEXE method do not represent the behaviour of a real arch, but represent the best approximation that was achievable without computers when the method was developed. Because of its simplicity and quickness the method is still widely used for the assessment of railway and highway masonry arches.

UIC Code 778-3R gives guidelines for the use of the MEXE method. Experience and latest research show that in a large number of situations the method seriously underestimates the actual load-carrying capacity of the bridges. On the other hand in some other cases MEXE has been found to provide non-conservative results. The method is generally used as a first sieve for the initial assessment and preliminary determination of load capacity. As MEXE can provide unreliable values for the load carrying capacity of masonry arches, some railway administrations proposed modifications to the method in order to achieve better conformity with their experience.

A review therefore has been undertaken of the MEXE method (Harvey, 2007a). The review included reworking the basic analysis that underpins MEXE and comparing the MEXE results with output from other methods.

The review has shown that the MEXE method had some drawbacks in its initial development and has been subsequently altered in ways that have not been fully understood. The result is that, in some cases, bridge capacity can be over estimated substantially.

Some of the alterations to the MEXE process in recent publications result in an overestimation of bridge capacity. This is particularly the case of the effects of longitudinal distribution through the fill which has little effect on larger span bridges but dramatically overestimates the capacity of bridges with spans less than 5 metres.

The provisional axle capacity obtained using the method is generally less than the actual capacity. It should not be taken as more than an indication that the arch may be suitable to carry rail traffic because:

-   minimum longitudinal distribution of loading has been assumed;
-   only that part of the arch under the track has been assumed to carry load;
-   the factors to be applied for condition are subjective and the validity of the use these factors is considered dubious.

3.3   Rule of thumb method

An assessment method based on the load capacity being directly related to the geometrical properties of the span, rise, and ring thickness of an arch has been developed (Harvey, 2007b).

In comparison with the alternative empirical method (MEXE), this method should deliver realistic results at no increased costs.

The concept for this method is that the assessment is quick and may be carried out by artisan bridge examiners when on site inspecting the condition of the arch. The aim is to enable the majority of arches with sufficient load carrying capacity to be identified with minimum work, and thereby permit assessment engineers to concentrate their efforts on those bridges which are not so obviously adequate for the task.

3.4   Pauser's method for the assessment of semi-circular arches

Pauser's method (Ingenieurbüro A. Pauser, 2005a) is a simple analysis tool that may be used for the assessment of both single and multi-span arches with haunching, whether constructed in

brick or stone. The method is best suited for the assessment of single span semi-circular arches. The method is based on the analysis of the arch at its ultimate limit state of load-bearing capacity, considering only that part which may be realistically assumed to act as an arch.

The computed value for arch capacity is considered conservative as the method neglects tensile stresses, the contribution of the spandrel wall and a soil model amplifying load capacity is not used.

3.5 RING masonry arch analysis software

A new version of the widely used RING masonry arch bridge analysis software (Gilbert, 2007) has been developed in collaboration with UIC.

RING 2.0 uses computational limit analysis techniques to estimate the ultimate load carrying capacities of bridges. A two-dimensional analysis is performed with the constituent masonry blocks of a bridge being modelled explicitly. These blocks are assumed to be rigid but are separated by masonry joints (contact surfaces) at which rocking, crushing and/or sliding failures are permitted to take place. Backfill material, if present in a bridge, whilst not modelled explicitly, is assumed to disperse live loads and to provide passive restraint.

To facilitate the assessment of railway bridges RING 2.0 includes within the software railway loading models and distribution of railway loads through the track and ballast modelled in accordance with relevant UIC leaflets.

3.6 High-level assessment of masonry arch bridges

High-level assessment of arches are generally based on finite element or discrete element models. The high-level assessment is generally only necessary when a structure is found to have insufficient load capacity using a lower level assessment method, or the assessment includes analysis of the effects of damages on load capacity.

The Guide to High-level Assessment (Brencich and Gambarotta, 2006) is aimed to provide a guidance for assessor engineers on the procedure of high-level assessment of masonry arch bridges by the use of commercially available finite element software packages.

The proposed assessment procedures include incremental non linear step - wise analyses performed on beam - like models and analysis on simplified 2D or 3D models. Parametric and case studied are discussed showing the validity limits of the different approaches.

3.7 Guide to the assessment of masonry arch bridges

A guide has been developed for the whole process of masonry arch bridge assessment (Harvey, 2007c). The sections of the guide deal with: Construction, Behaviour, Deterioration, Loading (including load distribution), Inspection, Assessment and Reporting. The core section on assessment is further divided into: Basic Principles, Modelling approaches, Three-dimensional effects, Levels of analytical tools and Complexities.

In order to determine the adequacy of a particular arch structure with the minimum degree of effort, the assessment should be carried out in levels of increasing refinement and complexity, with the initial level being based on the most conservative distributions of loads and analytical assumptions. If the structure is shown to be inadequate in relation to the required load carrying capacity at this level, assessment work should continue, with subsequent levels seeking to remove conservatism in the assessment where this can be justified.

4 WP2: INSPECTION AND MONITORING

4.1 General

Several inspection methods have been used to investigate the condition or to determine the structure of masonry arch bridges. The most common method is still the pure visual inspection. Destructive testing is also used although there is a tendency in recent years towards using non-destructive testing techniques.

Most assessment procedures require the masonry strength and some other mechanical properties as the major input parameters for assessment. Destructive Testing (DT) of masonry bridges is therefore necessary in many instances, although it is noted that the results of most destructive tests are affected by significant uncertainties and they may provide only local information on some part of the structure, and cannot be directly extended to the whole bridge.

Semi-Destructive Testing (SDT) methods are based on in-situ localised measurements and considered as surface or small penetration techniques which can provide only qualitative information on the masonry condition and be used only for preliminary investigation.

While conventional DT methods focus mainly on the mechanical characteristics of the materials, Non-Destructive Testing (NDT) methods can provide an overall qualitative view on the arch condition. NDT methods on the one hand seem to be most promising tools for the inspection of masonry arch bridges but on the other hand need a great deal of further study and research. The number of references and projects that have utilized NDT methods on masonry arches is very low and only a few calibration tests have been carried out. Consequently correlation of NDT data with the mechanical properties of the structure is considered limited at present. Nevertheless NDT usually requires an expert with sufficient skills to carry out the measurements and interpret the results so that the significance of data is recognized and that data is not used inappropriately. This 'strong reliance' upon the non-engineer specialist is generally not acceptable to the railway administrations. There is thus a need for close collaboration between bridge engineers and NDT specialists and to provide information for bridge engineers on the use of these specific testing methods.

Monitoring systems are occasionally installed on masonry arch railway bridges in order to follow the evolution of damage patterns such as cracks or deformations. The knowledge of this evolution can help preventing more serious damage or a total collapse of the structure. Monitoring may also provide information that can be used to determine the root causes of the defects. These may be from visual inspection or electronic data collection.

Load tests are carried out only in special cases on masonry arch bridges. However load tests are considered to provide the 'most reliable information' on the real structural behaviour.

Data and references have been collected from the railway administrations on the use of testing methods in the inspection and diagnosis of masonry arches. The main testing methods that the railway administrations have experience with, either by regular or experimental use, are summarized in Table 2.

The objective of WP2 was to give an overview on the available testing methods of masonry arch bridges and to give recommendations for the use of the methods and for the utilization of measured data.

4.2 Determination of material properties by destructive tests

A procedure for the determination of masonry compressive strength has been developed (Ingenieurbüro A. Pauser, 2005b). The procedure includes tests on the composite masonry and tests on its components. The characteristic value of masonry compressive strength are determined according to the number of samples and the coefficient of variation of measured data. For mortars, a punch test has been developed where a 10-to-25mm thick mortar sample embedded in-between two layers of gypsum is tested.

4.3 Non-destructive testing of masonry arch bridges

Masonry arch bridges rarely have accurate or sometimes any drawings of their construction or early repair details. The internal structure of arch bridges may be unknown from external appearance, and may include features such as haunching at support, vaulting, internal spandrel walls, ribs or the presence of saddle over the arch barrel. It may, therefore, be difficult to determine the physical dimensions of the main structural elements of the bridge. Moreover, materials used for the abutment, barrel, spandrel and backfill are variable, and interact. This inadequate knowledge of geometry and materials used complicates the problem of accurate modelling of behaviour. Further complication is the possibility of ring separation or the presence of other hidden defect and irregularities such as voids in the granular backfill immediately above the extrados, areas of reduced density and stiffness in the fill adjacent to the extrados, and cracking in

the arch ring. Bridge repairs and strengthening require sufficient knowledge on existing defects and their causes too. Hence it is essential that some information of the internal structure and condition of a bridge is obtained before any remedial work or strengthening can be carried out. In this respect NDT methods can play an important role both in the inspection and assessment process and later when the result of the strengthening process has to be checked.

The objective of a testing programme can be to quantify the parameters that are required for the assessment procedure or to provide information for the evaluation of condition. As a large variety of methods is available the choice of the most appropriate method for a specific problem can be rather complex.

Recommendations have been worked out (University of Pecs, 2006), based on the results of a test programme carried out and the experience of the railway administrations, on the use and optimal selection of NDT methods for specific inspection purposes of masonry arch bridges.

Table 2: Summary of testing methods

Destructive Testing Methods	Semi-Destructive Testing methods	Non-Destructive Testing methods	Monitoring methods
Mechanical tests on cored samples	Boroscopy, endoscopy	Georadar	Hammer tapping
Physical and chemical tests on cored samples	Flat-jack test	Infrared thermography	Crack monitoring
Standard tests on soil and backfill properties	Surface measurements (hardness, Schmidt hammer, penetration, pull-out tests)	Sonic methods	Laser profiling
		Conductivity measurements	Moisture monitoring
	Analysis of small diameter cored samples	Accoustic emmission	Deformation monitoring
			Dynamic test
			Load test

4.4 Catalogue of damages

A visual examination is the first vital step in an effective maintenance regime. An incorrect diagnosis may lead to other mistakes, like the implementation of unnecessary repairs. Sometimes, a lack of understanding of the behaviour of "masonry" materials makes diagnosis of causes of damage in arches difficult. In other cases if insufficient information is obtained in the inspection additional inspections will need to be carried out, thus increasing the inspection costs. Lastly, this lack of understanding can lead to an overestimate of the risk of collapse when the risk is negligible.

The Catalogue of Damages (Ozaeta and Martín-Caro, 2006) was developed using the experience of the railway administrations partaking in the project. The Catalogue is considered to be a tool to provide assistance with the inspection of masonry arch bridges. The scope of the Catalogue is limited to damages that could be detected by visual inspection of masonry arch bridges.

The main objectives of the Catalogue are:
- Identification of damages with recommendations for work required during and after the examination to enable the type and cause of damages to be identified.
- Identification of the most common mechanisms of deterioration of damages.
- Identification of the most common causes of deterioration of damages.
- Describing the effects of damage on the structural behaviour of the bridge.

The classification of damages is made according to the following structure:
- Foundation Damages:
  o Damages due to the degradation of the structural element
  o Damages due to loss of foundation support
- Superstructure damages:
  o Damages affecting structural resistance
  o Damages affecting durability

4.5 Load test of masonry arch bridges

If none of the analytical methods yields a sufficient result, consideration may be given to the use of an experimental approach to assess the load carrying capacity of masonry arch bridges. A calculated assessment presumes that together with the geometry, foundations and load, all essential material properties and status is known or estimated and that it is possible to describe the load transfer realistically in mathematical terms. An experimental approach evaluates the physical reality and should lead to a higher permissible working load as a rule.

Load tests may be used to verify serviceability, the load carrying safety factor and/or to calibrate an analytical model (e.g. FEM).

A suitable procedure is the application of loads to the structure and the simultaneous monitoring of the load-carrying behaviour, particularly deformations and strains as well as micro-crack formation.

One method for load testing utilises trains crossing the arch. Nevertheless, uncertainty may still remain if the load carrying safety factor has to be proofed by analytical extrapolation.

An alternative experimental non-destructive approach is to determine the load carrying capacity utilising a heavy counterweight and hydraulic load application. An external variable loading is used to reach a target load, including the necessary margin of safety, without infringing limit state criteria. On the basis of the measurements taken, either the structural safety is proofed or a critical load level is identified. This limit is characterised by the first signs of damage and is synonymous with the actual state of deterioration.

A guideline has been developed for the load tests of masonry arch bridges (Steffens and Gutermann, 2006). Measurements carried on selected masonry arches are evaluated in respect to coincidence with analysis results.

5 WP3: MAINTENANCE AND REPAIR

5.1 General

Masonry arches belong to the civil engineering heritage of the railways, therefore their substitution or refurbishment requires careful consideration. Total replacement of deteriorating masonry bridges is economically not feasible. The solution must therefore lie in optimised maintenance and repair strategies. Repairs to masonry bridges should take account of the existing structural capacity and replacement need only be carried out when it has been demonstrated that the existing load capacity is insufficient.

A fundamental requirement is that any maintenance and rehabilitation intervention should maintain the structural integrity of the arch and be physically, chemically and mechanically compatible with the existing structure. Strengthening works that do not take account of the fundamental modes of structural behaviour are unlikely to be beneficial.

The objective of WP3 was to give an overview on the available conventional repair and strengthening methods of masonry arches, demonstrate new methods of strengthening and to develop a methodology for the degradation modelling of arches to help their life-cycle management and intervention planning.

5.2 Repair and strengthening of arches

A survey was carried out to collect and evaluate the maintenance and repair solutions available for masonry arches in the participating railway administrations. These include methods for the restoration of waterproofing and drainage (such as drainpipes placed through the barrel, restoration of drainpipes; concrete saddle over the arch with bonded waterproofing; unbonded waterproofing on extrados; injection of arch barrel), methods for the restoration and strengthening of arch barrels (e.g. injection of arch barrel; RC shotcrete lining under the arch; concrete saddle over the arch; stitching of cracks and low pressure grouting; supporting barrel with steel rings), methods for the restoration and strengthening of abutments, piers and foundations (e.g. underpinning through the abutment; scour protection, stitching and grouting of abutment cracks; installation of props or invert slab; injection of soil under foundations) and

methods for the restoration of 3D integrity of arches (tying with rods and patrass plates; tying spandrel walls to new saddle on barrel; load dispensing concrete slab over the arch).

Important aspects to be taken into account in the design of masonry arch repairs (Ozaeta, Martín-Caro, Brencich, 2007):

- The most frequent cause of damage to masonry bridges is inadequate drainage of water thus repair strategies should always include the restoration of waterproofing and drainage systems.
- Most serious damage to arches arises from foundation problems and special attention should be given to their proper maintenance and repair.
- Repair and strengthening techniques should provide sufficient resistance against foreseeable future loads and effects (e.g. increases in axle loads, speeds, dynamic effects, and physical-chemical effects, etc.).

5.3 Expert Tool for degradation modelling

An Expert Tool (Bien, Kaminski, Rawa, 2006) has been developed for the degradation modelling of masonry arch bridges. The aim of work was to provide guideline for the numerical modelling of masonry arch damages, work out a methodology for the evaluation of bridge condition, the estimation of expected service life and to assist ranking and maintenance planning of existing bridges.

A pilot version of a computerised expert tool entitled Masonry Bridge Damage Evaluator (MyBriDE) supporting evaluation of degradation level for masonry bridges has also been developed. The system is able to analyze the influence of the most common damage types, such as strength reduction, longitudinal fracture and loss of material, on the carrying capacity and technical condition of typical masonry bridges.

6 NEW UIC LEAFLET ON MASONRY ARCH BRIDGES

The UIC leaflet on the assessment of masonry arch bridges is currently under revision and will be extended by utilising the deliverables of the project. The work is expected to be concluded in 2007.

The leaflet is intended to provide railway infrastructure owners, maintenance managers, bridge inspectors and consulting engineers with guidance on the inspection, assessment and maintenance of masonry arch bridges.

7 SIGNIFICANCE OF FURTHER RESEARCH

The deliverables developed in the current phase of the project are based on our current understanding of masonry arch bridges. Many significant matters have however been identified where there remains insufficient knowledge of the characteristics and structural behaviour of arch bridges to permit development of appropriate guidance.

Behaviour of masonry arch bridges under long-term service loads and the derivation of their serviceability limits are one of the important areas that require further research. There is a need for a predictive life-cycle management and maintenance planning of masonry arch bridges that is based on knowledge of the actual level of safety arising from a sufficient understanding to identify the degradation process, an appropriate system of acceptability criteria and the knowledge of the foreseeable effects and costs of intervention.

8 INFORMATION DATABASE

Further information on masonry arch railway bridges can be found on the Database of the project at: http://masonry.uic.asso.fr

The Database is intended to form a reservoir for existing knowledge of management processes and data applicable to masonry arches and to provide a platform to enable the railway administrations and other users to consult and share information.

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REFERENCES

Bien, J, Kaminski, T, Rawa, P. 2006. Technology and pilot version of expert tool supporting the evaluation of the degradation level for masonry bridges with damages. *UIC Report*

Brencich, A., Gambarotta, L. 2006. Guide to the high-level assessment of masonry arch bridges. *UIC Report (draft)*

Gilbert, M. 2006. Guide to use of RING 2.0 for the assessment of railway masonry arches. *UIC Report*

Harvey, W. J. 2007. Review of the MEXE method. *UIC Report (draft)*

Harvey W J. 2007b. Rule of thumb method for the assessment of arches. *UIC Report (draft)*

Harvey W J. 2007c. Guide to the assessment of masonry arch bridges. *UIC Report (draft)*

Ingenieurbüro A. Pauser. 2005a. Guide to the high-level assessment of masonry arch bridges. *UIC Report*

Ingenieurbüro A. Pauser. 2005b. Guide to the destructive testing of masonry bridges. *UIC Report*

Ozaeta, R. G, Martín-Caro, J.A. 2006. Catalogue of Damages for Masonry Arch Bridges. *UIC Report*

Ozaeta, R. G, Martín-Caro, J.A., Brencich, A. 2007. Guide to the execution and control of masonry arch repairs. *UIC Report (draft)*

Steffens, K., Gutermann, M. 2006. Guide to the load test of masonry arch bridges. *UIC Report*

The University of Pécs 2006. Recommendations to the non-destructive testing of masonry arch bridges (ed. Orban, Z.). *UIC Report (draft)*

UIC Code 778-3R. 1994. Recommendations for the assessment of the load carrying capacity of existing masonry and mass-concrete arch bridges, Paris.

UIC Report. 2004. Assessment, Reliability and Maintenance of Masonry Arch Bridges (ed. Orban, Z., UIC Masonry Arch Bridges Study Group*). State-of-the-Art Research Report of the International Union of Railways*, Paris.