NEW REPAIR AND REHABILITATION METHODS OF ROAD BRIDGES

World Road Association Technical Committee 4.3 – Road bridges
STATEMENTS

The World Road Association is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

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NEW REPAIR AND REHABILITATION METHODS FOR ROAD BRIDGES

Technical Committee 4.3 Road Bridges World Road Association
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EXECUTIVE SUMMARY
NEW REPAIR AND REHABILITATION METHODS FOR ROAD BRIDGES

In many countries, the average age of the road bridges stock is over fifty years, and a large number of the bridges are not in good condition. The corresponding economic issue leads to the need to search for innovative solutions to extend the service life of the bridges and rehabilitate them in the most cost-effective way.

This report draws on the results of an international survey. In a first stage, countries were asked about the most significant degradation problems affecting sixteen different elements of bridge structures.

Based on the responses received, twenty-two cases of degradation were selected affecting mainly reinforced concrete and prestressed concrete bridges. The cases analyzed included: chlorides corrosion of reinforced concrete elements, expansive and alkali-silica reactions, damage to prestressed concrete beams, deterioration of concrete slabs, damage due to fire, damage to bearings, corrosion of metallic culverts.

For each of them, countries were invited to describe the standard repair method used as well as innovative methods that have been applied. The comparison between the methods is made considering the criteria of: reliability, availability, maintainability and safety. The financial aspect and environmental sustainability are also examined on a case by case basis.
CONTENTS

FOREWORD .................................................................................................................................................3

1. INTRODUCTION ........................................................................................................................................5

  PURPOSE ..................................................................................................................................................5

  SCOPE .....................................................................................................................................................5

  LIMITATIONS .........................................................................................................................................6

    Types of degradation ...............................................................................................................................6

    Financial Evaluation .............................................................................................................................6

    State of the Art ....................................................................................................................................6

2. ASSESSMENT .........................................................................................................................................9

3. HOW TO COMPARE REHABILITATION METHODS ..............................................................................9

  GUIDELINES ..........................................................................................................................................9

  PRACTICAL EXAMPLES .......................................................................................................................11

    Method contract ..................................................................................................................................11

    Performance contract .........................................................................................................................15

4. DEGRADATION PROBLEMS QUESTIONNAIRE ..................................................................................16

5. NEW REPAIR AND REHABILITATION METHODS QUESTIONNAIRE .............................................19

6. RESPONSES AND ANALYSIS .............................................................................................................20

  6.1. PRESENTATION OF THE ANSWERS ..............................................................................................20

  6.2. ANSWERS RECEIVED .....................................................................................................................22

    6.2.1 Reinforced concrete bridge element (excluding slab): Chloride corrosion ......................................22

    6.2.2 Reinforced concrete bridge element (excluding slab): expansive reactions (including delamination),

      ASR (alkali-silica reactions) ................................................................................................................25

    6.2.3 Prestressed concrete beams damaged by impact ...........................................................................28

    6.2.4 Degradation of a prestressed concrete beam end .........................................................................31

    6.2.5 Pre-stressed concrete bridge element by post tension (excluding slab): Shear cracking ...............35

    6.2.6 Pre-stressed concrete bridge element by post tension (excluding slab): chloride corrosion with spalling...38

    6.2.7 Tendons chloride contamination ..................................................................................................48

    6.2.8 Corrosion of steel bridge elements (excluding slabs) ..................................................................54

    6.2.9 Fatigue cracks in steel bridge elements .........................................................................................57

    6.2.10 Protective coating defects/failures in steel bridge elements ..........................................................62

    6.2.11 Masonry and stone bridges: waterproofing of fillings ..................................................................66

    6.2.12 Cable bridge element: suspension and stay cables (excluding slab):

      anchoring and mono strands protection defects .................................................................................70

    6.2.13 Concrete deck slab – Underside low cover ...............................................................................75

    6.2.14 Redegradation of a concrete slab ...............................................................................................77

    6.2.15 Concrete deck slab: fire damage ..................................................................................................80

    6.2.16 Infiltration/leaking at the abutment .............................................................................................84

    6.2.17 Rocker Bearings Corrosion .........................................................................................................86
FOREWORD

Dear Reader,

Are you interested in:

• bridge degradation mechanisms;
• bridge rehabilitation techniques;
• innovative methods?

If so then you should find, in the following pages, some interesting ideas to help you in your daily work.

In a large part of the world, huge numbers of bridges were built about 50 years ago. A fair amount of them are now in poor condition and whether the bridges are managed by a public road administration or by a private company it is society (the inhabitants of a country) that must bear the cost of keeping them safe.

Due to increasing financial constraints on society it is usually not possible to simply rebuild bridges. That would be too expensive. Hence, bridge engineers are challenged to be imaginative, to extend the service life of the bridges and rehabilitate them within increasingly tight budgets.

This report will contribute evidence of innovative techniques, mostly for concrete bridge rehabilitation, but also for steel and masonry.

Firstly, you will find descriptions and information on bridge degradation problems that have been considered by 30 bridge owners to be the most important to address.

Secondly, for different specific degradation problems, you will find some rehabilitation methods that have been implemented by different bridges owners to solve the problems, by innovative means or not.

Perhaps you will be fortunate enough to find precisely the rehabilitation method you were looking for. More probably, you will find innovative ideas to be adapted to solve your specific bridge degradation problems.

You will also find general information about the importance of developing an innovative approach in bridge rehabilitation engineering, about the ways to assess those methods, and about who is typically mandated to do that: the road administration, the contractor or the consulting engineer.

Finally, a good knowledge of bridge degradation problems and an appreciation of the difficulties to rehabilitate bridges are essential to the improvement of bridge design, in both developing and developed countries.

All the contributors to this report, from 4 continents, wish you success through your use of this document.
1. INTRODUCTION

PURPOSE

For the cycle 2012-2015, the goal of the strategic theme related to bridges (Theme 4 – Infrastructure) is to improve the quality and efficiency of road infrastructure through the effective management of assets in accordance with user expectations and government requirements, while adapting to climate change and changing energy scenarios and policies.

It is in this context that the Technical Committee 4.3 Road Bridges, through its Working Group 2, has been involved in the Issue 4.3.2 - New Repair and Rehabilitation Methods, and has undertaken:

• a review of the new repair and rehabilitation methods by consideration of their cost-effectiveness, including materials, developed and/or installed and/or studied.
• a review of the methodologies for assessing the new repair and rehabilitation methods and materials.

The report is written for engineers responsible for bridge repair and maintenance needing to choose appropriate rehabilitation methods (e.g. road administration, contractors and consulting engineers).

The goal of this report is to:

• provide more information to assist the engineer selecting the most suitable rehabilitation method for a specific problem;
• propose guidelines for option evaluation, comparing cost effectiveness and the other attributes of alternative methods in a more transparent way, and;
• share knowledge on innovative rehabilitation methods.

SCOPE

This report sets out to present a collation of comparative information related to rehabilitation methods in use, as provided by international participants in response to questionnaires. The report focuses on permanent rehabilitation methods and excludes temporary solutions.

All bridge owners have to face bridge stock degradation. Reduced funding and road congestion impose increasing challenges for the engineer who has to select rehabilitation methods whilst taking into account:

• Reliability: will the technical performance of the method comply with specification requirements throughout the bridge’s lifetime? (This is related also to the robustness of the method.)
• Availability: does the rehabilitation method impose minimal traffic hindrance?
• Maintainability: does the method require minimal maintenance or monitoring during its service life?
• Safety: is it safe in execution and use? Are there any specific safety procedures to be followed during the execution, the inspection and/or the maintenance of the rehabilitation method?
• Cost: is the method acceptably viable, taking account of both initial and lifecycle costs?
• Sustainability: what is the impact of this rehabilitation method compared to others on the lifecycle of the bridge?

The scope of this report also concerns the innovative aspect of each rehabilitation method. Innovation could be embodied in the technique itself, for example, perhaps by the way it takes traffic into account, and/or by the reduction of the ecological footprint.

Faced with similar problems, bridge owners from different countries may use different methods to rehabilitate their bridges. The scope of this report is to compare these methods and to provide information to aid in comparative evaluation. With this report, we hope bridge owners will be better informed to choose the best solution.

LIMITATIONS

Types of degradation

It is not possible to include all bridge degradation problems in this report.

Types of bridge degradations are numerous and various and depend on a multitude of factors including structural types, bridge materials, climatic conditions, traffic loading, design standards, and the quality of construction and maintenance.

For this report we asked to our international World Road Association's colleagues to provide repair methods for some pre-selected bridge degradation problems in response to a questionnaire. This provided a reference basis for the comparison of different methods.

Financial Evaluation

Another limitation concerns the financial evaluation of the rehabilitation methods. It is very difficult to compare prices coming from different countries with different types of contracts. Furthermore, colleagues do not always agree to communicate precise prices due to commercial sensitivity and respect of competitive pricing.

For those reasons, financial aspects of the rehabilitation methods have only been evaluated on a relative basis.

State of the Art

This report is the result of sampling via selective questionnaires and hence is indicative of current practice but is not intended to be completely representative of the state of the art.

THE IMPORTANCE OF INNOVATIVE APPROACH AND TECHNOLOGIES

Evolution can be easily observed in the technical world where a lot of research has brought many technical products in the field of infrastructure. For a bridge engineer, the choice to perform some interventions in place of others can be difficult. We observe management based on conservatism in the road administrations. Despite well-known and documented performance and effectiveness, innovative methods still struggle to be more usually utilised. Why this
“wait-and-see” approach to the use of innovative methods? Maybe it is due to reticence, or disbelief in a better result, perhaps mistrust of the best action to perform.

Nowadays public road administrations all over the world are deeply engaged in solving the problems arising from the aging of infrastructure, from traffic growth, the increase of climate change effects and the need to face environmental goals. An important confirmation of this general address is found in the challenges issued in the European Commission White Paper on Transport (smart, green and integrated transports).

The use of new materials and techniques could make a great contribution to the solution of these problems, to extend the lifetime of bridges as much as possible in the new environmental conditions and to achieve a satisfactory cost-benefit balance. Hence innovation in bridges rehabilitation should be strongly encouraged.

For innovative solutions to be competitive, when comparing different technical solutions it is important to take account of the environmental costs, the future costs of maintenance and the lifetime extension of the structure assured by each solution.

In the field of road bridges, the main challenges for innovation should be:

- enhancing durability and extending service life;
- developing simple and efficient methods for monitoring and assessing structures;
- warranting the bridge performance under all weather conditions;
- sustainable design with resource and energy efficiency in construction and maintenance, and virgin material reduction by substitution or recycling.

In the field of concrete materials, the main objectives should be:

- developing sustainable UHPC, using supplementary cementitious materials (SCM) for replacing cement and fine virgin aggregate.
- as a matter of fact, the environmental impact of current, state-of-the-art UHPC is up to 2.5 times greater than with conventional concretes, but about 50-60% reduced impact can be achieved by sustainable UHPC, mainly by replacing cement by SCM from waste.
- developing lightweight self-compacting sustainable concretes recycling relevant elements of the existing structures. The innovation should study the possible combination of recycled concrete aggregates with light ones in order to obtain the best results for lightness requirements, mechanical properties and environmental impacts, minimising the huge CO₂ emissions due to the production of expanded clay and counterbalancing them with a very green operation (the use of recycled concrete).
- developing innovative fibre-reinforced cement-based materials, improving synergetic effects between nanoparticles and fibres for enhancing the mechanical performance, especially flexural strength and durability.

The use of such concretes could have great importance in the rehabilitation of reinforced concrete, pre-stressed concrete and steel-concrete bridges for enhancing their durability, resistance to environmental attacks, or reducing the self-weight of the structure.
As far as concern the new materials and techniques, composite materials could offer clever and reliable solutions for reinforcing, degradation or increasing the ultimate resistance of concrete bridges.

The CFRP (carbon fibre-reinforced polymer) have today a large support of experimental researches and practical applications: they can be used not only with a passive behaviour as reinforcing elements but even with an active role in prestressing concrete [1], [2]. To solve the problems of adhesion CFRP-support at very high temperatures or when exposed to UV rays, new composite materials are now available with fibres (glass, carbon or steel fibres) in an inorganic matrix, like FRCM materials (fibre-reinforced cementitious matrix). These techniques are very recent but some good guides for their use are already available, like the ACI 549.4R-13.

For steel structures new coating products and application techniques should be performed to enhance durability and reduce impacts on the environment and traffic.

In the field of monitoring, the recent development of energy efficient electronics at various technological levels from design to materials and circuitry has opened new possibilities for data analysis and wireless sensing. The power needs of wireless sensor networks (WSN) as well as small scale consuming electronics, typically few hundreds of microwatt, are in recent years being addressed by harvesting-generator capability. These capabilities have been demonstrated in many laboratory prototypes able to transform vibrations into electricity, but real applications are still lacking because of the difficulties in transforming random vibrations into electricity.

**METHODOLOGY**

In T.C. 4.3, Group 2 members were involved with issue 4.3.2: “New repair and rehabilitation methods”.

There are different ways to collect information related to rehabilitation methods. For example by issuing an open questionnaire to the Association’s members. This was done during 2004-2007 cycle for the report “Increase of durability and lifetime of existing bridges” [3], published in 2012 as a review of different case studies.

We decided to propose some bridge degradation problems to PIARC colleagues and use a questionnaire to ask how they repair them. This procedure allowed comparison of different methods on the basis of the same problem.

Group 2 members established a first questionnaire listing 16 different categories of bridge elements. A bridge element is a structural element made of a specific material. For example concrete deck slab and steel deck slab are two different categories of bridge elements.

For each category group 2 members were asked to propose the most relevant degradation problems to be examined from the point of view of repair and rehabilitation. They were also asked to select the 5 most important categories. This questionnaire is explained in chapter 4.

It was sent in French, English and Spanish to all members of TC 4.3 and 30 answers have been received from 22 countries.
Based on the information in those responses, group 2 members selected 41 degradation problems and prepared a second questionnaire. During this preparation, it was necessary to reduce the list to 22 problems.

For each degradation problem, a real case (problem description) was presented by group members.

This second questionnaire, explained in chapter 5, presents those problem descriptions. It was sent in French, English and Spanish and answers were received from 12 countries, detailing 59 standard methods and 48 innovative methods.

This report gives the synthesis of all these reported methods related to the different problem descriptions.

For each problem description, the different rehabilitation methods are compared, analysing the different aspects detailed in Scope chapter.

2. ASSESSMENT

Our reflections could guide bridge engineers towards a process for assessment of appropriate methods. Depending on the situation, different ways are possible to assess the various methods to repair or rehabilitate parts of bridges. Roughly they can be synthesised at the end of a comparative exercise, by looking at the net results of an “Advantages/Disadvantages” matrix.

One way to assess the repair/rehabilitation methods is to compare product quality and technical performance, based mostly on documentation, papers, and sometimes on personal experience. The control during the project is focussed on the product.

Another way to assess is to question functional performance; how a certain intervention could achieve long term and efficient results. This may require a deeper reflection including how to deal with the intrinsic causes of material degradation. It will be necessary to identify the risk of the different methods regarding different performances including durability. The control during the project has to be focussed on the identified risk.

For either of these two approaches – product-quality assessment or method assessment – after the assessment of the various methods, they must also be compared in terms of some general parameters: primarily the cost (construction, and long term), but also others such as sustainability, technical performance, and all aspects related to the users and the operation level. These two latter aspects have become more important nowadays. Each method must be assessed prior to comparing them.

3. HOW TO COMPARE REHABILITATION METHODS

GUIDELINES

Once the bridge degradation is well identified and the technical suitability of the method assessed, the bridge engineer will probably have to choose between several rehabilitation methods.
This is quite difficult because the comparison relies on different aspects combining technique, economy, environment, traffic etc.

The cost effectiveness is generally the first way to perform this comparison. The cost of a rehabilitation involves the cost of the rehabilitation itself but also the cost during the possible maintenance of this rehabilitation. Extra cost must also be included as traffic impact and signage, detour, temporary works, communication to road users, during both the rehabilitation and its possible maintenance. This cost will be analyzed in regard of the increase of the lifetime of the bridge. This value is difficult to determine. Firstly, the remaining lifetime of the bridge is not well known. From a general point of view, the lifetime is strongly dependent on the bridge maintenance and the evolution of traffic and environmental constraints, but these are unknowns and their estimation can only be approximated. Secondly the impact of the rehabilitation on the remaining lifetime must also be evaluated, with the same kind of incertitude. When this lifetime is used in an economical model, one must keep in mind the high uncertainty of this parameter.

The benefit of the rehabilitation may be more important than just the increase of the lifetime. It could also increase the service level of the bridge (larger number of lanes, increased load capacity etc.).

Sustainability must also be taken into account nowadays. First, the potential influence of climate change must be estimated. However, without actual knowledge on climate change impact, this remains a difficult step. A recent report from the World Road Association [4] concludes that the relationship between deterioration and damage of existing bridges and climate change is currently unknown and that further study of climate change will certainly lead to a deeper understanding of various impacts caused by climate change on bridge structures.

Sustainability must also be examined in regard to more short-term aspects:

- noise level;
- visual aspect;
- water preservation;
- waste product (lead etc);
- carbon foot print impact, and;
- embodied energy.

Comparing all these parameters to choose the best rehabilitation method may be done using a RAMS (Reliability, Availability, Maintainability and Safety) Assessment. This method needs to evaluate:

- reliability: technical performance of the rehabilitation method during all the lifetime. This is related to the robustness of the method to comply with the technical specifications during its service life;
- availability: impact of the rehabilitation method on the bridge service level during the works (traffic impact, disruption, etc.);
- maintainability: need for a specific maintenance or a monitoring after the bridge has been rehabilitated;
- safety: need for specific actions to be taken during execution, inspection and maintenance to ensure safety of workers.
These aspects are evaluated for example with 3 levels: -, +/- and +, in order to build a trade-off matrix of advantage/disadvantage. Financial and sustainability aspects may also be added, for example:

<table>
<thead>
<tr>
<th></th>
<th>Reliability</th>
<th>Availability</th>
<th>Maintainability</th>
<th>Safety</th>
<th>Financial</th>
<th>Sustainability</th>
</tr>
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<tbody>
<tr>
<td>Method 1</td>
<td>+</td>
<td>-</td>
<td>+/-</td>
<td>+</td>
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<td>Method 2</td>
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</tbody>
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This comparison between rehabilitation methods may be done by the road administration or by the contractor depending on the country. The next section develops a quick review of several processes.

**PRACTICAL EXAMPLES**

Two kinds of procedures exist to invite contractors to tender for rehabilitation work.

The first one is based on a specification describing the method to be used to rehabilitate the bridge. The method is selected by the road administration.

The second one is based on a specification which defines the objective of the rehabilitation. Each contractor will select the best method to be used to rehabilitate the bridge.

The following sections describe how it works in different countries.

**Method contract**

**Belgium**

Rehabilitation method is selected by the road administration.

For classic repair works, the project is prepared by the local offices of the Road administration (SPW).

For specific repair works, the technical expertise department of the road administration is involved in the definition of the project. Works may be specific regarding the way to take traffic into account but also regarding technical difficulties highlighted by the inspection procedure.

Rehabilitation methods are selected on the basis of administration experience.

Products to be used are described in both general and particular items of the specification documents.

The way the contractor will use the products on the field are generally his own responsibility. For each product, there are performance criteria.

Nearly every time, the contract is signed with the contractor with a tender in conformity to specification and with the lowest price.
Denmark
What is needed to be repaired on each bridge is decided by the Road Directorate based on knowledge gained during the bridge inspections, also performed by the Road Directorate.

The individual repair project is sent out in tender as a turnkey project with a very short description of what to be done on each bridge e.g. replacement of waterproofing, replacement of edge beams and guardrails, concrete repair on soffit and piers etc.

The contractor is not free to choose the repair method. In his preparations of the detailed project the contractor is required to respect the Road Directorate’s standards called “The Road Rules” and only to use products listed in the Road Directorate’s list of Approved products.

The contractor is free to choose within the financial year the starting date of the repair work but the duration of the repair work is part of the contract so he cannot decide how many weeks it will take to do the work.

The contractor is also free to choose working methods as long as the final product is in conformity to the Road Rules and other national standards.

Handling of traffic during the repair work is also the contractor’s responsibility and is always done in close cooperation with the road authority and the police.

Italy
When the repair works have no high costs and there are no doubts about the repair techniques to be applied, a detailed project is prepared by the technical offices of the road administration. The repair methods are selected mainly on the basis of previous experience of the quality of the products, on the reliability of the techniques and the required urgency for the rehabilitation.

The types of products and the techniques are described in the specification and general condition documents of the tender.

Japan
The aging of road infrastructures built at the time of high-economic growth after the World War II progresses rapidly in Japan. In order to reduce maintenance and re-construction cost in the future, we are now seeking a conversion to preventive maintenance which is carried out when the damages are slight, contrarily to breakdown maintenance which renovates infrastructures after the damages become serious.

The periodic inspection once in a five year period is carried out for the bridges of national highway administered by Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Long-term rehabilitation plan is scheduled based on the results of the inspection and rehabilitation works are executed. Although the works may be contracted including detailed design in some road administration’s projects, designs are usually performed by design companies.

At present, public works tenders are usually carried out in open competitive bidding in Japan, and in recent years, almost all tenders are applied in total evaluation bidding method. Total evaluation bidding method is a new method to evaluate the elements considering not only the price but also in terms of work, performance, safety and so on. This method tries to select the
successful bidder more globally compared to the conventional bidding method which was a competition on price only.

In addition, to apply new technologies, there is a New Technology Information System (NETIS) maintained and operated by MLIT as a database for the purpose of sharing and providing information about new technologies. The adoption of technologies registered with NETIS can be evaluated in the total evaluation bidding method in some cases. This system encourages opportunities to promote the introduction of the new technologies.

**United Kingdom**
The highway structures on UK major routes (classified as Motorways and Trunk Roads) are administered for central Government by the Highways Agency (HA).

The HA has subdivided the route network and employs managing contractors for the management and maintenance of each area for a fixed term. Each contractor has design, build and operational responsibility for their assigned section of route. Their contractual agreement sets requirements for factors such as route availability, structural performance, durability, life to next maintenance. They work according to technical and administrative standards set by the HA in the Design Manual for Roads and Bridges.

The maintaining Contractor procures investigation, selection and design of rehabilitation works according to the required performance of each structure. This may need prior technical approval from HA depending on the nature of the works or program. The maintaining contractor will then construct the remedial works and may employ specialist subcontractors if needed. The works are usually defined by a method and product specification.

Highway structures on all other UK roads are administered by local authorities and in some cases by other bridge owners, such as Network Rail and Canal and River Trust. They follow best practice guidance published by the UK Road Liaison Group, broadly following HA technical and administrative standards.

The diverse authorities adopt a range of different approaches to the specification and procurement of repair works. Many authorities have term contracts for construction, or for design and build, whereas others will procure works through tenders for individual work packages. Very few contracts would be to performance specifications.

**Canada - Québec**
After the selection of different bridges on the basis of the needs identified during the inspection program, a first draft of the project is presented at the first year of a 5-year planning program. Internal resources (Ministry), or external resources (engineering firm) with the supervision of Ministry staff, perform detailed condition surveys and realise (or mandate specialised laboratories to realise) investigations or expertise in order to present the most pertinent and cost-effective ways to re-establish the bridge in a very good condition.

When the final concept has been approved, the final documents – drawings / special provisions/ administrative regulations - are prepared. After a final verification by the Ministry administration staff, the project goes out to tender as prepared. The tender documents are downloaded on a special website where the contractors – with a certain fee – can obtain them. The bidding process
period can vary, from two to several weeks depending on the importance of the project. After the
closure of the bidding process, the propositions are analysed for their conformity and the final
selection of the contractor is made on the basis of the lowest cost conform bid.

It is possible for some projects that two alternatives are specified in the documents. The
contractors can bid in these cases on just one solution or both.

In conformity to the contract documents, there are two delays – a short one and a long one - that
have to be respected by the contractor. The short delay corresponds to the execution period of the
project. If the delays are not respected, some penalties can be imposed.

**South Africa**

Unless an incident of catastrophic nature occurs (i.e. accident, fire or flood damage that require
immediate intervention by way of emergency repairs), rehabilitation and repair of structures on
the National Road network in South Africa is normally the result of periodic bridge inspections
that are performed under appointment of suitably qualified Engineers with a minimum design
experience history (typically 10 years for a structure of Strategic importance).

Based on the outcome of these regular inspections, structures in the same geographical area are
grouped together to form a single implementation project. Through a tender process, Consulting
Engineering Service providers are then procured and after detailed inspection of the identified
failures and risk areas, they will proceed to compile tenders for the bidding process for Contracts
for Work execution based on the Committee of Land Transport Officials (COLTO) Standard
Specifications for Road and Bridge Works supplemented by series 12 000: Specifications for the
Rehabilitation of bridges for State Road Authorities (dealing with Access, Demolition And
Removal Of Structural Concrete, Surface And Structural Repair Of Concrete Members, Grouting
And Crack Injection, Sprayed Concrete, Protective Coatings And Treatments, External Bonding
Of Steel Plates, Bars and Sections, Replacement And Repair Of Ancillary Bridge, Survey And
Testing, Jacking).

For structural repairs, a specific design will be prepared for the bidding process. Prospective
tenderers are obliged to submit prices for this method (postulated tender) but alternative tenders
may be entered and will be considered if they are more cost effective.

For the execution of the rehabilitation and repair works, the specifications for the bidding process
will be based on a combination of prescribed method and performance criteria.

Generally a minimum requirement will be for products to adhere to a national or international
institution for the promotion and maintenance of standardisation and quality in connection with
commodities and the rendering of services (e.g. ASTM, AASHTO, SANS, SABS, etc). This
would typically apply to cementitious mortar or concrete, Aggregates, Admixtures, mixtures,
Epoxy systems, Bonding agents, etc.) In certain instances minimum requirements in terms of
mix proportions and strength requirements will also be specified (e.g. repair mortar shall comply
with the strength requirements of the concrete in the structural member to be repaired).

Specific requirements for certain processes will also be detailed and compliance will be enforced
during construction phase (e.g. preparation of repair surfaces and concrete contact surfaces,
batching, mixing, sequence of execution, surface finish, curing and protection, cementitious
mortar or concrete repair, epoxy mortar repair, grouting of dowel bars and anchors into holes and pockets, working characteristics of grout). The contractor however remains responsible for the final design and performance of the repair materials.

Furthermore, provision is also made for Proprietary Repair materials / systems to be utilised based on the past experience of the quality and performance of these systems used under similar circumstances / industry track record. This would typically apply to Protective Surface Coatings, Proprietary cementitious repair compounds, epoxy mortars, grouting, crack repair and crack injection. The Consulting Engineer will consult with the Client (Road Authority) in this regard to ascertain the preferred methods.

The repair systems could typically be provided by well-known established companies. In order to allow new players to enter the market, provision would also be made for tenderers to propose alternative Repair Systems in which case the tenderer shall submit details of the Repair System to the evaluating authority for approval during the tender period. The onus is on the tenderer to prove that the alternative system is suitable for the intended application. During execution phase, the product shall be applied strictly in accordance with the manufacturer's instructions. This applies to Batching and mixing, Application of the repair material, Protection and curing, Packaging, handling and storage, etc.

Due consideration will be given to the ease of implementation of the repair method and design. The environmental, health and safety and traffic impact of the various methods are also taken into account before the final selection of repair method and the bidding process commences.

**Performance contract**

**Netherlands**

In the Netherlands performance contracts contribute to the overall management and maintenance of the road network in cooperation with contractors. In the contract description of the performance, the emphasis is on maintaining the “daily functioning and performance” of the network and controlling the risks of the network performance, besides “maintaining a certain state” of the network assets.

Performance contracts leave the daily management and amount of maintenance of the network to the contracted party. In the contracts the risks to the network are identified to get and keep e.g. traffic flow and safety at a desired level. A specific form of risk analysis, Failure Modes and Effects Criticality Analysis (FMECA), focuses on the physical condition of objects, e.g. bridges and viaducts.

The Dutch Standard NEN 2767-4 indicates the condition of building and installation components in an objective and unambiguous manner. This standard is used to define a “fitness level” in the contract for both the start (the inventory of contract) and the end (completion) of the contract. It is up to the contractor to get arguably the aspired “fitness level” upon completion.

The main change using performance contracts is that the contractor can choose his own inspection and maintenance method. He only has to prove that he has delivered the promised quality. He performs these checks himself. Quality assurance is the responsibility of the contractor.
Italy
In the case of important rehabilitation projects, because of the extent and severity of the degradation problem, a preliminary choice of the repair methods to be used is made by the technical officers entrusted with the bridge maintenance, based on their experience, but the contractors have the possibility to propose other products and/or techniques. The proposition of the contractor is then based on the documentation presented to prove the quality of the products, the reliability of the techniques and the previous experience in their application in bridge repair works. The final choice is made from a score tender considering the economic part and the quality of the system / products (generally 30-50%, depending on each particular case).

4. DEGRADATION PROBLEMS QUESTIONNAIRE

The main idea of this report is to compare new repair and rehabilitation methods based on real cases. Group 2 members have proposed cases presenting a specific bridge with a specific degradation.

Therefore the first step was to select the degradation problems to be considered. A first questionnaire was developed in English, French and Spanish and sent to World Road Association TC 4.3 members. This questionnaire (Appendix 1) presented several bridge elements categories and for each of them asked for the most relevant degradation problems to be examined from the point of view of repair and rehabilitation methods. The five most important bridge elements categories were also to be selected.

The bridge element categories were:

- reinforced concrete bridge element (excluding slab);
- prestressed concrete bridge element by pre tension (excluding slab);
- prestressed concrete bridge element by post tension (excluding slab);
- metallic (steel, aluminium) bridge element (excluding slab);
- wood bridge element;
- masonry and stone bridges;
- cable bridge element: suspension and stay cables (excluding slab);
- concrete deck slab;
- steel deck slab;
- deck waterproofing;
- bridge pavement;
- expansion joint;
- bearings;
- abutment;
- embankment, and;
- culverts (concrete and/or steel/soil structure).

30 answers were received from 22 countries by the end of June 2012.

Those responses were analyzed by Group 2 members and they selected 46 degradation problems related to the different bridge elements categories. They are presented regarding the number of votes/tips for each of the bridge element categories:
Reinforced concrete bridge element (excluding slab) – 14 tips:
• Expansive reactions (including delamination)
  > AAR (alkali-silica reaction)
  > DET (delayed ettringite formation)
• Corrosion of rebars
  > Carbonation
  > Chloride ingress
  > Low cover
  > Short durability of repairs
• Cracking
  > Structural (deflection, shear, etc.)
  > Materials
  > Internal - Shrinkage
• Degradation at beam ends

Prestressed concrete bridge element by pre tension (excluding slab) – 14 tips:
• Corrosion of strands with or without prestressing losses
• Fire damage
• Exposed and/or damaged strand due to impact
• Degradation at beam ends
• Cracking
  > Structural (deflection, shear, etc.)

Prestressed concrete bridge element by post tension (excluding slab) – 9 tips:
• Corrosion
  > under tension (defective sealed ducts)
  > chlorides
• Cracking
  > Longitudinal
  > Transversal
• Injection
  > Ducts not sufficiently filled with mortar
  > Bad quality of ducts injection

Metallic (steel, aluminium) bridge element (excluding slab) – 9 tips:
• Corrosion
  > Connections – pack rust (gusset plates)
  > Loss of section
• Fatigue cracks
• Protective coating defects / failures
  > Management of recoating residue (dangerous material)

Expansion joint - 8 tips:
• Infiltration / leaking
• Transition problem Cracks at the interface pavement – joint
• Impact, noise (comfort)
Concrete deck slab – 8 tips:

- Edge degradation
  > Barriers → connection with deck
  > Waterproofing
- Cracking:
  > Cracks near shear connectors
  > Cracks in joint between prefabricated slab
  > Thermal cracking
- Concrete damaged
  > Chlorides
  > ASR
- Fire damage

Deck waterproofing – 7 tips:

- Problems of adhesion
  > Metallic decks
  > Steep slope decks
  > Air bubbles underneath due to not enough heating or too much heating
- Degraded waterproofing (Leakage)
- Insufficient drainage (including near expansion joint)

Masonry and stone bridges – 5 tips:

- Damaged Waterproofing
  > Waterproofing of the fillings
  > new waterproofing
- Delamination
- Splitting arch-arch barrel – spandrel

Cable bridge element: suspension and stay cables (excluding slab) – 4 tips:

- Anchoring defects (corrosion, Badly wedged strands, fatigue, …)
- Degradation of protection or unprotected strands, ducts, (Insufficient seals)
- Corrosion
- Cables excessive vibration

Bearings – 3 tips:

- Bearing degradation

Abutment – 3 tips:

- Unequal settlement
- Scouring / undermining

Embankment – 3 tips:

- Embankment degradation

Culverts (concrete and/or steel/soil structure) – 3 tips:

- Deformation of steel culverts
- Corrosion (steel)
• Leaks of backfill soil
• Separation of seams

Wood bridge element – 2 tips:
• Rot / decay → high humidity in weak points
• Loose connections
• Coating degradation due to UV rays (protective coating failure)
• Insects and marine borers
• Delaminations (glulam)

Steel deck slab:
• Orthotropic steel decks
  > Fatigue
  > Localised deformations

It was on the basis of this list that the main questionnaire was prepared, as described and explained in the next section.

This preliminary list is also interesting in itself because it represents degradation problems that seem the most relevant for the 30 respondents.

5. NEW REPAIR AND REHABILITATION METHODS QUESTIONNAIRE

The main questionnaire approached the basic objective of this report which is to study and compare different repair and rehabilitation methods in use worldwide, with an emphasis on innovative techniques.

A questionnaire remains the most effective method to share information on international practitioners’ experience. To facilitate the task of the respondents, it was decided that the main questionnaire should present questions against a series of practical examples, each illustrating one of the degradation problems selected from the first questionnaire. The selected degradation problems are described in section 4 above. The practical examples were proposed by group 2 members based on their experience.

It was important that the main questionnaire should collect sufficient information to enable comparison between the methods for repair and rehabilitation. In particular each innovative technique was to be evaluated against the equivalent standard method in terms of its performance in the following parameters:

• Reliability;
• Availability;
• Maintainability;
• Safety;
• Cost, and;
• Sustainability.

So the questionnaire was designed in a template format presenting a series of standard questions for each case. The respondents were thereby asked to identify whether they had experience of
solving each problem, and if so then to provide comparative information on methods, effectiveness and cost. Anonymity was assured to encourage free reporting of lessons learned. The standard questions in each case included:

- Did you have a standard method (proven method in your country) for this problem? If ‘Yes’, describe it briefly.
- Describe your innovative solution.
- Pictures of the innovative solution.
- In which way is it an improvement of your standard method (technical, lifetime, traffic impact, increasing load capacity, etc.)?
- What’s the financial impact of this solution comparing to the standard method? Explain?
- What makes it a sustainable method (new material, recycling, etc.)?
- Describe the way you assess this innovative method (inspection, measurements, structural effectiveness, etc.).
- General appreciation of the method.
- References.

After iterative reviews of the draft versions, the final version of the main questionnaire was sent to all TC4.3 members for their distribution to the volunteer participants in their home countries.

6. RESPONSES AND ANALYSIS

6.1. PRESENTATION OF THE ANSWERS

Participants from 12 countries (Argentina, Belgium-Wallonia, Canada-Quebec, Denmark, France, Italy, Ireland, Japan, Poland, Spain, United Kingdom, and USA) responded, providing details of 59 standard and 48 innovative techniques for repair and rehabilitation.

The results are presented and discussed in the sections below.

The next table gives an overview of the answers received.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Section</th>
<th>Degradation problem</th>
<th>Standard method</th>
<th>Innovative method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.2.1</td>
<td>Corrosion of rebar on pier cap and columns from chlorides due to expansion deck joint leaking. Restricted access to the upper face of the pier cap</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>6.2.2</td>
<td>On the edge beams of the bridge are a lot of cracks with white precipitations which is estimated to be caused by AAR-reactions mainly. Chlorides and frost/thaw is also a part of the problem</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>6.2.3</td>
<td>Girder 1 of span 2 was hit by a sand truck. Approximately 20 feet of the girder was damaged. All of the bottom strands were exposed for approximately 10 feet of the damaged area directly above a driving lane. None of the strands appeared to be damaged by the impact.</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>6.2.3</td>
<td>Impact caused by an excavator arm. Concrete pluck on the first two beams. Length of the pluck between 250 - 350cm, approximately 70cm from the centre of the span, broken up to 80% strands on first beam, broken passive reinforcement. Previous reparation is visible.</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>6.2.4</td>
<td>Degradation of prestressed concrete beam ends. Probable loss of tension and shear capacity at the beam end.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Problem</td>
<td>Section</td>
<td>Degradation problem</td>
<td>Standard method</td>
<td>Innovative method</td>
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<tr>
<td>---------</td>
<td>---------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>----------------</td>
<td>------------------</td>
</tr>
<tr>
<td>6</td>
<td>6.2.5</td>
<td>Shear cracking - prestressed concrete beam end. Crack width up to 0.6 mm</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>6.2.6</td>
<td>Degradation of prestressed concrete beams – water with chloride ingress through anchorage. Some strands are broken.</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>6.2.7</td>
<td>Due to leakage in the ageing waterproofing, water with de-icing salts penetrates the deck mainly under the gutter. Water arrives in the anchorage and follows the tendons. After performing a few window openings, it appears that tendon corrosion is still moderate but that chloride content is too high: 0.05 to 0.17 % (m/m grout, acid extraction). Cement content is about 70 % (m/m grout). There is nearly no void in the metallic duct.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>6.2.8</td>
<td>Rainwater penetrated between steel members and concrete deck and caused corrosion. Loss of section is proceeding and vertical members might be at risk of failure.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>6.2.9</td>
<td>Some typical examples of fatigue cracking which has occurred in steel bridge.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>6.2.10</td>
<td>Examples of protective coating failures which have occurred in steel bridges. How to repaint with a long lifespan, reduced traffic impact, toxicity of fumes, …</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>6.2.11</td>
<td>The distribution of moisture in the masonry arch bridges is mainly initiated by infiltration from the platform, which are transmitted through the granular filling to the structural elements of masonry, generating a series of processes of alteration of these materials and, therefore, affecting their resistant and durable behaviour. The solution must find a way to stop the water through the fillings of a masonry arch bridge.</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>6.2.12</td>
<td>Degradation of protection, or unprotected strands, anchoring defects</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>6.2.13</td>
<td>Delamination of concrete – underside of the deck – due to too low cover. Carbonation behind the reinforcement.</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>15</td>
<td>6.2.14</td>
<td>The deck slab is contaminated by chloride on all the thickness of the slab. Chlorides content reach 0.3% (m/m concrete – acid attack). Carbonation is less than 8 mm, Renewing waterproofing has stopped new water and chloride ingress. But after 10 years concrete spalling due to corrosion started again while waterproofing is still in good condition. What do we have to do to avoid corrosion due to chloride still present in the concrete ?</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>6.2.15</td>
<td>A stolen car was placed in the tunnel and set on fire. Severe damages to the concrete both on slab and walls resulting in large areas with exposed reinforcement.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>6.2.9</td>
<td>Typical examples of fatigue cracking which has occurred in orthotropic steel deck</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>6.2.16</td>
<td>Water is leaking at the joint in the low corner of the bridge. The bridge is not built with a specific expansion joint because of the relative short span only a primitive bitumen seal is placed. The problem is critical because the water will damage the anchorage zone of the prestressing steel.</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>6.2.17</td>
<td>Upward corroded roller bridge bearings. Due to leaking expansion joints the roller bearings at the abutments have corroded. The repetitive motion of the bridge produces a waver like corrosion that pushes the bearing up to 5 cm upwards. Cleaning the bearing (by sandblasting) lets the deck slab fall down with 5 cm, destroying the expansion joint and a effecting a dangerous drop/elevation in the drive way.</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
Problems 3 and 4 were merged and so were 10 and 17 in the rest of the report.

Respondents classified the method as standard or innovative depending on their own experience.

### 6.2. ANSWERS RECEIVED

#### 6.2.1 Reinforced concrete bridge element (excluding slab): Chloride corrosion

**Description of the problem**

In multi span simple supported bridges a water tight expansion joint between the spans is needed in order to prevent chloride contaminated surface water to reach the pier caps and columns under the expansion joint. When the expansion joint starts to leak due to ageing, surface water and de-icing salt has free access to the pier cap and columns. Within a short period of time the reinforcement in the structure will start to corrode resulting in a surface of the structure with visible corroded reinforcement on the top and vertical faces of the pier cap (*illustration 1*).

![Illustration 1 - Pier cap with water ingress through the expansion joint](image-url)
Methods available
In order to repair damages like this, a two-stage rocket must be fired. Stage one is to stop the cause of the damages which means to make the expansion joint water tight again. Stage two is to repair the areas of the pier cap which have been affected by the chloride contaminated surface water.

Method A – Concrete repair - Denmark
A standard method to make the expansion joint water tight again is simply to repair it or replace it with a new one of the same type.

Mainly two types of expansion joints are used. One is an asphaltic plug type, and the other is a mechanical joint. Both types can easily be repaired. Cracks in the asphaltic plug type can be filled with hot liquid bitumen and a leaking mechanical joint can be repaired by replacing the rubber gasket.

One of the problems related to expansion joints is that the service life is short in many cases, especially for joints of asphaltic plug type. In addition, the expansion joints require regular maintenance. For bridges in service, the movements are restricted to primarily temperature effects and movements from traffic loading, since creep and shrinkage mainly take place in the early stage.

For some bridges, as an innovative method, it is possible to reduce the number of expansion joints and in that way halt ingress of additional chlorides from the de-icing salts (illustration 2). For the joints that cannot be omitted a durable solution with mechanical joints should be installed (illustration 3, next page).

Illustration 2 - Suppression of expansion joint

In order to repair the pier cap a standard method will be to:

- remove chloride contaminated concrete by water jetting or manual chiselling (illustration 4, next page).
- clean the reinforcement and concrete (not required if water jetting has been utilized)
- shotcrete or casting against formwork of the areas involved.
- consider surface treatment.
The advantages are primarily that joints that are eliminated (continuity of the slab) will require less future maintenance. In addition high quality mechanical joints have a significant longer service life compared to e.g. asphaltic plug joints.

When the joints are watertight the future chloride impact and possible frost-thaw damages will be halted. In this way, a significant reduction of the future maintenance costs can be obtained. In addition, the service life for the remaining expansion joints is increased from 5-10 years (asphaltic plug joints) to 30-40 years when replaced with mechanical joints.

**Method B – Cathodic protection - Japan**

An innovative solution to be applied when repairing the pier cap is to install an active cathodic protection system. Cathodic protection *(illustration 5, right page)* is an electro-chemical way to stop corrosion in reinforcement in areas of the pile cap which cannot be removed by water jetting or manual chiseling.

Cathodic protection is a good solution as long as it works. A disadvantage of cathodic protection is that it needs to be monitored very frequently because as soon as a failure in the installation occurs corrosion in the reinforcement starts immediately.
Conclusion and Comparison of the methods
The first step to be taken for both methods is to make the joint water tight in order to stop the cause of the damage to the pier cap and that will be the same for both methods. If possible it could be advantageous to reduce the number of expansion joints.

When it comes to the repair of the damaged pile cap method A is a well proven method which can last for a very long time if it has been done in the right way. The repair needs no further attention apart from the regular inspections done to the bridge structure as a whole. Method B, the cathodic protection, needs to be monitored frequently throughout its service life. That requires a lot more manpower over time. There can be cases where method A is impossible to perform in order to repair the pile cap and in those cases cathodic protection can be a good alternative. Our recommendation is always to consider method A before choosing method B.

6.2.2 Reinforced concrete bridge element (excluding slab): expansive reactions (including delamination), ASR (alkali-silica reactions)

Description of the problem
In order for alkali-silica reactions to take place inside the concrete, three different factors must be present at the same time. They are reactive porous flint (present in the aggregates mainly in the sand fraction); alkalis (coming from the cement and deicing salt) and, as the third factor, water. During the alkali-silica reaction the reactive sand in the aggregates expands creating an expanding product called alkali-silica gel which creates cracks in the concrete element. As time goes by, the gel will be visible as white crusts on the surface of the concrete element.

On a bridge, the edge beams in particular are vulnerable because water and deicing salt will always be present and if the sand used in the concrete contains reactive porous flint all three factors are present for the reaction to proceed.

In illustrations 6 and 7, next page, below is an edge beam on a concrete bridge shown with severe attacks of alkali-silica reactions.

Methods available
One method to stop the alkali-silica reactions to take place is to control and exclude one of the three mentioned factors from the structure. The easiest factor to handle in order to stop the alkali-silica reactions is to keep water away from the structural element in question.
Method A – Thin polymer cement concrete layer - Belgium
An innovative solution can be to apply a water tight surface protection to the edge beam. In practice it can be done by applying two layers of thin polymer cement concrete (PCC) with glass fibre tissue. All the external surfaces of the edge beam are treated by a flexible coating made by a double thin PCC mortar and a glass fibre tissue (150 gr/m²) between each layer. The tissue is placed on the fresh first PCC thin layer.

The method is fast and easy to perform and also relatively cheap. It can only be used in the early stage of the degradation process. The method will only stop the alkali-silica reaction and prevent further degradation.
**Method B – Beam edge replacement - Denmark**

In the case the edge beam is damaged by the alkali-silica reactions to an extent where it no longer is useable and need a replacement, a method used in Denmark is presented.

A standard design project has been developed for replacement of edge beams with new in situ cast edge beams (*illustration 8*). The standard project has been carried out since there are many existing bridges constructed between 1965 and 1980 suffering from edge beams in a very poor condition mainly due to chloride ingress and alkali-silica reactions, etc. For edge beams in poor condition, there is a risk of loose concrete dropping down on the traffic below the bridge, and in some cases the edge beams are in a condition no longer able to support the guardrail safely.

The advantage of the solution is that the edge beams will be replaced in a similar way for all bridges not depended on the consultants and contractors involved. The standard project has now been improved by adding polypropylene fibres to the concrete mix. The fibres reduce the quantity and the size of cracks initiated primarily by shrinkage.

The project contains an option for stainless steel rebar (*illustration 9*). The option is mainly used for bridges with heavy traffic close to the edge beams so they are heavily exposed to de-icing salts.
An advantage of the Danish method is that the contractor can reuse their formwork since the technical solution is a standard practice and the cost for consultancy is reduced since the overall design is reduced (illustration 10).

The cost savings for a motorway bridge of around 1,000 m² by using the standard method is estimated to be 15,000 € in reduced design costs and 100,000 € in saved contractor payment because the contractor can reuse his formwork.

Since the contractor can reuse their formwork (steel structures attached to the bridge deck) the CO₂ emission related to fabrication of the steel is reduced and makes it an environmentally sustainable method.

**Conclusion and Comparison of the methods**

Method A is a preservative method that can be used in cases where the alkali-silica problem has been detected before any severe damages could take place. Method B can be used in cases where the structural element is damaged to an extent where a replacement is the only solution. Method A will always be cheaper than method B and also easier to perform. Method B is an interesting way of reducing costs considering that alkali-silica reactions are frequently so advanced that a beam replacement is the only option.

### 6.2.3 Prestressed concrete beams damaged by impact

**Description of the problem.**

The risk of bridges and viaducts being impacted by oversized vehicles is highly probable. Numerous incidents from different counties have been reported where concrete beams and bridge decks have been superficially or structurally damaged in this way.

In most cases, only the first beam was damaged (illustration 11, right page), with the outer reinforcement being either cut or showing severe plastic deformation. The web of the beam shows the typical Δ-shape wedge, but seems to be intact.

In cases where the damage is more extensive, most of the pre-tensioning strands are cut and the web and lower flange of the concrete beam is destroyed (illustration 12, right page).
Methods available
Two countries – Netherlands (NL) and Canada-Québec (QC) - submitted answers, proposing innovative methods as well as standard practices combined with relatively new retrofitting methods.

Method A – Replace concrete with FRP
The standard method for minor impact damage is to remove all the damaged concrete and reinforcement and replace it with new material (concrete and rebar). Cracks are to be injected and in particular cases the web (shear reinforcement) and lower flange can be strengthened with fibre reinforced polymer plates/sheets (FRP retrofit) (illustration 13, next page).

Method B – Replace beam
The standard method for major impact damage is to replace the entire beam and top slab.

Especially in viaducts that are frequently impacted by oversized vehicles, it may be favourable to replace old beams with new beams that have lower flanges that close the entire lower surface of the deck (illustrations 14 and 15, next page).
Method C – Adding external post tensioning

In some cases it is just not practical to replace the entire beam or top slab, either because the extent of damage is cause for consideration / discussion (should an entire beam be replaced because of a few broken strands) or because replacing the beam causes more damage than the impact itself (for instance the beam is situated in the middle of the deck).

In those cases the impact damage is regarded as minor impact damage and repairs would consist of injection of cracks, replacement of damaged concrete and rebar as follows. The loss of pretensioning cables or strands is repaired with:

- external post tensioning of the beams, with standard post tensioning cables (illustration 16, right page).
- external post tensioning of the beams, with fibre reinforced polymer plates (illustration 17, right page).
Conclusion and Comparison of the methods
All the methods have a good reliability, maintainability and sustainability. A choice should be exercised in each particular case, mainly depending on the impact on the traffic and costs.

Method B, with the design of closing the lower surface of the deck, is more relevant to bridges that are frequently impacted.

6.2.4 Degradation of a prestressed concrete beam end

Description of the problem
The problem is the degradation of the end of a pre-tensioned, prestressed concrete bridge beam. The concrete degradation is mainly caused by corrosion of the stirrups confining the main reinforcement (illustration 18, next page). Due to the high corrosion activity, there is a probable loss of tension and a loss of shear capacity at the beam end.
Methods available

Method A – Renewing deteriorated concrete - Japan, Poland, Canada - Québec

All the methods proposed are standard and consist to a selective removal of the deteriorated concrete and its replacement with new material - in restoring the original section, or in adding an additional thickness of concrete (Canada - Québec) or a polymeric material (Japan).

Method B – Renewing deteriorated concrete and FRP strengthening - Japan

Description
Prior to the repair itself, the method includes a detailed investigation by video camera in order to inspect the difficult-to-access parts of the beam end close to the abutment (illustration 19, right page). The prior-to-repair survey can also include a sampling of the affected concrete to measure its chloride content. These material condition surveys are realised to gain the best possible knowledge of these bridge parts and to plan the best intervention.

Inspection between beam end and abutment is made by video scope with special guide device.

The removal of the deteriorated concrete can be done by light hammering, by concrete and rebar sandblasting or waterjet blasting (illustration 20, right page). This last technique for removal the unsound concrete is appropriate for reaching hard-to-access areas and is less detrimental to concrete, rebars and tendons left in place than hammering.

The repair of the deteriorated parts of the beam is performed using different types of material, such as self-leveling concrete or high early strength proprietary polymer cement mortar (illustration 21, page 34).

Some methods for beam end repair can be considered innovative. In Japan, the experimental use of repair material with corrosion inhibitors is being tested to attenuate chloride absorption, to prevent subsequent macrocell corrosion, to get a greater protection in aggressive environments
and to increase the service life between interventions. The addition of carbon fibre reinforced polymer (CFRP) sheets or plates (Japan and Poland) is planned sometimes to complete the intervention, particularly to provide a higher structural performance in the case of a probable loss of tension at the beam end (illustration 22, next page).

Illustration 19 - Investigation behind beam end

Illustration 20 - Damaged concrete removed by water-jet blasting

In Japan, there are ongoing experiments with adhesive materials applying to the interface between chipped concrete surface and polymer cement mortar to increase bonding strength. Also the investigation of FRP sheet to the concrete surface is undergoing which supersedes carbon fibre sheet.

Quality assessment
The investigations before the intervention give a better picture of the condition of the concrete, and help to identify the best solution. In general, the standard methods proposed provide good results.

Advantage/disadvantage
- Reliability: Not exceptional method except for hard-to-access zones. The products utilized have good historical field experience.
- Availability: It is highly dependent on the design of the bridge and on the extent of the degradation.
- Maintainability: No particular maintenance, and regular inspection afterwards.
Illustration 21 - Casting polymer cement mortar

Illustration 22 - Installation of carbon fibre sheet
• Safety during execution, inspection and maintenance: No specific aspect except the need for a platform.
• Financial aspect: The methods proposed are not considered expensive.
• Sustainability aspect: The execution of preliminary investigations and the use of non-standard materials tend to extend the service life of intervention.

**Conclusion and Comparison of the methods**

New aspects of how to perform a standard repair method are clearly popular in beam end repair. Among the proposed answers, there have been new ways to inspect allowing to a better diagnostic of the deterioration problem, and new repair materials intended to improve the service lifetime of the intervention and to minimize the restrictions to traffic and other users. The integration of some relatively innovative ways to realize common interventions, like beam end repairs, are not generally very costly, but have a substantial benefit in long term, considering the strategic structural importance of those bridge parts.

6.2.5 **Pre-stressed concrete bridge element by post tension (excluding slab): Shear cracking**

**Description of the problem.**

On a concrete bridge prestressed by post tension constructed in 1978 (illustration 23), shear cracks are observed at the beam end with crack width up to 0.6 mm (illustration 24).

![Illustration 23 - Overview of the bridge](image)

Illustration 23 - Overview of the bridge

![Illustration 24 - Shear stress cracking at beam end](image)

Illustration 24 - Shear stress cracking at beam end
Methods available

Method A - Cracks injection - Canada - Québec
This method consists in pressure injection sealing of cracks.

Method B – External stirrups - Poland
With this method shear capacity is increase by installation of external stirrups (illustrations 25, 26 and 27).

Illustration 25 - Strengthening of the concrete beams carried out by installing external stirrups

Strengthening of the concrete beams was carried out by installing external stirrups. Stirrup is made mostly of two black bars installed in holes drilled in superstructure. These bars are joined together at the bottom and top by flat steel plate using hex nuts (illustration 27, right page).

Anchoring in the concrete slab is integrated, but the bottom nuts may be exposed. Holes around the bars must be filled with epoxy resin or cement grout. Constructed stirrups are coated with epoxy corrosion protection system. The strengthening was a main part of the complete rehabilitation of the bridge including replacement of the waterproofing, sidewalks and bitumen layers of the roadway.
Method C – Extra concrete slab and external stirrups - Denmark

Strengthen the precast, prestressed concrete beams with a RC slab cast on top.

To satisfy the additional shear capacity required, stainless steel high strength bars can be drilled into the sides of each of the beams, as indicated in the figure below. The bars are connected below the beam by a steel plate. On top of the slab the bars are attached with a steel plate (Illustration 28, next page). Hence, the bars could accommodate shear forces in the same way as normal stirrups. Stainless steel is recommended since the bars are not covered with concrete at the internal voids in the slab.

The strengthening was carried out along with a complete rehabilitation of the bridge including replacement of the waterproofing (with new bitumen sheets and surfacing). The (soffit clearance) under the bridge is reduced after the strengthening is carried out. However, the additional “stirrups” are only installed over pedestrian sections and slopes near the abutments, so the height restriction does not affect the traffic (Illustration 29, next page).

Conclusion and Comparison of the methods

Method A is fairly conventional and simple; however, it does not necessarily address requirements with regards to shear capacity issues.

Method B is quick and easily achieved.

Method C can be carried out along with the traditional rehabilitation with a minor additional disturbance for the traffic below the bridge, when the drilling is carried out and the steel plates
are attached on the soffit of the beams. This is an ideal solution if additional load capacity is required as well since the alternative would be to replace the bridge superstructure. The replacement of the bridge deck would have a significantly larger impact on the traffic during execution. The sustainability lies in the strengthening and repair of the bridge compared to replacement. Besides the standard principal inspection (5 year frequency), no follow-up measures are required. Since the vertical bars are of stainless steel and the upper plate is cast in with concrete (and hot dip galvanized) no corrosion problems are expected. The only risk of corrosion is the steel plates on the soffit which can be addressed through the use of zinc hot dip galvanizing.

6.2.6 Pre-stressed concrete bridge element by post tension (excluding slab): chloride corrosion with spalling

Description of the problem.

The pre-stressed concrete beams are degraded by water ingress with chloride through anchorage (*illustration 30, right page*). Corrosion and ruptures of post-tensioning strands are observed (*illustration 31, page 40*).
On another bridge, a state of diffused cracks and uncontrolled water flows has induced partial corrosion of the post-tensioning cables, resulting in almost 50% of wires broken and causing reduction of the bearing capacity of the decks (main damage generally located mid span) (illustration 32, next page).

Methods available

**Method A: Concrete repair - USA**

This first method consists in a standard concrete repair (patching) if sufficient strength remains. Otherwise typically, the element has to be replaced.
Illustration 31 - Post-tensioning tendons: corrosion and wires ruptures

Illustration 32 - Post-tensioning tendons: corrosion and multiple wires rupture

Method B: Strands cleaning - Denmark
Rehabilitation of corroded post tensioned cables (illustration 33, right page) can in some cases (if only minor corrosion is present) be carried out by removing the concrete with water jetting
(Illustration 34). In this way, the strands are cleaned without the damage that would occur if manual chiselling was used. One requirement is that the strands have to be linear or with a curvature where the concrete can be removed without loss of the pre-stressing.

Illustration 33 - Window opening on a post-tensioning cable

Illustration 34 - View taken after water jetting including local removal of duct
Method C: Recalculation and patch repair - USA
The method was applied on a bridge, built in 1961, with four simple spans. The longest span is 64.5 feet (19.66 m) (illustration 35). Cracks and concrete spalling were observed along the internal post-tensioning cables (illustration 36).

Illustration 35 - General view of the bridge

Illustration 36 - Cracks and concrete spalling along internal post-tensioning cables

Load rating calculations were performed on the girder to determine capacity with loss of section and loss of bond at affected section. The exposed tendons and rebars were coated with epoxy sealant and the area was patched with cementitious material which provides corrosion protection.

Method D: Corrosion inhibitor ultrasonic injection - Belgium
Due to leakage in the ageing waterproofing, water with de-icing salts penetrates the deck mainly under the gutter. Water arrives in the anchorage, follows the tendons and leads to corrosion (chloride content is moderate but still too high: 0.05 to 0.17% (chloride mass relatively to grout mass, acid extraction). Cement content is about 70% (m/m grout). Waterproofing will be renewed and new water penetration will be stopped. The aim is to manage the long term risk of tendons corrosion induced by chlorides trapped in the grout by injecting a corrosion inhibitor solution in the tendon using an ultrasonic pump. If large void are detected during this process, a cement grout is also injected afterward (refer to 6.2.7 for further details).
Method E: External post tensioning - Japan
Compensate for the loss of post-tensioning due the breaking of post-tensioning tendons, by installing external cables.

Method F: Monitoring - Japan
Continuous monitoring of tendons and cables; Improvement of monitoring technology
Failure due to further pre-stressing loss due to the progress of deterioration is a significant concern and continuous monitoring is strongly advised if no alternative measures are being implemented (illustration 37).

Through transfer of the continuous monitoring data to the maintenance office by means of optical fibre cable technology, ongoing adjudication of the stability of the structure is possible and the hence cost of repeated on-site data collection at the bridge can be omitted.

Illustration 37 - Monitoring at cable anchorage

Since there are concerns associated with the breaking of pre-stressing tendons due to the progress of deterioration, traffic safety is continuously confirmed by monitoring bridge deflection and tension of external cables.

Method G: External post tensioning and FRP - Italy
On a bridge with severe post tensioning cable corrosion, the rehabilitation consisted in the installation of external unbonded cables positioned on the lateral faces of the damaged beams and providing a FRP reinforcement on its soffit (illustration 38, page 45).
Several tests were carried out on the beams with the aim of assessing their structural condition, with particular interest in the residual pre-stressing loads and the integrity of the cables:

- Cable layout was determined using electromagnetic and radar detectors.
- Direct and borehole visual inspections were performed on the cables, also utilising a digital flexible video end-scope.
- Release tests were performed for evaluating the stresses acting on concrete due to the residual pre-stressing force and to the dead load.
- Release tests on the pre-stressing strands have also been performed in order to estimate the residual tension acting in the cables.

The supplementary reinforcing system designed for the specific case study consists in the application of external unbonded cables positioned on the lateral faces of the damaged beams and in gluing a FRP reinforcement on its soffit. The cables (each consisting of 9 strands, cross-section area of 12.51 cm²) were tensioned to about 500-600 MPa to restore the original performance of the beam. The tensioning procedure of the applied cables has been studied specifically for each beam in such a way to increase progressively the compression stress in the sections up to a specific value.

A similar system was applied to the “Peinstretta” viaduct in Italy (illustration 39, page 46) where the supplementary reinforcing applied consisted of 6 externally unbonded cables positioned on the lateral faces of the damaged beams as well as gluing FRP reinforcing to its soffits (illustration 40, page 47). In this case the cables, each 11.55 cm² in cross section, were tensioned to about 600 MPa to restore the original performance of the bridge.

**Conclusion and Comparison of the methods**

While methods A to D merely attempt to redress or reverse and inhibit the degenerative corrosive action, more serious intervention may be required to retain the load bearing capacity of structures. It is in this situation that continuous monitoring of bridge deflection and tension of external cables becomes crucial. The above “halting” interventions are however somewhat sustainable since the remaining service life of the structures can be prolonged for considerable time, thus reducing the material consumption and they are particularly effective when the problem is of a localized nature (e.g. at leaking construction joints as opposed to spread throughout the girders).

A condition rating analysis may provide justification for repair as opposed to replacement and has the benefit of being more economical compared to replacement. It retains the use of the structure in-place with only repair materials used. More frequent inspections and rating analysis are however required.

Method E calls for major intervention but has the advantage of the capacity of the structure being reinstated while ongoing advanced monitoring is achieved through method F. When an emergency event occurs or is predicted or when catastrophic failure is approached, the traffic restriction can be decided by transferring the monitoring data to the maintenance office automatically.

Method G: The tensioning procedures make it possible to restore the original pre-stressing by unbonded tendons. Future re-tensioning of the cables will be possible without interrupting traffic. Increased lifetime and load capacity is thus achieved. The cost of the adopted solution, carried out without traffic interruption was significantly lower than demolition and reconstruction.
Illustration 38 - General views of the rehabilitation works
Illustration 39 - General view of “Peinstretta” viaduct in Italy
The method leaves intact the static scheme and allows restoration of pre-stress. The system should be continuously monitored to verify the structural behaviour of the beam compared to the design provision. Each beam is controlled by measuring the compressive strain of the concrete and the vertical deflection at mid-span. The effective force applied by the external strands is monitored by ring load cells disposed near the cross anchoring beams. The deflection measurements were performed at mid-span by means of topographic levelling, using a digital level and invar staff. Loads cells were implemented to control the eventual loss of externally applied force due to concrete creep.

The final behaviour of the strengthened beams was verified by means of static load test. Strain and deflection induced in the structure by means of eight 350 kN trucks were monitored as well. Strain measurements were done with the same gauges used during the external cable tensioning. Deflections were measured by topographic levelling at mid-span, quarter-span and at the supports. Significant improvements were achieved.

The reinforcing system applied to the beams has made it possible to elevate the safety factors from about 1.26 to acceptable values in accordance with the actual prescribed rules (>1.5). Furthermore, the increased compressive stress in the beams allowed the reduction in risk of fissures opening, thus further protecting the existing cable from corrosion.
6.2.7 Tendons chloride contamination

Description of the problem.

The bridge illustrated here is a post-tensioned continuous box girder bridge of 240 m length with 4 spans, built in 1973 (illustration 41).

Tendons are placed from one end to mid length. At that time, it was difficult to manage full length (240 m) tendons (illustration 42).

Near the mid pile, anchorages are positioned in the upper face of the deck. Half of the 44 deck anchorages are placed just under the surface-water drainage gutter (illustrations 43 and 44).
Due to leakage in the ageing waterproofing, water with de-icing salts penetrates the deck mainly under the gutter. Water arrives in the anchorage and follows the tendons (illustration 45).

After performing a few window openings (illustration 46), it appears that tendon corrosion is moderate but that chloride contain is still too high: 0.05 to 0.17 % (m/m grout, acid extraction). Cement content is about 70 % (m/m grout).

There is nearly no void in the metallic duct.

There is nearly no concrete spalling due to corrosion.

Waterproofing will be renewed and new water penetration will be stopped. But how to manage the long term risk of tendons corrosion induced by chloride trapped in the grout?

Illustration 45 - Inside the box girder

Illustration 46 - Tendon window opening

**Methods available**

**Method A: Patch repair and Carbon Fibre Sheet– Japan**

**Description**

After removing delamination, spalling and deteriorated concrete (illustration 47, next page) of the existing concrete structure (using water jet), section loss will be repaired using materials such as concrete or polymer cement mortar.
In order to prevent future corrosion, concrete or cement mortar may have corrosion inhibitor added.

After that, carbon fibre sheet may be added is necessary (illustration 22, page 34).

Illustration 47 - Removing deteriorated concrete

Quality assessment
Carbon fibre sheet adhesion has to be measured.

Advantage/disadvantage

- Reliability:
  - Regarding the problem as described, (chloride pollution in the tendons without concrete spalling) replacing only degraded concrete will not be enough to suppress tendon chloride induced corrosion risk.
  - The adhesion between carbon fibre sheet and concrete is still in research and development regarding its durability.
- Availability: low impact on the traffic
- Maintainability: the risk of corrosion is not reduced. Corrosion may continue and may need new repair in future.
- Safety during execution, inspection and maintenance: normal risk, except when applying carbon fibre plate. Personal protection is needed.
- Financial aspect: normal price but may increase if new repairs are needed during bridge lifetime.
- Sustainability aspect: it extends bridge lifetime
**Method B: Cathodic protection – Japan**

*Description*
Application of cathodic protection to try to stop the electrochemical reaction on the rebar surface by the disappearance of the corrosion electric current.

Electric current (around 5-30mA/m²) is provided with internal rebar as a cathode. The current flows to the cathode, the corrosion electric current disappears, and the corrosion reaction at the surface of the tendons stops.

*Quality assessment*
Different controls have to be done during execution:
- Electric continuity between tendons and rebars
- Current intensity measurement
- Performance of the remote control

*Advantage/disadvantage*
- Reliability: Due to the risk of mono atomic hydrogen production and subsequent embrittlement if a current value becomes too high, some bridges authorities do not allow cathodic protection with pre or post-tensioning tendons.
- Availability: low impact on the traffic
- Maintainability: This simple method needs a continuous control of the current injected to the cathode during its whole lifetime.
- Safety during execution, inspection and maintenance: normal
- Financial aspect: need continuously provision of electricity
- Sustainability aspect: it extends bridge lifetime

**Method C: Corrosion inhibitor ultrasonic injection – Belgium**

*Introduction*
The method consists in an injection of corrosion inhibitor solution in the tendon using ultrasonic pump. If large voids are detected during this process, a cement grout is also injected afterwards.

*Inhibitor injection*
Holes are drilled at regular intervals along the cable path through the concrete and the duct (illustration 48, next page). A tube is tightly sealed inside each hole to permit the fitting of a reciprocating pump. The pump's compression chamber is then filled with the inhibitor solution.

The high frequency compression and depression created by the reciprocating pump forces the liquid to penetrate within the duct.

Control holes on both sides of the injection hole permit the technician to monitor the movement of the inhibitor solution inside the duct (illustration 49, next page). When the liquid overflows through both control holes, the pump is moved to the next injection hole (illustration 49, next page).

The heart of the high frequency reciprocating pump developed for this application consists of a power ultrasonic transducer with a sonotrode confined in a compression chamber. The expansions and retractions of the sonotrode create overpressures and underpressures at ultra high frequency speed.
These pressure variations force the liquid to penetrate the micro-cracks present in the grout. The power acoustic waves applied to the liquid also have an expanding and retracting effect on the walls of the micro-cracks at ultrasonic frequency, which makes it easier to introduce the liquid into the cracks. In addition, these acoustic waves cause generalized very low amplitude vibrations favouring the progression of liquid between the duct and the grout. Finally, since the liquid is in a vapour phase cavitation state, it enables to clean interstices and micro-cracks, thereby contributing to the penetration of liquid in the cracks.

The inhibitor injection may not be stopped in a chloride polluted area. All the polluted parts must be treated.

_Cement grout injection_ 

_Illustration 50, right page_ represents an injection time map for several tendons. Each arrow marks represents the injection holes that were effectively used. Two consecutive marks are located one meter apart. The distance between injection and control holes is about 50 cm. The travel times indicated in the legend of _illustration 50, right page_ are the times necessary for the inhibitor solution to migrate from an injection hole to an adjacent control hole.
Considering the inverse relationship between injection travel times and the lack of grout (porosity and/or voids), this diagram constitutes a precise map of the quality of the protective cement grout filling.

Based on this map and the injection holes already in place, additional precision filling of the grout defects can be made with fine micro-cements.

**Conclusion**

The protection of cables achieved this way is homogeneous and definitive. This method is now applied since 1994 [5], [6]. Regular inspections of treated bridges reveal no resumption of tendon corrosion.

**Quality assessment**

Windows opening has been performed on several bridges up to 15 years after treatment. There is no corrosion observed.

**Advantage/Disadvantage**

- Reliability: the protection against corrosion remains all the bridge lifetime
- Availability: low impact on the traffic
- Maintainability: no future action needed
- Safety during execution, inspection and maintenance: normal except corrosion inhibitor may not contaminate the bridge environment
- Financial aspect: The method is relatively expensive (about €500/meter of treated tendon). When the chloride pollution is limited in length, this method is very interesting because you avoid the replacement of the bridge element.
- Sustainability aspect: it extends bridge lifetime

**Conclusion and Comparison of the methods**

All methods extend the bridge lifetime.
The method A may be adopted if there is some concrete deterioration. But it does not reduce the risk of corrosion where there is no spalling but only chloride pollution.

The method B is a good solution for the problem presented. It is a well-known method. But it needs a continuous maintenance of the system throughout the remaining lifetime of the bridge. Some bridges authorities do not allow this method with pre or post tensioning tendons.

The method C is also a good solution. It is a new and relatively expensive method.

6.2.8 Corrosion of steel bridge elements (excluding slabs)

Description of the problem.
Corrosion is an important and frequent cause of degradation of steel structure mainly in severe environmental conditions, and made several times worse by a bad design of the structural details.

For steel elements embedded in concrete the corrosion generally arises from rainwater ponding at the interface of the steel element with concrete because of inadequate design details for draining water away (*illustrations 51 and 52*).

![Illustration 51 - General view of the problem](image)

![Illustration 52 - Detailed view](image)

Methods available

**Method A: Local steel repair – Italy**

*Description*
The traditional method has the following stages of repair

  a - Blasting of corroded surfaces
  b – Evaluation of loss of section
c – Repair with steel plates of thickness sufficient to restore the needed resistance and/or durability, connected to the existing elements with high strength bolted or welded joints applied at undamaged area to secure reliable load transfer.
d – The step c could be preceded by an in-depth analysis to provide the possibility of selective repairs, accepting some deterioration while repairing others.

Quality assessment
It needs a careful evaluation of loss of sections,

Advantage/Disadvantage
- Reliability: the lifetime depends on the severity of corrosion environmental attacks
- Availability: impact on the traffic to be evaluated in each particular situation
- Maintainability: inspections are needed with a frequency of not more than 10 years
- Safety during execution, inspection and maintenance: normal
- Financial aspect: good cost-effectiveness if step d is adopted
- Sustainability aspect: the structure lifetime is extended

Method B: Local steel repair – United States
The steps of this standard method are:

a – Chipping of the concrete until the corroded surface is completely exposed
b – Sand blasting to eliminate corrosion it is required.
c – Evaluation of loss of section
d - Repair with steel plates of thickness sufficient to restore the needed resistance and/or durability, connected to the existing elements with high strength bolted or welded joints applied at undamaged area to secure reliable load transfer, restoring the chipped part of the concrete.
A possible alternative is to encapsulate with concrete an additional portion of the damaged element to restore the structural strength.
e - As in the first method presented method an in-depth analysis could allow a selective procedure, repairing only where it is necessary for safety and durability.
f - Design of the contact area between steel and concrete to assure drainage of rainwater, for example giving adequate slope to concrete surfaces.

The method is the standard one generally adopted, efficient enough for reliability and safety; Sustainability and cost-effectiveness could be improved adopting a selective procedure (step e).

Careful monitoring is needed to control the possible pounding of water.
The assessment should be done is as for method 1.

Quality assessment
A careful evaluation of loss of sections is needed, Different controls have to be done during execution:

Advantage/Disadvantage
- Reliability: it depends on the environmental conditions
- Availability: to be evaluated in each case, but generally with low impact on the traffic
- Maintainability: careful monitoring is needed to control the possible ponding of water.
- Safety during execution, inspection and maintenance: normal
• Financial aspect: cost-effectiveness could be improved adopting a selective procedure (step e).
• Sustainability aspect: the lifetime is extended mainly by taking good care of the design of the contact area (step f).

**Method C: Suppress concrete/steel contact – Japan**

*Description*

When there is no need of composite structural action between steel and concrete, this method involves changing the structural detail into an open cut type (*illustration 53*), with the following working steps:

a - Chipping all the concrete where the steel element is embedded  
b – Sand blasting to eliminate corrosion  
c – Evaluation of loss of section  
d - Repair with steel plates of thickness sufficient to restore the needed resistance and/or durability, connected to the existing elements with high strength bolted or welded joints applied at undamaged area to secure reliable load transfer. Since the fall of objects from an open cut is possible, countermeasures against injuries to a third person must be adopted, for example closing the open cut with light steel plates (*illustration 54*).

*Illustration 53 - Suppression of the contact between steel and concrete*

*Illustration 54 - Closing of the opening*
Advantage/Disadvantage
- Reliability: the elimination of steel-concrete contact gives an increase of the bridge lifetime
- Availability: to be evaluated in each case
- Maintainability: inspections needed at least every 8-10 years
- Safety during execution, inspection and maintenance: since the fall of objects from an open cut is possible, countermeasures against injuries to a third person must be adopted, for example closing the open cut with light steel plates
- Financial aspect: rather expensive
- Sustainability aspect: increases the bridge lifetime.

Conclusion and Comparison of the methods
All the methods extend the bridge lifetime but they need careful investigation of the structure.

In the case of steel elements embedded in concrete superstructure, method C should be preferred whenever it is possible.

6.2.9 Fatigue cracks in steel bridge elements

Description of the problem
Fatigue cracks are a typical damage of steel structures due to cyclic load conditions. The problem is particularly important for orthotropic steel decks (illustration 55), where cracks can occur at the connection of the vertical web stiffeners or of the longitudinal ribs with the steel platform plate caused by the cyclic loads very severe in this kind of structure elements (illustrations 56 to 59, next page).

Illustration 55 - Orthotropic steel deck
Illustration 56 - Fatigue cracks between U-shape rib and deck plate

Illustration 57 - Fatigue cracks in the deck plate near a cross rib

Illustration 58 - Fatigue crack between vertical stiffener and the deck plate
Methods available

Method A: Holes drilling and patching plates – Japan

Description
With this traditional method, the repair work method consists of two stages, for emergency and for permanent measures:

a – for emergency, holes are drilled at the tip end of fatigue cracks to stop the evolution of the cracks and to stop the concentration of stresses.
b – patching plates are then attached with high strength bolts connection for a permanent repair, as illustrated in the examples of illustration 60, next page.

An improvement of the method could be to examine by FEM very accurate analysis of the stress distribution around the crack area in order to optimize the patching plates repair as form their dimensions and distribution.

Quality assessment
The performance of the method appears good, as demonstrated by experience.

Advantage/Disadvantage
• Reliability: the repair reportedly remains all the bridge lifetime
• Availability: low impact on the traffic
• Maintainability: inspections with a frequency of not more than 5 years
• Safety during execution, inspection and maintenance: normal
• Financial aspect: it is an economical way for solving the problem
• Sustainability aspect: it extends the lifetime of the bridge.

Method B: fatigue zone detected by structure recalculation – Denmark

Description
This innovative method consists in the introduction of new structures that should be able to redistribute the load relieving the damaged ones. It needs an in-depth analysis of load distribution of the damaged structures and of the repaired ones for optimizing the repair new structures and introducing them where it is strictly necessary.
An example is illustrated in *illustration 61, right page* concerning the repair of some damaged corbels connecting the main girder of a steel bridge: the damaged plates were not replaced, instead, a bent structure was placed in the damaged corbels to relieve the stress distribution in the damaged parts of them.

*Quality assessment*

It needs an in-depth analysis of the repaired structures.
Advantage/disadvantage
- Reliability: it gives an high increase of the structure lifetime
- Availability: there is no or low impact on the traffic
- Maintainability: monitoring with a frequency of not more than 10 years
- Safety during execution, inspection and maintenance: normal
- Financial aspect: in general it is more expensive than the traditional method
- Sustainability aspect: the bridge lifetime is extended

Method C: Extra concrete slab on orthotropic deck – Japan
Description
In the last years the method A is sometimes improved by introducing as permanent measure, steel fibre reinforced concrete (SFRC) for upper surface of the deck plate (illustration 62), in addition to the repair of the ribs. In this way the stiffness of the orthotropic steel structure and consequently the fatigue resistance are considerably upgraded. The asphalt layer is reduced by the thickness of the SFRC. In some case all the asphalt layer is replaced by the SFRC layer.
Quality assessment
A good performance has been demonstrated by experience.

Advantage/disadvantage
• Reliability: it extends the bridge lifetime
• Availability: impact on the traffic
• Maintainability: inspections with a frequency of not more than 5 years
• Safety during execution, inspection and maintenance: normal
• Financial aspect: rather expensive
• Sustainability aspect: the lifetime of the bridge is extended

Conclusion and Comparison of the methods
All the methods have a good performance.

Methods A, B are rather economical.

Method C has a very good reliability but it is more expensive. The choice of this method requires, however, the complete removal of the existing pavement, and therefore it is advisable when the fatigue cracks damage is not localized but more generalized in the steel deck. Furthermore the new asphalt layer should be of reduced thickness to take account of the SFRC layer and maintain a constant total thickness above the steel deck.

6.2.10 Protective coating defects/failures in steel bridge elements

Description of the problem
Protective coating problems are very common in steel structures due either to environmental attacks or bad quality and application techniques of paints.

The problem is the main factor influencing the durability of the steel elements of a bridge and its correct solution is important for the performance of the bridge in terms of lifetime, costs and sustainability.

Methods available
Method A: Repainting – Italy

Description
This traditional method has two stages of repair

a – blasting of the deteriorated surfaces by electrical power tool and hand tool, until the required class of surface preparation is reached
b – repainting with the same coating (conventional) of the existing bridges (primer and final coating), using gondola and brush coating

Quality assessment
Assessment of paint quality with paint product inspection, visual controls (uniform colour) and thickness measurements of the coating film.

Advantage/disadvantage
• Reliability: the lifetime is rather short (8-10 years horizon) using traditional paint products.
• Availability: the production of abrasive materials, fumes and paint fragments has a negative
impact on traffic.
• Maintainability: careful controls of the paint film with a frequency of not more than 5 years
• Safety during execution, inspection and maintenance: normal for inspection and maintenance; during the repair works, protective measures must be taken to control emission of fine dusts in the air
• Financial aspect: low cost with standard paints
• Sustainability aspect: negative impact on the environment due to the presence of fumes and fine materials during the execution.

Method B: Film peeling chemical – Japan

Description
The working steps are:

a – to peel and remove existing coating of painting film with a film peeling chemical, reducing the bonding strength of coating to the steel support (illustration 63)
b – vacuum blasting (illustrations 64 and 65)
c – application of high resistance fluororesin type coating
Quality assessment
As for method A, process of paint product inspection, visual controls (uniform colour) and thickness measurements of the coating film are required.

Advantage/Disadvantage
• Reliability: high increase of the paint lifetime
• Availability: Adopting the vacuum technique, since the abrasive injection nozzle and withdrawing hose are unified, the blasting and the withdrawing works occur at the same time, without any scatter of the abrasives, fumes and paint fragments in the air, without impact on traffic.
• Maintainability: as for method 1 with inspections frequency of not more than 10 years.
• Safety during execution, inspection and maintenance: The peeling work becomes easier since the adhesive forces are weakened. Although the effective area of vacuum blast is smaller than in an ordinary open air type blast, the working time of blasting is shortened by combination with peeling chemicals.
• Financial aspect: Although the initial cost of repair is higher, when considering the life-cycle cost, mainly for the use of fluororesin type of paint, the method is advantageous since the expected life can reach about the double than in the case of method A (20 to 50 years instead of 10).
• Sustainability aspect: no fine dust in the air during the coating works. In addition, compared with polyurethane coating, the fluorinated ones have no variation in colour or gloss and the surface properties are unchanged (no entry of water and hydrates ions).

Method C: Painting high piers or towers – Japan
Description
In the case of the coating repair of high steel piers or towers, mainly in suspended or cable stayed bridges), an alternative to the previous methods (illustrations 66 and 67) is to use a magnetic wheeled gondola and a repainting machine with a number of painting rolls as necessary.
Quality assessment
The assessment is as for the methods A and B, with frequency of inspections (5 or 10 years) depending on the type of the paint film used for the recoating.

Advantage/Disadvantage
In addition to the characteristics of each one of the two previous methods, the rate of all the operations of repainting is increased and the cost of repainting is reduced.

Method D: Self indicating technology epoxy primer – Italy
Description
A remarkable improvement of quality in coating repairs could be carried out using an epoxy primer having a self-indicating technology (SI-technology) which allows the accurate control of film thickness by the applicator and easy identification of low dry film thickness area by the inspectors. In fact with SI-technology the adequate film thickness is reached when the surface is completely covered and the paint film is opaque, so the colour is used as indicator of thickness.

The repainting stage is as follows:

a. application of the epoxy SI-technology primer until the films became opaque (thickness of about 150-170 μm). Only if a greater thickness (170-200 μm) is required the thickness must be checked by measure.

b. a final coating with a fluoro resin coating of about 40 μm.

In comparison with the other methods there is the high reliability, which is a very important goal in repair works.

Quality assessment
The assessment is as for the previous method B.

Advantage/Disadvantage
• Reliability: higher than for the other techniques
• Availability: low or no impact on traffic depending if the vacuum technique is used or not
• Maintainability: monitoring as for method B
• Safety during execution, inspection and maintenance: normal
• Financial aspect: costs could be compared with the ones of method 2
• Sustainability aspect: as for method B.
Conclusion and Comparison of the methods
The use of new paint products and coating techniques allows remarkable advantages for all the performance characteristics.

The initial costs are higher, but they become lower if taking in a due account of the reduced maintenance costs.

6.2.11 Masonry and stone bridges: waterproofing of fillings

Description of the problem
The bridge is a masonry arch bridge built in brick, and consists of a 3.00 m span and 0.62 m thick. The width of the bridge is 10.00 m.

The distribution of moisture in the masonry arch bridges is mainly initiated by infiltration from the platform, which is transmitted through the granular filling to the structural elements of masonry, generating a series of processes of alteration of these materials and, therefore, affecting their resistant and durable behaviour (illustrations 69 and 70).

The solution must find a way to stop the water through the fillings of a masonry arch bridge.

Methods available
Method A: Waterproofing on the arch – United Kingdom
Description
The traditional method consist in an over slab arch with standard reinforced concrete with addition of spray applied waterproofing membrane.

Illustration 69 - General view of water infiltration

To place a conventional slab it would have been necessary to excavate over the whole bridge down to the crown of the brick arch, relieving compressive forces in the arch. Total road closure would also have been required.
The innovative method uses excavation of trenches approx 1-2 m. Arch relief was therefore only localised, maintaining overall stability of the bridge. Trench technique precluded use of traditional steel rebar cage, instead a steel fibre reinforced concrete can be used.

The technique allowed a lane to remain open to traffic throughout the works.

Minimizing impact of bridge maintenance activities by maintaining lane opening has huge benefit to local community who would otherwise have encountered lengthy diversion routes and community severance.

**Quality assessment**
The solution is now totally buried and is not directly inspectable. The structure’s performance is monitored through biennial general structural inspections.

**Advantage/Disadvantage**
- Reliability: It is a definitive solution, it achieves project objectives - strengthening and waterproofing.
- Availability: Maintain lane open to traffic.
- Maintainability: no special maintenance.
- Safety during execution, inspection and maintenance: Less risk to stability of the arch.
- Financial aspect: The innovation solution was approximately cost neutral to traditional solution.
- Sustainability aspect: it extends bridge lifetime.

**Method B: PVC waterproofing below pavement – Belgium**

**Description**
This solution is used for bridges with low traffic, especially for greenways network.

The new structure will be (from top to bottom):

- Ash pavement (mix of stone and ash);
- Stabilized sand;
- PVC membrane 2 mm thick, hot sealed;
• geotextile (150 gr/m²) (shear resistance);
• arch filling.

A double longitudinal slope 2% is provided to reject water towards transversal drainage placed on both side and beyond of the bridge. The membrane is longer than the bridge to avoid water infiltration in direct of the abutment.

Transversely, the membrane goes up along the parapets and is fixed by a non-corrodible profile.

**Quality assessment**

Visual inspections of previous bridge rehabilitation using this method show the good performance of the waterproofing.

**Advantage/Disadvantage**

- **Reliability:** Perhaps, waterproofing will not be perfect. But for an arch bridge some few leakages may be acceptable.
- **Availability:** lane or bridge closure to traffic is required but for a short time.
- **Maintainability:** No maintenance except the profile along the parapet.
- **Safety during execution, inspection and maintenance:** normal
- **Financial aspect:** very cheap regarding traditional method
- **Sustainability aspect:** Avoid using new material to concrete the slab or to renew the filling.

**Method C: Replace the filling by concrete – Ireland**

**Description**

Install a concrete saddle (replacing the filling) and apply a waterproof membrane. Provide a channel for water to flow away from back of arch. Injection resins have proven to be partially successful but expensive.

**Method D: Lime milk injection – Spain**

**Description**

Lime milk is injected into the filling, at controlled pressure, through pipe tube with intermediates valves, avoiding rigid points or areas of increased strength that could cause stress concentration is generated. Implementation phases of work:

1. **Execution of the drilling,** with the length and inclination according to plans (*illustration 71, right page*). The holes run in a dense grid, drilling with recovery witnessed by rotation with diamond crown, diameter 90 mm and the length indicated according to drawings. After perforation the PVC tube (diameter 40 mm) with sleeve valves every 1 m is placed. The space between the drill pipe and the adapter sleeve is injected with lime mortar / bentonite (4/6 % in weight)
2. **Injection.** Elapsed at least 24 hours after the injection between the drill pipe and the adapter sleeve, one proceeds to the injection of lime with double packer from the inner to the outer valves. After valve rupture the injection goes on with a pressure of 1.5 Bar to a critical threshold 3 Bar. Injection ends when the expected amount (50 l / valve) is reached or the maximum pressure (3 bar) is exceeded (*illustration 72, right page*).
3. **Sealing the hole.** After the injection, the pipes are filled with a single injection of lime mortar and reconstruction mortar is used to hide the outer tube head
Quality assessment
A coring can be made before and after the process to test the quality of the fill.

A load test can be performed to check the increased stiffness of the bridge after injection.

Visual inspections will allow testing the lack of waterproofing problems through fillings, which manifest as spots on the facing of the vault

Advantage/Disadvantage
The traditional solution involves a traffic condition and increased cost. Furthermore, injection of fillers get a second objective, which is a consolidation of them, giving them greater rigidity is achieved.

- Reliability: Injection is not always well controlled.
- Availability: there is no influence to current traffic over the bridge.
- Maintainability: perhaps a second phase of injection may be necessary.
- Safety during execution, inspection and maintenance: normal.
• Financial aspect: It is cheaper, while the material consumption is lower.
• Sustainability aspect: Avoid using new material to concrete the slab

**Conclusion and Comparison of the methods**
Considering the specificities of the bridge to be rehabilitated, the most suitable method will be different. For a quick and low cost solution, method B can be interesting. If the bridge must also be strengthened, methods A and C may be considered. If it is not possible to operate on the upper face, method D may be appropriate.

6.2.12 Cable bridge element: suspension and stay cables (excluding slab): anchoring and mono strands protection defects

**Description of the problem.**
In both cases presented, the problem is the water penetrating inside the elements of the bridge (anchorages, principal cables, etc.) with associated corrosion problems.

**Suspension cable bridges**
The corrosion protection system for the main cables was originally designed as a traditional system with galvanized wires, zinc paste, wrapping wire and paint but there were serious problems with the corrosion protection system for the main cables. This was designed as a traditional system as described above. However, during construction it was decided to omit the zinc paste. This fact combined with a somewhat defective paint system and other details allowed water ingress and led to an accelerated deterioration of the corrosion protection. Large amounts of water flowed through the cables and ran out at the low points. The water was analyzed and the Swedish Corrosion Institute concluded in 2003 that the zinc galvanization on the cable wires would be depleted within about ten years. The cables were opened and inspected in connection with the retrofit project in 2004. This was just six years after the bridge opened and there was depleted zinc and signs of ferrous corrosion on the bottom wires of the cable and the inside of the wrapping wire (*illustration 73 left*).

**Stay cable**
There is ingress and accumulation of water in the anchorage. There is no chloride in the water but there is some deposit showing an internal corrosion (*illustration 73 right*).
Methods available

Method A: Renewing corrosion protection

A traditional method (renewal of the existing corrosion protection system) would encompass:

• Removal of the wrapping wire.
• Coordinated removal of cable bands and erection again after cleaning and application of an anticorrosion product.
• Wedging and cleaning of strands.
• Applying a corrosion protective treatment on strands.
• Compacting of cables and application of fillers wrapping wire.
• New caulking of cable bands.
• Paint treatment on the surface of the wrapping wire.

Method B: Dehumidification – Denmark

Retrofit of Main Cable Corrosion Protection by Dehumidification

These systems have also been further developed and optimized into integrated systems, where corrosion protection of the main cables and one or more other steel elements are incorporated in the same system. The main principle is that steel does not corrode when the relative humidity (RH) is below 40%. Between 40% and 60% corrosion can occur, though at a very low rate as illustrated below. In practice, short periods with relative humidity of up to about 50% are acceptable. The dehumidification system is composed of the following main components:

1. Sealing system

For sealing the 20 m cables sections between the cable bands, an elastomeric wrap with a thickness of 1.1 mm and a width of 200 mm was chosen. It is applied with a 50% overlap, for a total thickness of 2.2 mm. It is applied under tension with a special wrapping machine. After wrapping a section, it is heat bonded with a special heat blanket, which bonds the two layers together and shrinks the material slightly, giving an even tighter fit. Special details have been developed to ensure sealing at the transition to the cable bands and to give a uniform appearance (illustration 74).

For sealing cable bands, saddles, injection/exhaust collars and other components, special details have been developed. These are generally based on a double barrier system with a combination of sealer strips and adhesive caulking. Materials which have been applied for similar usage over many years on bridges are generally applied.

Illustration 74 - Main Cable Wrapping (left) and Heating of wrapping (right)
2. Dehumidification system

The dehumidification system produces dry air and blows it through sections of the main cables. The system assures overpressure inside the sealed cable system. While the sealing system may have minor imperfections in the form of small leaks, no water or moisture will enter the cables, as the overpressure will prevent this. The dehumidification system is made up of the following main components:

- Dehumidification systems, one in the bridge girder at mid-span and one in the cross beam at the top of each pylon
- Injection points, at mid-span through collars and at pylon top through the saddles (illustration 75)
- Exhaust points, through collar at intermediate points in the main span and in the anchors rooms (illustration 76).

Illustration 75 - Humidity injection sleeves at mid span

Illustration 76 - Exhaust and monitoring sleeve

Advantage/Disadvantage

- Reliability: the double overlapped layer guarantee the protection, and the dehumidification system avoids the water or moisture inside the main cables.
- Availability: the accessibility to high altitude areas of the cables and superior anchorages is difficult. In the low altitude areas of the cables traffic could be interrupted in some lanes.
- Maintainability: the dehumidification system needs a continuous maintenance. The control and monitoring system allows adjustment of the system, and data from the system provide information if the system is performing properly. Instrumentation is arranged at the
dehumidification plants and at injection and exhaust points. These instruments and plants are connected to local PLC’s (Programmable Logic Controller) which in turn are connected to a central computer, which stores all data.

- Safety during execution, inspection and maintenance: especial preventive measures when working at high altitude areas.
- Financial aspect: cheaper than traditional method.
- Sustainability aspect: no waste generated and the material to be used is very little.

**Method C: Innovative corrosion protection – Japan**

Another innovative method consists of (illustration 77):

1. Blasting by water jet
2. Injecting a petrolatum paste
3. Covering by a corrosion proof tape

**Illustration 77 - Injection of corrosion protect material (left) and completion by corrosion proof tape (right)**

**Advantage/Disadvantage**

- Reliability: the injection of petrolatum paste is difficult to control.
- Availability: the accessibility to high altitude areas of the cables and superior anchorages is difficult. In the low altitude areas of the cables traffic could be interrupted in some lanes.
- Maintainability: the effectiveness of this method will be confirmed by continuous measurement of cross section by magnetic flux method.
- Safety during execution, inspection and maintenance: especial preventive measures when working at high altitude areas.
- Financial aspect: cheaper than traditional method.
- Sustainability aspect: the blasting by water reduce the waste generated and the material to be used is very little.
Method D: Corrosion inhibitor injection and new PEHD duct – Belgium

The last innovative method consists of:

1. Injection of corrosion inhibitor solution in the anchoring part using ultrasonic pump in order to stabilize potential corrosion (illustration 78 left).
2. Placement of a PEHD (High-density polyethylene) duct on the stay cables. This is done using 2 half pipes welded on site. Each 6 m long element is fixed in the middle on an internal stainless cable. Overlapping of one element over another one avoid water ingress but permit elimination of condensation water (illustration 78 right).

Illustration 78 - Injection of corrosion inhibitor (left) and cables protected (right)

Advantage/disadvantage

• Reliability: the injection of corrosion inhibitor is difficult to control.
• Availability: the accessibility to high altitude areas of the cables and superior anchorages is difficult. In the low altitude areas of the cables traffic could be interrupted in some lanes.
• Maintainability: In the future, load measurement will be done on the stay cables (frequency method).
• Safety during execution, inspection and maintenance: especial preventive measures when working at high altitude areas.
• Financial aspect: cheaper than traditional method.
• Sustainability aspect: the material to be used is very little.

Conclusion and Comparison of the methods

Methods B and C present difficulties to control and guarantee the injection of products (petrolatum paste, corrosion inhibitors).

All methods described present the same difficulties for safety during execution and are cheaper than the standard method.

All methods require a continuous future control of the protected areas according to different systems.

Preventive methods B, C and D are cheaper and the materials used or waste generated is very little compared to reactive method A.
6.2.13 Concrete deck slab – Underside low cover

Description of the problem.
The problem is the delamination of concrete slab underside – due mainly to low cover (illustration 79). Carbonation is present behind the reinforcement. The bridge is thick slab type and was built originally around 1967.

Four countries – Japan (JP), Belgium (BE), Poland (PL) and Québec-Canada (QC) - have submitted answers, representing both standard and innovative methods. Each country proposed one method, with the exception of Japan, who has detailed three different approaches. One of them consists of a low concrete cover in a structural problematic situation.

Illustration 79 - Slab underside delamination due to carbonation

Methods available

Method A: Concrete renewing – Canada - Québec - Japan
The standard methods proposed consist of a partial demolition of deteriorated concrete and its replacement with shotcrete, low density concrete or polymer cement mortar (in the case of localised degradations). In Canada-Québec proposal, there is the application of a corrosion inhibitor on exposed rebars followed by the application of a protective coating over all the surfaces of the underside.

In the standard Japan proposal, the different steps of a high quality intervention are detailed. After the removal of deteriorated concrete, an emphasis has been expressed about the importance of cleaning the rebars and the application of rust preventive material over them (epoxy resin base) (illustration 80). An intermediate step is the application of a primer on concrete surfaces exposed after demolition. A precision is given about the concrete repair material, insisting on the potential of a lightweight polymer mortar with glass fibres based on early high-strength cement (illustration 81, next page).

Illustration 80 - Application of rust preventive material on the rebars
Method B: Cathodic protection – Belgium, Canada-Québec
The methods proposed as innovative are of electrochemical type.

Once more, in order to slow down - even to stop - the corrosion process, cathodic protection (CP) systems are the ones that have been mainly considered by two respondents.

The Belgium method expressed a greater confidence with an impressed current CP system (with titanium mesh – illustration 82) because they consider it as more reliable.

The Canada-Québec one suggests that a CP galvanic sprayed zinc system could be an interesting alternative.

Method C – Japan
This innovative method of slab the strengthening consists of the construction of an «underside overlay» (illustration 83, right page) integrating a specialised anchored mesh and an additional thickness of concrete. It is obvious that this rehabilitation is only possible if the girders (or the structural system forming a thick slab) have sufficient load capacity.

Conclusion and Comparison of the methods
All the methods considering repair or rehabilitation of an existing slab by an intervention on its underside are usually simple operations, with no need of large equipment and facilities. In addition, the interventions realised on the underside of the slab do not generate any traffic restrictions on the upper roadway of the bridge. The simple repair – patch type – of bridge deck underside can be considered as a low-cost intervention. But, it has to be mentioned that the real effectiveness of this type of repair depends on various factors, like the degree of surface preparation, the repair materials utilised, and the ambient conditions related to the exposed surfaces afterwards.
Cathodic protection (CP) systems are well-known and verified method to protect reinforcement rebars against corrosion. It needs a low power supply and does not produce any pollution. In the past, the main disadvantage of CP systems has often been the need to verify the control unit to be sure about its effectiveness. Nowadays, its efficiency can be well-controlled in using remote equipment. The service lifetime of a well-designed and well-operated CP system can be as long as 30 years. Its cost can be considered as relatively low compared to a slab replacement.

In some cases, it can be planned to increase the load capacity of the superstructure.

The strengthening of a slab by a rehabilitation of its underside (method C) is not common, but its feasibility opens the door to a potential structural intervention in particular cases.

6.2.14 Redegradation of a concrete slab

**Description of the problem**
The problem is the re-degradation of a concrete slab on steel girders bridge (illustration 84) after intervention about 10 years earlier. This intervention consisted mainly in the installation of a waterproofing membrane to stop new water and chloride ingress from the top of the slab. The actual condition of the slab is a chloride contamination (0.3 % m/m concrete) on all its thickness. The carbonation is less than 8 mm. New delaminations are observed on the underside of the slab (illustration 85, next page).
Methods available

**Method A: New waterproofing – Denmark – Canada-Québec - Japan**

*Description*

The standard method consists of a repair of the top of the slab with the installation of a new waterproofing membrane (prefabricated bituminous weldable sheets), followed by the realisation of a road wearing surface (multi-layer bituminous material).

*Quality assessment*

Well-known method with a relatively good efficiency depending on the condition of the slab.

*Advantage/disadvantage*

- Reliability: The inclusion of a waterproofing membrane slows substantially the dynamic of the corrosion.
- Availability: Standard products and equipments.
- Maintainability: Localised maintenance possible in the perimeter of the repairs.
- Safety during execution, inspection and maintenance: No specific aspect.
- Financial aspect: Robust and cheap method.
- Sustainability aspect: A slab repair & rehabilitation strategy is usually a good option conditionally to a substantial extension of its lifetime.

**Method B: Electrochemical chloride removal – Denmark – Poland - Japan**

*Description*

The innovative ways to intervene are identified mainly as electrochemical methods. Japan (JP) has tested the chloride removal method in order to re-establish a proper non contaminated environment for the top of the existing concrete slab.

One of the advantages of the chloride removal is that the process of removal of the deteriorated concrete is minimal, just like the need to realise extensive repairs. The chloride removal solution involves a temporary operational period of 4 to 8 weeks during which the whole set-up has to be maintained in place (*illustration 86, right page*). One uncertainty of this intervention method is in identifying the best timing to execute it. It certainly needs a substantial amount of data related to chloride content associated with the penetration depth and corrosion activity, in order to make a good decision. A negative factor is certainly the cost, considering that the method is expensive, but in certain cases (soffit, vertical surfaces of piers or abutments), there is no traffic impact.
Following this step, the installation of a cathodic protection (CP) system has been put forward. Denmark has targeted more specifically the zones along the kerbs where the chloride concentration is greater (illustration 87).

Poland has specified to carry out this type of electrochemical method on all the surfaces of the slab – top and soffit – experimenting with zinc sprayed layer in one case and zinc bars system in another case. Despite the relatively high cost for installation of a CP system, a life-cycle cost analysis can establish that this option can be economically interesting compared to the total deck replacement. The installation of a CP system as a rehabilitation method can also be considered as a sustainable option because of the smaller implications of the different stages of realisation (less demolition products, less consumption of new concrete, less impact on environment, less impact on users). The CP system solution extends the service lifetime of major existing parts, postponing the deck replacement project.

Other interventions to rehabilitate the soffit have been experimented with a full shotcrete surface repair (Denmark), and also the use of carbon fibre polymer (Japan) to reinforce some zones that are more deteriorated.

As an innovative way to intervene, one respondent (Denmark) has planned the construction of a new reinforced concrete overlay over which a new liquid (acrylic) membrane has been sprayed. The membrane system included a topping with fine (small) aggregates used as the new road wearing surface. This project has permitted a slab rehabilitation (non-replacement) to combine
with a deck strengthening which would has not been possible if a standard bituminous wearing course had been re-established, considering the extra dead load involved.

Quality assessment
Electrochemical methods are designed to address corrosion-induced deterioration.

Advantage/Disadvantage
• Reliability: On the basis of a well-designed solution, an electrochemical method has a very good efficiency. Overlay + sprayed membrane represent a promising option.
• Availability: Electrochemical solutions are usually available.
• Maintainability: Depending of the electrochemical solutions, no-maintenance, or distance-monitoring are possible. Limited historic for sprayed membrane but promising.
• Safety during execution, inspection and maintenance: No specific aspect.
• Financial aspect: The relatively high installation cost of electrochemical options can become competitive when considered in a Life Cycle Cost Analysis. Overlay + sprayed membrane have shown a cost benefit for construction.
• Sustainability aspect: Electrochemical solutions require particular materials and technologies but it results in a fair extension of the structure lifetime.

Conclusion and Comparison of the methods
The chloride removal and CP systems installation can be viewed as costly and time consuming but compared to a slab replacement it can be considered as a cost-effective rehabilitation due to its expected long duration lifetime and its substantial reduction of user constraints.
The decision to intervene on existing slabs instead of its replacement is considered as sustainable in the way that it causes less negative impact on environment. In another perspective, because of their relatively new age, it is difficult to state the real effectiveness (lifetime duration).
The cost of the part of the project involving a liquid membrane has been about 60 % cheaper compared to the cost of a standard prefabricated membrane with a multilayer of bituminous material. It can be considered as a promising way for the rehabilitation of an existing slab.

6.2.15 Concrete deck slab: fire damage

Description of the problem
Fire damage to bridges is not a frequent occurrence compared to fire in commercial, domestic or industrial buildings. A fire in a building can be fuelled and maintained by an abundance of combustible materials. A bridge usually has no inherent fuel load and a fire may be the result of a vehicle collision, particularly involving fuels, cargo, tyres or other flammable materials (illustration 88, right page). Fire can cause significant disruption to the operation of a bridge and the travelling public, depending on the extent and severity of damage and whether pre-stressing steel is involved. Immediate safety measures may include totally or partially closing a bridge, reduced speed limits as part of an overall traffic management response, posting a load limit or placing netting to collect fragments of spalling concrete.

Concrete can sustain various degrees of damage depending on the severity of the fire and the high temperature levels reached. The effect on concrete components of high temperature fire includes:

• reduction in compressive strength;
• micro-cracking within the concrete microstructure;
• color changes consistent with strength reductions;
• reduction in the modulus of elasticity;
• various degrees of spalling;
• loss of bond between concrete and steel;
• possible loss of residual strength of steel reinforcement and possible loss of tension in prestressing tendons

Methods available

Method A: Concrete repair – Netherlands
Following the investigation and assessment of visual defaults and temperature effects of the fire damage on concrete and steel (illustration 89, next page), a detailed repair process is been developed.

Standard practice for fire-damaged concrete requires that all the severely fire affected concrete be removed from behind the steel reinforcement and pre-stressing tendons, to a depth of at least one bar diameter. The removed concrete is then replaced with flowable or hand/trowel applied polymer modified cementitious materials or spray applied gunite cementitious repair materials.

Such repair of concrete must include:

• breaking back all the fire affected concrete to sound and dense concrete and exposing as much of the steel reinforcement as possible;
• preparation of steel reinforcement and concrete substrate;
• application of an appropriate steel primer and substrate bonding coat; and
• rebuilding to the original surface profile using either flowable, hand/trowel applied polymer modified cementitious materials or spray applied gunite cementitious repair materials.
Illustration 89 - Example of fire damage

Method B: Steel plate reinforcement – Japan
A stolen car was placed in a pedestrian tunnel under an approach road to motorway M14 in DK and set on fire. The ordinary reinforced tunnel was 7.2 meter long and 10.2 meter wide (illustration 90). Severe damages to the concrete, both on the slab and the walls were observed, resulting in large areas with exposed reinforcement (illustration 91, right page).

After removing the damaged concrete, a cross section was restored by applying polymer cement mortar. A steel plate was attached (illustration 92, right page) on the new concrete surface in order to restore the reinforcement capacity. An adhesive agent was injected between the steel plate and the concrete surface for optimum bonding. During the repair works, the individual steel plates were connected by field welding.
Both the adhesive injection agent and the field welding form an innovative technique to restore the fire damaged reinforcement. Quality assessment was done by an adhesion test and hammer test complying with criteria. Overall compliance was done by measuring deflection of the bridge and strains in the steel plates by ways of a loading test.
**Conclusion and Comparison of the methods**

The chosen method is highly dependent on the results of the fire damage investigation.

The investigation and assessment of fire damaged concrete and reinforcement comprises both visual inspection and the use of various tests to establish the full extent of damage and the residual quality of the in-situ concrete and reinforcement. The visual inspection should be supplemented with consideration of temperature effects of fire damage on concrete, the physical properties, petrographic examination, temperature effects on reinforcing steel and prestressing strands and the temperature effects on the concrete/steel interaction.

Fire-damaged concrete and fire-affected reinforcing steel should be replaced.

However, it is considered that although the fire-damaged concrete must be removed behind the normal steel reinforcement to afford a good mechanical key and affect a good concrete repair, the pre-stressing tendons may not have to be exposed any further if they are not physically damaged or unravelled. It is considered that leaving prestressing tendons undisturbed in somewhat lower quality, yet bonded concrete is a better result rather than replacing that concrete with repair materials. The effectiveness and efficiency of the prestress transfer to the existing fire-affected concrete would be superior to that developed after removal of the fire-affected concrete and replacement with a material which will not provide composite prestress action after the repair.

The deficit in constructive safety margins can be lifted by the innovative Japanese method.

**6.2.16 Infiltration/leaking at the abutment**

**Description of the problem.**

Short bridges with a total length up to around 40 meters are often built without specific expansion joints at the bridge ends. In the bridge shown below is leaking water at the joint in the low corner of the bridge. Because of the short length of the bridge (33.4 meters) only a primitive bitumen seal is placed in the pavement at each end of the bridge (illustration 93, right page). Because of the leak in the bitumen seal surface, water has access to the anchorage zones of the prestressed girders just below and if the leak is not repaired a critical damage will occur in those anchorage zones.

**Methods available**

*Method A: Bitumen seal – Poland - Japan*

An easy standard repair method is just to renew the bitumen seal. This method is not a durable solution and the problem with water leaking down on the girders will return within a short time.

*Method B: Sealing foam – Japan*

A more durable and innovative solution is to stop the water by filling up the gap at the bridge ends with a special sealing foam (illustrations 94, right page and 95, next page) after the deteriorated concrete and salt adhesion are removed with water jet and replaced with new concrete.

*Method C: Installation expansion joint - Japan*

A very durable but also expensive repair method is to build in a mechanical undrained expansion joint like the one shown on illustration 96, next page.
An elastic sealing material is built into the expansion joint to make it complete water tight.

**Conclusion and Comparison of the methods**
Method A and B are both relatively cheap and easy to perform. Their life span is both estimated to be short compared to method C. All three methods need to be monitored in order to evaluate their performance which may be done by principal inspections with appropriate intervals.
Method C also has a positive influence on traffic noise coming from the joint while the cars are passing over the joint.

6.2.17 Rocker Bearings Corrosion

**Description of the problem**

Corroded rocker bearing *(illustration 97, right page)*:

- The rocker bearings at the abutments of this highway-over-railway viaduct have corroded due to leaking expansion joints.
- The expansive effects of corrosion of the rocker element combined with repetitive, cyclical thermal movements over time have pushed the bearing up to 5 cm upwards.
• Cleaning the bearing (by sandblasting) would let the deck slab fall down 5 cm, destroying the expansion joint and effecting a dangerous drop/elevation in the drive way.

Methods available
Method A: New bearing at the same place

Description
In a “standard” method of bearing replacement, the bridge deck has to be lifted slightly by temporary jacks sufficient to remove and replace the existing bearings. These might require design and installation of temporary jacking brackets with associated local strengthening of the bridge.

Illustration 97 - Corroded rocker bearing: 3 – 5 cm upward displacement of the bearing; caused by the combined effects of corrosion and cyclical thermal deck movement

The old bearings are then removed and new bearings are installed at the same location. This can be difficult due to the restricted working space.

Quality assessment
Provides new bearings, with assured long term performance and durability.

Advantage/Disadvantage
• Reliability: Bearing reliability is standard. There may be reliability risk associated with operation of the temporary jacking system.
• Availability: If the bridge was not originally designed for bearing replacement then it will require assessment and likely modification for the installation of temporary jacks. It will be necessary to raise the bridge deck sufficiently to remove the existing bearings before installing the new units. At this stage the deck is supported only on temporary jacks. It is usually
necessary to interrupt traffic flow at least periodically during the process. Traffic control might be required beneath the deck to accommodate the temporary works.

- Maintainability: After installation, the bearings require regular inspection the same as other bearings.
- Safety during execution, inspection and maintenance: Safety during execution of this method is critically important when the bridge deck is being raised and supported on temporary jacks. Safety during inspection and maintenance is the same as with any other bearing.
- Financial aspect: this method requires provision for temporary jacking and traffic management associated with raising the deck.
- Sustainability aspect: Standard product, but with potential traffic congestion impacts on the environment.

**Method B: New bearing with flat jack at a new place – Japan**

**Description**

In this innovative method for bearing replacement [7]:

- New permanent bearings are provided at different locations to the existing bearings;
- equip new bearings with flat jacks (illustration 98);
- locate the new bearings close to the existing steel rocker bearings;
- transfer the bearing force by jacking (illustration 99), then;
- pour mortar around the flat jacks beneath the base of the new bearings.

![Illustration 98 - New bearing with flat jack](image)

![Illustration 99 - New bearing with flat jack: Load transfer](image)
Quality assessment
Provides new bearings, with assured long term performance and durability.

Advantage/disadvantage
- Reliability: Reliable. Minimal risks associated with jacking.
- Availability: This installation method causes minimal traffic disruption. Its adoption is limited for the cases where a location can be secured for the new bearing and for girder types which can accept the load transfer. The method requires minimal temporary works so should require minimal traffic management below deck.
- Maintainability: After installation, the bearings require regular inspection the same as other bearings.
- Safety during execution, inspection and maintenance: This installation method eliminates risk associated with reliance on external jacking.
- Financial aspect: This method does not require provision for temporary jacking and traffic management associated with conventional installation methods.
- Sustainability aspect: Standard bearing product, without potential traffic congestion impacts on the environment. Although the flat jack is made of steel, it has outstanding corrosion performance because the anti-rust treatment is applied and is covered with mortar after reaction force is transferred.

Conclusion and Comparison of the methods
If the bridge can accommodate them, then replacement bearings which incorporate their own installation jacking system offer cost and risk savings in temporary works and traffic management.

6.2.18  Bearings: Horizontal rotation of roller bearings

Description of the problem.
Structure: A multi-span steel viaduct carrying a busy, elevated, 4-lane, urban highway, constructed in 1969. The viaduct deck has 4 main longitudinal steel beams carrying transverse steel beams and a waterproofed reinforced concrete deck slab sealed in asphalt surfacing. The deck is supported on a series of reinforced concrete columns and is divided by movement joints, yielding several full-width, independent deck sections. Some deck sections are continuous over several piers, fixed at one pier and guided over the other by means of steel roller bearings, one per beam. Several rolls have moved (illustration 100, next page).

Methods available
Method A: Roller relocation – Poland
Relocation of rollers under traffic by using temporary tower supports if possible.

Method B: Roller relocation – Japan
Disassemble the corroded steel roller bearing, clean the roller and apply lubricant after cleaning. If the damage of roller is severe, replace the roller. Apply maintenance painting to arrest progress of corrosion.

Method C: New elastomeric bearing - Japan
Replace steel roller bearing with elastomeric bearing (illustration 101, next page).
Illustration 100 - The bearing problem

Illustration 101 - New elastomeric bearing
(Photographs courtesy of Japan Bridge Bearing Association.)

- Reinstate horizontal move function with shearing deformation of elastomeric.
- Reduce seismic loads for piers by improvement into horizontal force distribution system.
- Improve durability by adoption of elastomeric bearing.

**Method D: New low-friction sliding bearing - Japan**
The old roller bearing is substitute with a low-friction sliding bearing *(illustration 102, right page)*. Rehabilitation is achieved by replacing the dysfunctional bearing(s) with a low friction type sliding bearing. It is assumed that the single roller type bearing shown on the photographs is moved to
right side of the picture by slippage of roller, since the pinion required on the side of roller was lost due to breakage of its fixing bolt and the upper shoe is inclined to left-down side direction.

Single roller type bearing is likely to get damage since its direction of movement and rotation is same. Therefore, it is desirable to replace with sliding bearing which has equivalent friction factor with design friction factor of roller bearing (=0.05).

Illustration 102 - Low-friction sliding bearing

**Conclusion and Comparison of the methods**

Whilst methods A and B suggest remedial work to be performed to the existing bearings, large scale intervention may be required if the bearings are damaged beyond repair.

The technical adjudication of method C yields a high score for the following reasons:

- Increased load capacity (Seismic resistant performance is improved / can be assessed by analysis).
- Possibility of catastrophic collapse resulting from large earthquake is reduced. New method is considered as an effective measure in a country subject to frequent earthquakes like Japan.
- Since the horizontal move function is highly-trusted, maintenance cost can be reduced.
- Elastomeric bearing is resistant against corrosion and damage. Durability can be assessed by inspection and testing of materials and components.
- Cost: Higher than standard method
- Lifetime: Durability of horizontal move function is highly-trusted.
- Traffic impact: None.

Method D suggests the adoption of a pot bearing instead of a single roller type bearing, affording the possibility to retain the height by not exceeding the roller bearing and not to be restricted to movement in one direction. In addition, adoption of low friction material can restrain the horizontal force to substructure at ordinary condition.

Maintenance is easier compared to a single roller type bearing and since it is stable, unforeseen trouble such as departure of roller is unlikely. Consequently, maintenance cost can be reduced.

Conventionally, PTFE materials have been used for sliding materials. However, since its design friction coefficient (=0.10) is larger compared with roller type bearings, polyamide type sliding material (which has higher durability and lower friction property) is adopted. Since the sliding mechanism is simple and clearly visible, it is easier to detect when the bearing is damaged.

Note: The currently policy for newly constructed bridges in Japan is to prohibit single roller type bearings. In cases where single roller type bearings are still in use and the existing bridges show indications of damage, it is expected that replacement will be advanced in future.
6.2.19 Abutment Undermining (Scour)

Description of the problem
The concrete thick slab bridge was constructed in 1951 (illustration 103).

The abutment lies directly on the rock without any piles.

Due to the degradation of the rock, the bridge foundation is undermined (illustration 104).

Methods available
Two proposed and described methods are standard. Replies to foundation undermining problem we received from France, Japan, Canada Quebec and Irish Rail. Last three were similar, thus combined them into a single one and described using Japanese answer.
Method A: Gabion – France

Description
The foundation reconstruction use gabion (metallic mesh with stone filling). After reparation of damaged sections the bottom slab is reconstructed using a flexible material: gabion (*illustrations 105 and 106*).

![Illustration 105 - Gabion based rehabilitation](image1)

![Illustration 106 - Gabion based rehabilitation](image2)

General view of the method

Quality assessment
Using regular inspection there are no visible degradation until more than 10 years on the different applications.

Advantage/Disadvantage
- Reliability: simple and robust method. Using a flexible material is interesting regarding future settlement of the river bed.
- Availability: this method may require stopping of the water flow during reparation
- Maintainability: There is nearly no maintenance, except regular inspection.
• Safety during execution, inspection and maintenance: no specific aspect except working in a river.
• Financial aspect: This method is cheap and quick.
• Sustainability aspect: Use of natural material (stones) and extending bridge lifetime.

Method B: High strength and workable concrete – Japan, similar declared Canada Quebec and Irish Rail

Description
Scour protection by setting concrete form made of high-strength and high-workable reinforced concrete (Flow-value: 56-60). The casting is 1 m width and 20 cm higher than the waste concrete level (illustration 107).

Illustration 107 - General view of the method

Quality assessment
Quality test performed during construction allow to control concrete strength resistance and confirm the correct self-compaction of the high-strength and high-workable concrete.
Advantage/Disadvantage

- Reliability: This is an improvement of the standard method which consists in a normal re-concreting of the pier.
- Availability: Using high-strength and high workable concrete, the traffic restriction on the bridge is reduced (4 days works)
- Maintainability: There is no maintenance, except regular inspection.
- Safety during execution, inspection and maintenance: no specific aspect except working in a river.
- Financial aspect: The repair cost becomes expensive; rather use standard concrete. However traffic restriction on the bridge is reduced by shortening the work duration.
- Sustainability aspect: Use of new concrete with different adjuvant. The bridge lifetime is extended.

Conclusion and Comparison of the methods

Strengthening of the river bed with method A is ecological (natural material filling the gabion) and cheap. Although method A will protect abutment against further undermining needs to reconstruct the damaged section first.

Scour protection presented by method B reduces the repair period and the traffic restriction period to minimum (approx. a week after the identification of foundation scour) by application of high strength concrete. Cost of the repair is higher rather than the standard method. However, socio-economic impact can be reduced by shortening the traffic restriction period. Foundation is well-protected against undermining in the future.

Note: Concrete strength test and confirmation of self-compatibility of high-strength and high-workability concrete needs to be done after casting the form.

Both methods are easy to maintain – no action needed in the future, extending also bridge lifetime.

6.2.20 Metallic culvert corrosion

Description of the problem

The steel soil structure is crossed by a river (Illustration 108).

Illustration 108 - General view of the steel soil structure
A complete steel dissolution is observed at several places under the water level of the river (illustrations 109 and 110). This impacts the stability of the culvert.

Methods available

**Method A: Glass reinforced polymer lining – United Kingdom**

*Description*

Glass Reinforced Polymer Lining (and grouting) of the culvert (illustration 111). This method was more used with brick construction but may be use also with steel-soil structure.
This method prevents further degradation and deformation of the culvert. Smooth finish led to improved water flow through structure.

In Quebec a similar solution is applied with PVC tube and in Poland they use a shotcrete layer.

**Quality assessment**
Biannual inspection of the structure identifies deterioration and its causes.

**Advantage/Disadvantage**
- Reliability:
- Availability: Zero disruption to road above,
- Maintainability:
- Safety during execution, inspection and maintenance: prefabrication of liner allowed less site based staff carrying out installation only.
- Financial aspect:
- Sustainability aspect: Preserved original material, very little waste. Enhanced rather than replaced strength capacity of existing culvert.

**Method B: Cathodic protection – Belgium**

**Description**
The culvert is only corroded in the lower part. The strengthening is only needed at that place. It is done by a local reinforced concrete structure (*illustrations 112 and 113, next page*). However, corrosion may continue on the back side of the steel. The solution is completed by a cathodic protection (*illustration 114, next page*) to slow down even stop corrosion of external and internal steel faces. With the CP, only reduction reaction (cathode) will take place on the steel structure.

Sacrificial anodes are placed in the soil (to protect external steel face) and in the concrete (to protect internal steel face).

In order to allow river transit during the rehabilitation works, tubes are placed in the concrete structure. There is no deviation of the river.

*Illustration 112 - Principle of reinforcement*
Quality assessment
Different controls have to be done during execution:

- Electric continuity measurement
- Current intensity measurement
- Performance of the remote control

Advantage/Disadvantage
- Reliability: This is a first application. Regular inspection will permit better appreciation of the reliability of the method.
- Availability: Zero disruption to road above,
- Maintainability: This method needs a continuous control of the current injected to the cathode throughout its life time.
- Safety during execution, inspection and maintenance: Execution is not easy for the workers due to the small dimension of the culvert.
- Financial aspect: In addition to the concreting, the cost of the installation is about 25,000 to 30,000 €. Electrical provision is not included.
- Sustainability aspect: Need continuously provision of electricity and renewing of the sacrificed anodes (after 20 years).
• Sustainability aspect: Preserved original material, very little waste. Enhanced rather than replaced strength capacity of existing culvert.

Conclusion and Comparison of the methods
The first solution realizes a new structure inside the original culvert. It may be a glass reinforced lining, a PVC tube or a shotcrete layer. It is important to evaluate the load and hydraulic capacity of the new structure. It may be insufficient.

The method B is more a rehabilitation method. It needs a continuous maintenance of the system throughout the remaining lifetime of the bridge

7. CONCLUSIONS

At the end of this report, it appears that the most common bridge degradation problems concern reinforced and prestressed concrete bridges, and more specifically they are corrosion problems. Many of these problems are related to internal post-tensioning tendons. This is due to the fact that this technology has been widely used in several bridge stocks, that evidence of the beginning of degradation is difficult to observe, and that the rehabilitation methods are not easy to find and to apply.

For steel bridges, fatigue cracks have become a larger problem than originally imagined. This problematic situation is coming up in an increasing way with aging structures.

Many rehabilitation methods have been detailed in this report. Eventually it is only a partial overview limited to the 59 answers received, but one may observe the following:

• The increase of real rehabilitation methods that preserve the structures instead of replacing part of them. Cathodic protection is a good example.
• The frequent use in some countries of fibre reinforced polymer (FRP) plates or sheets with occasional use of post-tensioning of those elements.
• If partial replacement of concrete elements remains a necessity, the evolution in the concrete technology offers different new options such as lightweight or high performance concrete, or reinforcement with fibres.

Innovative methods are already used by road administrations who responded our questionnaire. But these interventions must become more numerous and more ambitious. Of course, whether a method is considered innovative or not differs around the world. Meanwhile the received answers do not indicate a geographical or national influence on the innovative approach. Nevertheless, it seems normal that innovative methods are experimented mostly in developed countries, where different R & D projects are more common.

In the same way, it is not possible to conclude that there is a cultural difference among the practices in different countries.

Looking to all the rehabilitation methods, it appears clear that quality assessment of the product or the method is not yet applied enough. Bridge engineers need to develop this aspect in the future. However this aspect is not the only important aspect of a rehabilitation method. Availability, maintainability and safety have become topics that are progressively significant.
Facing degradation problem, bridge engineers have to compare different rehabilitation methods and to choose one of them. In a large majority of countries, this is done by the road administration. In few countries, as in the Netherlands, this is done by the contractor involved in the rehabilitation project, on the basis of the performance criteria given by the road administration.

The analysis and the proposed solutions to address degradation problems should be done progressively in collaboration with materials specialists and also experts in financial analysis, resulting in more frequent «life-cycle cost analysis» (LCCA), even for rehabilitation projects. A «far-future» objective will be to include a life cycle analysis («cradle-to-grave») in order to consider the global impact of one intervention compared to another.

In this report, the financial aspect has also been considered for the analysis of rehabilitation methods. However, relevant information has been difficult to collect. First, the participants to the questionnaire seem not to feel able to provide precise financial information. Second, given that contracts are different from one country to another, it has been difficult to determine what are the services really included in a price and consequently to compare them.

The next challenge in the future will probably be to find technical solutions to upgrade existing bridges. It already appears with some projects that increase bridge service level (increasing lane number and load capacity).

Acting on the source of the problem remains also essential. For example, it is and still will be in a near-future a true and considerable challenge to avoid chlorides ingress in concrete bridges elements.

All those informations on degradation problems and rehabilitation methods are very important for bridge designers. Unfortunately, there is quite a substantial time between the construction and the appearance of a degradation process in a bridge, which delays the feedback loop of the effectiveness of a specific design. Meanwhile, information exchanges must increase between bridge design, bridge inspection and bridge maintenance technical teams, and also with bridge management staff.

Finally, facing to an ever-aging bridge stock requiring rehabilitation, bridge engineers must think out of the box and be incited to use innovative practices, on the basis of reliable assessing methods. This challenge seems to be the same all around the world.

8. BIBLIOGRAPHY / REFERENCES


APPENDICES

1. FIRST BLANK QUESTIONNAIRE: DEGRADATION PROBLEMS

2. SECOND BLANK QUESTIONNAIRE: REHABILITATION METHODS

APPENDIX 1 - FIRST BLANK QUESTIONNAIRE: DEGRADATION PROBLEMS

Dear TC 4.3 colleague,

In relation with issue 4.3.2: *New repair and rehabilitation methods*, group 2 members would like to examine several degradation problems that can occur on bridges and compare different innovative repair and rehabilitation methods that can be applied to solve these problems. Methods can be innovative by the technique, the way to take traffic into account and/or the reduction of the ecological footprint.

In order to select to most interesting degradation problems group 2 members would like to present you this first questionnaire.

Please give, at your opinion, the most relevant degradation problems to be examined on the point of view of repair and rehabilitation, in regard of different categories. Add a short description of the degradation problem. You may propose different problems for one category. If you are not concerned by a category, simply write: “not concerned”.

Example:

Prestressed concrete bridge structure (excluding slab):
- Prestressing lost by corrosion: corrosion of post-tensioned cables due to infiltration of water with de-icing salts through the anchorage or the upper part of the duct (near the pile).
- Impact due to overheight vehicles: cracks in concrete and prestressed tendons rupture.
- Settlement of the structure due to cables and/or concrete creep.

Wood bridge:
- not concerned

Tip also the 5 most important categories at your opinion.

_Please send your filled questionnaire before 30th June 2012 at the following e-mail address:_

*pierre.gilles@spw.wallonie.be*

We will be back to you in 2013. At that time on the basis of the selected degradation problems, we will ask you (and also other members of the World Road Association), to present your repair and rehabilitation methods, and if applicable your experience of innovative ones, in order to manage these degradation problems.

Thank you for your contribution.
TC 4.3 – Group 2 – First questionnaire

Filled by:

Name:

Country:

At my opinion, for the following categories, the most interesting degradation problems to be examined on the point of view of repair and rehabilitation methods are:

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<th>Please tip the 5 most important categories to be study</th>
<th>Categories and degradation problems</th>
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<td>Reinforced concrete bridge element (excluding slab):</td>
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<td>Prestressed concrete bridge element by pre tension (excluding slab):</td>
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<td>Prestressed concrete bridge element by post tension (excluding slab):</td>
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<td>Masonry and stone bridges:</td>
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<td>Cable bridge element: suspension and stay cables (excluding slab):</td>
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<td>Culverts (concrete and/or steel/soil structure):</td>
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APPENDIX 2 - SECOND BLANK QUESTIONNAIRE: REHABILITATION METHODS

PIARC Technical Committee 4.3 Road Bridges
Working Group 2 – New repair and rehabilitation methods

August 2013

Dear colleagues,

Are you involved in bridges rehabilitation? In that case, PIARC needs your contribution!

ABOUT PIARC

The World Road Association was created, more than 100 years ago under the name of the Permanent International Association of Road Congresses (PIARC). Its vision is to be a leader in the exchange of knowledge on road transport practices within an integrated sustainable transport context. The World Road Association is participating in this effort through the work of its Technical Committees composed of experts appointed by member governments. For the present cycle (2012-2015), the goal of the strategic theme related to bridges (Theme 4 – Infrastructure) is to improve the quality and efficiency of road infrastructure through the effective management of assets in accordance with user expectations and government requirements while adapting to climate change and changing energy scenarios and policies.

It is in this context that the Technical Committee TC 4.3 Road Bridges, through its Working Group 2, is involved in the Issue 4.3.2 - New Repair and Rehabilitation Methods, and will undertake:

- a review of the new repair and rehabilitation methods, including materials, developed and/or installed and/or studied by consideration of their cost-effectiveness;
- a review of the methodologies for assessing the new repair and rehabilitation methods and materials.

ABOUT THE QUESTIONNAIRE

Working Group 2 wants to compare new repair and rehabilitations methods used in different country. Twenty-two (22) degradations cases have been prepared, mainly based on existing cases.

We do not expect that recipients will complete every section. However, for those cases, where you have some experience, we ask you to please describe repair or rehabilitation methods that you already realised and which can be considered as «new» or innovative for you, at least as far as concern the experience in your country.

You can download the full questionnaire at this address: https://echangefichiers.spw.wallonie.be/easyshare/fwd/link=vdjG.2JOk8Rv.1_VKHldID in English.

Please feel free to add photos (without copyright) and drawings to your answers.
The completed questionnaire has to be sent with www.wetransfer.com at e-mail address pierre.gilles@spw.wallonie.be up to 30th September 2013.

All these data will be analysed and compared in a final report available for free in late 2015 on PIARC website: www.piarc.org. The report will present new repair and rehabilitation methods with advantages and disadvantages of each method. The methodologies to assess these methods will also be described in order to bring more confidence with them.

ABOUT THE BENEFIT TO ANSWER

The collective aims are very important to all bridge specialists and could have benefits for both developed countries and countries in transition. It could also help you to improve the way you manage your ageing bridge stock.

Your input is very important to the success of this project. We know the task it represents to complete this questionnaire. I implore you to take the time to fill in and submit this questionnaire (or to contact a more appropriated person to do so) and to consider it as a contribution in the Association’s Vision to be one of the world leaders in the exchange of knowledge.

Best regards

Pierre GILLES (Belgium)  
Leader - Working Group 2 - TC 4.3 Road Bridges  
pierre.gilles@spw.wallonie.be