BRIDGES AND RELATED STRUCTURES

20 September 2007 (pm)

TECHNICAL COMMITTEE C4.4
BRIDGES AND RELATED STRUCTURES

INTRODUCTORY REPORT

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EXECUTIVE SUMMARY

Bridges are fundamental links in all national, regional or local road networks. Any malfunctioning, lost of bearing strength or capacity to accommodate the increasing traffic intensity without restrictions, represent important costs in the economy of a region. Consequently, administrations need to devote the necessary resources for assuring the functionality and safety of bridge stocks.

Depending on the level of development of the countries and their recent history, periods of intensive bridge construction have been concentrated in periods of, perhaps, one or more decades. In many European countries the period after World War II was critical in the construction of the road networks, bridges included. Other countries concentrate the development in their road infrastructure construction in parallel with economic expansion peaks.

We have many examples of such intensive construction periods coinciding with the onset in the use of “new” structural materials, such as steel or concrete. The intensive use of concrete, for example, in the periods when their properties regarding durability were not suspect have resulted in cases where some bridges that have been inherited have an undesirable level of condition.

The progress in the knowledge of the properties of concrete and steel, the improvement in the construction quality control, the recommendations for reaching a durable structure from the design phase and the new tools for management of bridge stocks have been changing the scenery nowadays.

The work of the TC4.4 Committee during the last few years has been devoted to exploring the way different countries in the world approach the question of bridge durability improvement in all phases of their life, i.e. design, construction and service, as well as to comparing the criteria and procedure in different bridge administrations with implemented Bridge Management Systems (BMS) to prioritize the resources for maintenance and repair.

As historical bridges are in many countries an important subset of the bridge stock, the Committee decided to announce a call for contributions by engineers who are responsible for their maintenance, as they are special structures that sometimes do not fit in to standard management systems.

The session TC4.4 organized by the Bridges and Related Structures Committee, will be organized in three parts and will include the following:

- **Presentation of the technical work of the Committee**
    - How to improve durability in the design and construction phases
    - How to increase durability in service life: innovative versus standards methods
    - Revision of prioritization criteria and procedure in BMS

- **Invited speakers on historical bridges**
  - Analysis of historical bridges using the mixed discrete element method
  - Criteria to ensure the durability of masonry foundations of bridges
  - Management of historic bridges
  - Virginia Department of Transportation's Historic Bridge Maintenance Plan
  - Bridge owner’s benefits from probability-based management of old bridges – Practical Experiences
- **Aspects for debate and future work**
  - Durability in design phase
  - Durability in construction phase
  - Maintenance & durability
  - BMS for improving durability
  - Historical bridges
  - Future work

COMMITTEE MEMBERS WHO CONTRIBUTED TO THE REPORT

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Peter Graham, Australia	Task 3 Chair
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1. INTRODUCTION

In any country the transport of persons and goods is a key stone in the economy, progress and welfare of the nation, and this circumstance is more relevant the higher its level of development . The importance of transport is easily extrapolated from the country level to a supranational territory.

Bridges are fundamental links in all national, regional or local road networks. Any malfunctioning, loss of bearing strength or capacity to accommodate the increasing traffic intensity without restrictions, represent important costs in the economy of a region. Consequently, administrations need to devote the necessary resources for assuring the functionality and safety of bridge stocks.

Depending on the level of development of the countries and their recent history, periods of intensive bridge construction have been concentrated in periods of, perhaps, one or more decades. In many European countries the period after World War II was critical in the construction of the road networks, bridges included. Other countries concentrate the development in their road infrastructure construction in parallel with economical expansion peaks.

The intensive use of concrete, for example, in the periods when their properties regarding durability were not suspect have resulted in cases where some bridges that have been inherited have an undesirable level of condition.

The progress in the knowledge of the properties of concrete and steel, the improvement in the construction quality control, the recommendations for reaching a durable structure from the design phase and the new tools for management of bridge stocks has been changing the scenery nowadays.

The way different countries, with different environments, materials, construction methods and maintenance rules, attempt to improve durability was considered an interesting objective to be explored by this Committee.

Durability is, of course, a vast field of work and TC4.4 has focused the activity in collecting information on how different countries deal with this matter in both bridge design and construction phases.

During the useful life of a bridge the maintenance required for solving durability problems implies multiple aspects, methods and techniques, many of which have been analysed previously in other PIARC bridge Committees. In the current period it was decided to compare practical experiences in the use of innovative methods versus traditional techniques for solving a durability problem.

The Bridge Management Systems (BMS) are not implemented in all bridge administrations but are extensively used and are considered as a fundamental tool for managing large bridge stocks. One of the critical modules in a BMS is the prioritization of the use of maintenance and repair resources in a network. As it is not always clear the criteria and procedure used, the Committee has collected information from many administrations in order to try to give an analysis of this specific matter.

This Introductory Report attempts to give a vision of the main topics to be presented and discussed in the session TC4.4 devoted to Road Bridges and related structures.

1.1. Program of the session

The session is intended for any technician related to the maintenance of bridges, the procedures for improving durability (designers, constructors) and bridge management. Those interested in masonry and historical bridges have the opportunity to attend several presentations regarding this special group of bridges.

The session is structured in three parts:

- **Presentation of the work of Committee TC4.4**

- Task 1: Improvement of durability in the design and construction phases
Review for a number of countries of the specific factors affecting durability for usual constructions materials: concrete, steel, others. Considerations included in design codes and good practices or recommendations.

- Task 2: Increase of durability and lifetime of existing bridges
Comparing innovative methods versus traditional for improving or solving specific damage problems.

- Task 3: Approaches to cost effective management of bridges
A review of the information on different BMS regarding the optimization and prioritization methods and criteria used will be presented.

- **Contribution of invited speakers on masonry and historical bridges**

Many aspects of historical and masonry bridges need specialization and skills in those technicians who manage these kind of structures. A selection of five works from around the world have been selected to be presented in the session:

- *Management of historic bridges. Finland.*
- *Bridge owner's benefits from probability-based management of old bridges – Practical Experiences. Denmark*
- *Virginia Department of Transportation's Historic Bridge Maintenance Plan. USA*
- *Analysis of historical bridges using the mixed discrete element method. Portugal.*
- *Criteria to ensure the durability of masonry foundations of bridges (masonry bridge foundations). Spain.*

- **Discussion and future work**

A discussion on every critical aspects regarding all previous matters presented will follow. Finally a proposal of the Committee for future works under the PIARC structure will be presented and debated.

2. THE COMMITTEE WORK

2.1. Durability in the design and construction phases

Feedback from inspection and maintenance experience has highlighted durability problems in highway structures, often even when materials specification and construction has been satisfactory.

These problems can often be linked to a design approach that minimises initial cost rather than attempting to adopt a whole life costing model.

Constrained maintenance budgets and the secondary costs of repair works in high traffic volume situations have further exacerbated the effects of durability problems in highway structures.

This investigation has sought to pool the experience of the members of the PIARC Committee 4.4 in respect to of current design and construction philosophy in identifying and responding to perceived durability problems.

The sub group working directly on this task consisted of eleven members of the committee drawn from European countries apart from the representative of Canada.

A questionnaire was formulated by this group for circulation to PIARC members. It was agreed to limit the scope of the enquiries to steel and concrete bridges of medium span (less than 150 meters individual span), as this represented the bulk of the bridge stock and long span bridges were recognized to be a specialized area. The questionnaire sought the considered view of experienced practitioners rather than the result of formal research which was unlikely to be available

The questionnaire covered:

- General Information on the network covered
- General Information current design standards
- Environmental conditions
- Materials Data (Concrete and Steel, with respect to improving durability)
- Highlighted Durability Problems
- Design Practice
- Detailing Practice
- Envisaged Developments in the field of Durability

Responses were received from twenty sources, some being the consolidation of several inputs within one country. The study brings focus to the range of the many variables involved in questions of durability, and serves as a useful source of comparative data for designers and those responsible for writing design codes.

2.2. Durability and lifetime of existing bridges

Based on a questionnaire distributed to all members and corresponding members of PIARC technical committee TC 4.4, the scope of this study was to present an inventory or a library of examples on methods of minimizing the maintenance or repair cost and/or minimizing the traffic restrictions through increasing the durability and lifetime of existing bridges or other highway structures or structure components.

How to increase the durability and/or minimize the traffic restrictions are presented by an evaluation and comparison of a traditional repair method of solving a detected problem against a new, alternative repair method of solving the same problem. The definition of the traditional method and the new method was up to the questionnaire respondent.

The examples of solving problems were completed with recommendation for future design or detailing of bridges or other structures to avoid the detected damage/problems in the future. The principal of the study appear in the included figure.

The study will comply with the general PIARC, ST4, strategic goal: “to improve the quality of road infrastructure through effective management of road infrastructure assets in accordance with the user expectations and manager’ request.”

49 responses have been received from approx. 60% of TC4.4 member countries and corresponding member countries. The examples are from North America, Japan, Europe, South Africa and New Zealand.

The examples cover all essential construction components (bridge decks, slabs, supporters, parapets etc.), as well as traditional and new alternative repair solutions for different causes of damage due to insufficient design, detailing, construction and maintenance and due to impact from traffic, fire, environment etc. or new political requirements. It is the working groups impression that the forwarded responses are topical and that it is reasonable to anticipate that each country has forwarded their best ideas or examples on how to extend bridge life time, minimize agency cost and /or minimizing work-ing period and traffic restrictions.

All responses are divided into the following main and subgroups to have easy access to the ideas/proposals:

Main group	Sub-group
1.0 Whole bridge/culverts	1.1 Insufficient carrying capacity 1.2 Corrosion 1.3 Demands on a new bridge on an existing road
2.0 Superstructure, slab and beams	2.1 Insufficient carrying capacity 2.2 Insufficient width 2.3 Delamination, spalling and reinforcement corrosion 2.3.1 Slab 2.3.2 Beams 2.4 Rotting of timber 2,5 Deflection
3.0 Substructure, pier and foundation	3.1 Settlement 3.2 Deteriorated concrete 3.2 Insufficient carrying capacity
4.0 Bridge components or furniture	4.1 Leaking of deck joint 4.2 Insufficient or destroyed parapets 4.3 Wearing/deteriorated pavement 4.4 Wearing of painting

The practical examples demonstrate that considerations about the free traffic flow and reduction of repair cost have been the major inspiration for proposing new alternative methods of carrying out the repair works.

Many examples from the responses are about reduction of working time and avoidance of traffic restrictions e.g. replacement of a culvert by relining a new culvert inside the old one instead of digging up the road for replacement, and about the use of new materials e.g. strengthening of concrete beams or slabs with carbon fibre sheets instead of replacement.

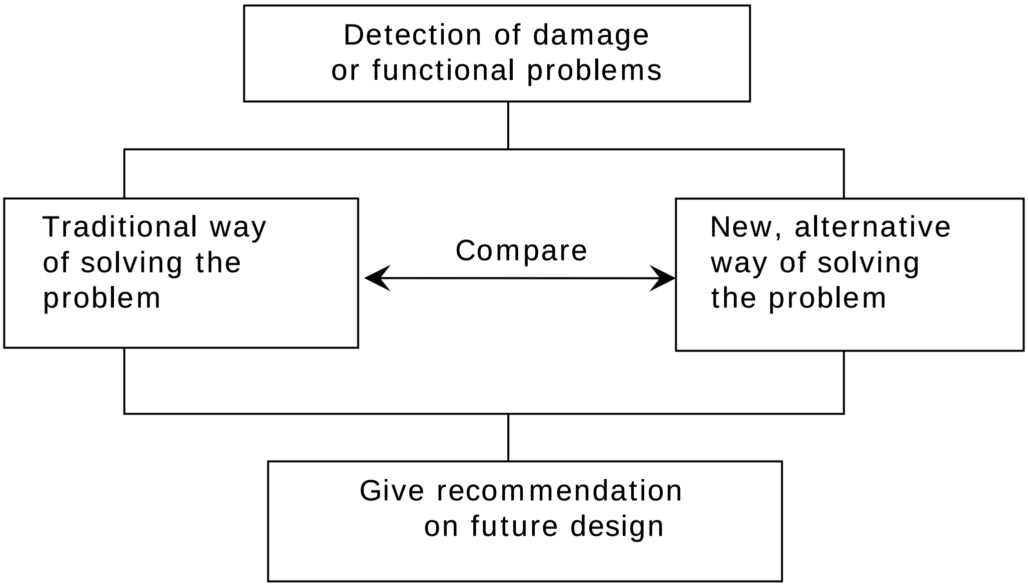
More examples are about cost reduction right now by postponing the repair works or reduce the rate of determination e.g. cathodic protection of reinforcement under corrosion. One example reduces the cost by demonstrating sufficient carrying capacity using probabilistic calculation methods.

Many examples have focused on cost reducing using new materials and in the same moment eventually extent the life time e.g. repair corroded steel culvert with fibre reinforced shotcrete.

Most examples also include recommendations to avoid the same damage or problem occurring in the future. Examples of essential recommendations are:

- Implementation of joint less bridges
- No hinges at mid span!
- Rebars in decks should be more resistant to corrosion
- Make every part of a structure accessible for maintenance, repair or re-placement

It is TC 4,4's hope that the examples in the inventory will inspire agencies, consultants and contractors in similar situations to select the optimal maintenance or repair strategy.



2.3. Approaches to cost effective management of bridges

The challenge in bridge management is to ensure that all bridges in a road network remain fit for their intended purpose over their' design life and beyond at minimum life cycle cost. Against this background, the PIARC Bridges and Related Structures Technical Committee identified the need to investigate the current practices in network level prioritization of bridge maintenance interventions that have been adopted by a sample of member countries.

The committee considered that a survey of member countries would be of interest both to countries with developed systems and those with systems under development. In the case of the first target audience group the study would provide a means of benchmarking existing systems or as stimulus to enhancements while countries that were developing systems would have access to a reservoir of information and contacts they could draw on to build or enhance similar capabilities.

The analysis of the responses to the questionnaires that were submitted by twenty three countries has provided an indication of the minimum data sets and processes that are required to conduct network prioritization. Although different prioritization philosophies have been adopted by contributors there is convergence in the data sets that are required. This is primarily in the bridge and road inventory items but to a lesser extent in the rated deterioration of components where there is significant divergence due to condition, damage and repair priority philosophies that have been adopted by the surveyed countries as a measure of component deterioration. However, regardless of the favoured philosophy, consistent, current and reliable inventory and condition data are essential to prioritization of bridge maintenance interventions to facilitate the necessary data , analysis and reporting functionality.

The project team has conducted an analysis of the various network prioritization approaches adopted by countries that have responded to the Task 3 questionnaires on “Cost effective Bridge Management” and concludes the basic data set and processes that are required to prioritize bridge maintenance interventions at the network level.

The primary items that will be reported are;

- Work and data flow processes
- Analysis of Bridge Management Systems submissions
- Analysis of prioritization methods
- Modification of system derived prioritization outputs
- Management of unfunded priorities.

3. INVITED PRESENTATIONS

Historical Bridges are structures requiring special treatment in aspects like inspection, evaluation, repair, rehabilitation and, in general, management. Many countries have a wide patrimony of historical bridges, some of them still in and use bearing intensive traffic loads and being cared for as monumental constructions. Other old bridges, usually in secondary roads, suffer a lack of specialized maintenance, or are simply abandoned, and frequently bridges, perhaps with not a high monumental relevance, but in any case beautiful structures, are definitively lost.

The approach to maintaining old stone, brick, wood and steel historical bridges requires special consideration in analyzing the structural behaviour, the aesthetic preservation, the materials for repairing, the environmental protection, etc. Historical bridges are always considered as a special part of the road network.

Developing or in transition countries have an important deficit in the management of their historical road structures. Funds are directed mainly to enlarge and maintain the main road system and maintenance of historical constructions is not a priority. The experience of other countries with efficient management systems of historical bridges could help to improve the situation.

For these reasons TC4.4 decided to prepare a call for contributions devoted to historical bridges.

3.1. Management of historic bridges.

Jouko Lämsä. Road Administration/ Bridge Committee, HELSINKI. Finland

The Finnish Road Administration (Finnra) currently manages about 40 bridges that are classified as museum bridges, and thereby historic bridges, according to the criteria of the National Board of Antiquities, which is Finland's highest museum authority. Finnra's historic bridges have belonged to the Road Museum, which today is managed by Mobilia, a road traffic museum. When the Road Museum was established in the 1970s, there was a special museum committee that included specialists from the fields of history, museums and technology. Today the museum operation is governed by special regulations, and official responsibility for the museum operation has been transferred from the central administration to the Häme district.

The regulations contain instructions concerning the assessment, inspection and maintenance of bridges that are selected to be historic bridges. The most important criteria for selecting historic bridges are national historical significance importance in terms of bridge construction technology, importance for the history of roads and communications local special significance authenticity conditions for surviving in its present state.

The selected bridges represent the oldest preserved examples of different bridge types found on Finnish public roads or bridges that have otherwise been classified as being important and having cause to be preserved for future generations. The bridges are constructed from various materials. The sites have been selected from different parts of the country as evenly as possible.

The oldest bridges constructed from different materials, which are still in use and maintained by Finnra, are: a stone bridge from 1777, a wooden bridge from 1837, a steel bridge from 1856, and a reinforced concrete bridge from 1911. Because most of the bridges in Finland were constructed from wood until the early 1900s, maintenance and restoration of wooden bridges have had an important role when making selections. The total length of the above-mentioned oldest wooden bridge from 1837 is 77 m.

To preserve information about historic bridges, a book has been written about the construction, builders, structure, and decision-makers associated with each bridge. In addition, books containing very detailed information have been written about several individual bridges. Historic bridges on the road network are designated with special road signs accompanied by information signs about the history of the bridge in several languages. The most important information about former already dismantled bridges includes drawings, photographs and other documents stored in the archives of the National Archives and the National Board of Antiquities.

3.2. Bridge owner's benefits from probability-based management of old bridges

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The growth of national economies in the later half of the 20th century has resulted in steadily increasing traffic volumes on trading routes and in an increase in the demands placed on an aging bridge stock. Ironically, economic growth has not resulted in an increase in the budgets available to bridge owners for maintenance of their aging resource.

The approach adopted by the Danish Road Directorate (DRD) in addressing this challenge has been to attempt to exploit advances in scientific methods in the management of its old bridges. Old bridges are valuable in the sense that they represent a value for the transportation system but also in the sense that thy represent cultural and historical heritage.

This paper provides an overview of current practical experience. A general discussion of the approaches adopted is provided with specific emphasis placed on the significant cost benefits to bridge owners of adopting these approaches. A discussion of the future challenges faced by bridge owners is provided. Probabilistic approaches incorporating uncertainty modelling have provided the DRD with significant monetary savings. The paper presents a discussion of the guideline recently published by the DRD for the application of reliability based approaches in capacity rating and maintenance management of old and historical bridges.

Examples of the use of the guideline for assessing/managing real structures are presented along with the significant cost savings which have resulted from its use.

3.3. Virginia Department of Transportation's Historic Bridge Maintenance Plan.

Malcolm T. Kerley, P.E. Chief Engineer .Virginia Department of Transportation. Virginia. USA

The Virginia Department of Transportation (VDOT) maintains the third largest state maintained transportation network in the United States. In order to preserve Virginia’s heritage as well as provide for today’s mobility needs, VDOT has developed a Historic Bridge Management and Maintenance Plan. The development of the plan was a joint effort of core VDOT Divisions—Structure and Bridge; Environmental; and the VDOT Research Division, the Virginia Transportation Research Council (VTRC).

This paper presents VDOT’s Historic Bridge Management and Maintenance Plan. In a number of projects since the 1970s, VDOT, through VTRC, had documented the various types of older bridges in Virginia, and had evaluated these for historic significance. These thematic bridge studies include metal truss bridges, stone masonry and concrete arch bridges, wooden covered bridges, non-arched concrete bridges, and movable span bridges. Historically-significant structures which were eligible for the United States National Register of Historic Places were identified. Once historic significance had been determined, the next logical step in dealing with these historic structures was the development of a management plan for each historic structure.

This project utilized the data already gathered by VTRC, along with technical information provided by VDOT central office and district personnel. Additional input was provided by the Virginia Historic Structures Task Group, an interagency, interdisciplinary committee charged with making recommendations for Virginia’s historic transportation structures.

The Task Group includes civil engineers, architectural historians, an archaeologist, and an environmental scientist, who are representatives of various state and federal agencies: VDOT, VTRC, the Federal Highway Administration, and the Virginia Department of Historic Resources (the State Historic Preservation office). This project identified and considered the numerous issues (including legal, engineering, regulatory, financial, preservation and political issues) that arise concerning historic bridges.

Different kinds of treatment, management, and maintenance options were also identified and evaluated, and specific recommendations were formulated for each one of Virginia's historic bridges under VDOT purview. An historic bridge management database was specially developed and refined for this project..

The plan included specific management and maintenance recommendations for each of Virginia’s 55 National Register-eligible or National Register-listed bridges under VDOT purview. These include early-19th century stone masonry arch turnpike bridges, mid- and late-19th century wooden covered bridges, metal truss bridges ranging in age from 1870 to the 1930s, and early 20th century arched and non-arched concrete bridges.. Several bridges have been or may soon be taken out of vehicular service, and the plan recommendations supported their continued or potential adaptive use as footbridges and bicycle bridges in waysides or park settings. In accordance with the recommendations formulated by the plan, a few bridges were offered to governmental or private groups who are willing to assume ownership and liability of these structures. Currently, over 30% Virginia’s historic bridges have been rehabilitated following recommendations in this plan. Other projects are in the planning stages.

3.4. Analysis of historical bridges using the mixed discrete element method.

Gilberto Antunes Ferreira. Polytechnic Institute of Viseu - School of Technology, Department of Civil EngineeringDEC-ESTV-IPV,. Viseu. Portugal

This paper presents an analysis of historical bridges using the mixed discrete element method The discrete element method applied to a system of blocks, originally applied to the study of jointed rock masses, was quickly adapted and generalized to other studies, such as the structural behaviour of historical masonry buildings and bridges.

This method is particularly appropriated to the representation of structures whose character is predominantly discrete with blocks, rigid or deformable, without the need to specifically contemplate the joint with any type of element, as it is required in the finite element method. The main advantages of the method result from the possibility of each block to suffer finite displacements and rotations, separate from the other ones completely, and establish new contacts.

The existent formulations consider models constituted by blocks, rigid or deformable, or by rigid particles, whether in 2D or in 3D. In order to enlarge its domain of application a rigid mixed plane model of discrete elements was developed, including both the blocks and the particles. This makes it possible to accomplish 2D studies of masonry arches bridges, modelling the arch and the spandrel walls with blocks and the fill with particles.

This model follows the classic requirements of the discrete element method, introducing some new concepts, namely, the new definition of contacts, the adaptation of the detection method to new types of contact, the generation of the mesh of particles between the extrados of the arch and the road surface, among others.

The developed 2D algorithm allows the determination of the eigenvalues and eigenvectors of the structure, which is very useful to calibrate the numerical model. The application of the mixed discrete element method to the quasi-static analysis of structures is specially indicated for the calculation of the bearing capacity and respective collapse mode of masonry arches bridges, and an example of this type is presented.

3.5. Criteria to Ensure the Durability of Masonry Foundations of Bridges

Masonry Bridges Task Group of the Bridges Committee of the Spanish branch of PIARC. Presented by J. León. Prof. Escuela de Ingenieros de Caminos. Madrid. Spain.

The percentage of masonry bridges (road and railway) existing in Spain represents about 30-40% of the total amount of bridges, that is, similar to the average value amount all over Europe. Such noble structures, functioning after decades or even centuries of service life, are still able to achieve the current requirements, which represent a remarkable example of “sustainable engineering”.

Nevertheless, to be sure that the old bridge, including its old foundation, can still be of use —which is often the best solution—, engineers must decide what and how to do in order to broaden the platform, strengthen the vaults, repair, and so on. Such a decision usually implies to survey and strengthen its foundation. In the specific case of masonry structures, the evidence or the risk of scour is enough to afford the study of the foundation, even though no broadening or other repair operation was, in principle, needed. As is well known, the rather brittle behaviour of foundations under scour, of fatal consequences, is the main reason that justifies, in itself, a profound analysis of the foundation features and bearing capacity.

It is worth mentioning that, since 2003, about 50% of the total rehabilitation cost of such structures is dedicated to different operations in foundations. The Spanish authorities of road and railway exploitation also inform that approximately half of the works on masonry bridges are the result of the damages caused in foundations.

Two years ago the Masonry Bridges Task Group, a subdivision of the Bridges Committee of the Spanish branch of PIARC, started the task of preparing a document or guideline containing criteria for engineers that must under-take this relatively “unusual” problem of assessing an existing masonry foundation and, thereafter, the design of a solution for rehabilitation or strengthening. Thus, the document contains a short description of the common typologies, available surveying techniques, structural principles of their mechanical behaviour and the practical rules of design regarding strengthening and repair. It is particularly important to mention that the document includes a chapter dedicated to the study of bed rivers and scour, of great importance in those cases.

The document, prepared by a group of experts from different specialities, presents a rigorous but pragmatic layout of the problem and its solutions. As it usually happens with masonry structures, the common engineer is forced to deal with “uncommon” material (masonry) of “uncommon” structures (old existing ones) and, simultaneously, wise advanced techniques of characterization and intervention.

4. FUTURE WORK

It is usual in PIARC that any Committee, at the end of the 4 years period working in selected items, recommends for the next period some aspects of the work not fully covered together with some completely new subjects.

The Committee agreed that durability is a concept too wide to be covered in a single period. In a first glance TC4.4 focused to request information on how different administrations try to improve the sustainability of the bridge stock, which rules are implemented for improving the future structural and material behaviour in the design phase and in the construction process.

The Committee also explored how prioritization is afforded and the benefits of innovative versus traditional ones for repairing a bridge. There are many other items to be explored in the future under the umbrella of durability. A list including only some of them:

- Environmental factors affecting
- Laws of chemical attack and progression models
- Physical and chemical damages
- Definition of the condition of a structure
- Detection of damages
- New materials
- Etc...

Apart from durability there are other subjects with enough interest to be considered in the future. The Committee explored many of them and proposed, among others:

- Assessment of existing structures
- Monitoring of bridges: Methods and benefits
- Management of historical bridges
- Aesthetics in bridges: Efforts and cost.

DRAFT CONCLUSIONS

Regarding the work developed by the Committee in the three tasks, some draft conclusions can be advanced:

Regarding durability in the design and construction phases:

- Durability issues are being realised as major factors in the design of highway structures. Engineers have formerly concentrated on assuring the strength of structures, but the increasing search for overall optimal financial performance for the whole life of such structures has raised the profile of questions of durability.
- This survey, over a significant portion of the bridge stock, illustrates the wide range of factors affecting these issues; from conceptual design, through material specification to design and detailing practice, to construction and eventual maintenance regime and repair strategies. The role of the environmental conditions which the infrastructure inhabits is also of vital importance.

- Given the wide range of variables involved and the subjective nature of some of the enquiries, it cannot be expected that a simple panacea for the problems associated with durability would emerge. However there is considerable agreement over the significance of the major durability issues, and the combination of measures which are necessary to mitigate these problems.
- The data set provides a valuable reference point for bridge engineers to take an overview of the situation in their own country, and contrast it with the situation in other countries with similar conditions but with perhaps alternative approaches to mitigating durability problems, which may warrant closer examination.

Regarding use of innovative methods for maintenance or repairing

- The major inspiration for proposing new alternative methods were considerations about the free traffic flow and the reduction of repair cost.
- The use of new organic materials for repairing damages is a common innovative alternative.
- Frequent proposed recommendations to avoid typical problems were: avoiding bridge joints or mid span hinges and bridge parts accessibility for maintenance and repairing.

Regarding Bridges Management Systems prioritization methodologies:

- Network level analysis is essential to identify investment candidates that will maximise the return from available funding levels.
- Consistent, current and reliable inventory and condition data are essential.
- Automated Bridge Management Systems are required, for all but the smallest networks, to facilitate the necessary data analysis and reporting functionality.
- Various prioritization methodologies and attendant factors have been adopted by the surveyed jurisdictions however condition/deterioration is the primary factor in the surveyed systems.
- All surveyed countries conduct a manual review of the system derived investment candidates to take account budgetary limits and aspects of operation and maintenance of the road works not considered in the automated analysis. The primary reasons for modifying the investment candidates are imposed budgetary limits or operational matters that dictate a diversion of funding to other infrastructure assets.
- Unfunded priorities must be actively and transparently managed to mitigate further deterioration, risk to users and legal liability.