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ADVANCEMENT OF INSPECTION TECHNIQUES / TECHNOLOGIES AS A PART OF BRIDGE MANAGEMENT SYSTEMS

A PIARC TECHNICAL REPORT

TECHNICAL COMMITTEE 4.2 *BRIDGE COMMITTEE*

PIARC

STATEMENTS

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

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020– 2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions, and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organizations or agencies.

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World Road Association (PIARC)
Arche Sud 5° niveau
92055 La Défense cedex, France

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A PIARC TECHNICAL REPORT

TECHNICAL COMMITTEE 4.2 *ROAD BRIDGES*

AUTHORS/ ACKNOWLEDGEMENTS

This report has been prepared by Working Group 2 of the Technical Committee TC 4.2 of the World Road Association (PIARC).

The contributors to the preparation of this report are:

- Gonzalo Arias Hofman (Spain)
- Matej Kusar (Slovenia)
- Dimitrios Papastergiou (Switzerland)
- Erwin Pilch (Austria)
- Jean-Luc Dabert (France)
- Fairul Z. M. Abas (Malaysia)
- Feng Pengcheng (China)
- Kazuo Endo (Japan)
- Krzysztof Zoltowski (Poland)
- Hee Chul Kim (South Korea)
- Heungbae Gil (South Korea)
- Hyun-Ho Choi (South Korea)
- Lilia Sifaoui (Tunisia)
- Mahamadou Bachirou Nakoira Abba (Niger)
- Marcelo Marquez (Chile)
- Masafumi Kamata (Japan)
- Michele Mele (Italy)
- Morten Wright Hansen (Norway)
- Olari Valter (Estonia)
- Peter Augscholl (Austria)
- Sébastien Flawinne (Belgium)
- Veronique Mauvisseau (France)

The editors of this report are Joseph Hartmann (USA) for the English version, Jean-Luc Dabert (France) for the French version and Gonzalo Arias Hofman (Spain) for the Spanish version.

The Technical Committee was chaired by Kiyohiro IMAI (Japan), and Pierre GILLES (Belgium), Joseph Hartmann (USA) and Gonzalo Arias Hofman (Spain) were the French, English and Spanish-speaking secretaries, respectively.

EXECUTIVE SUMMARY

2023R19EN

ADVANCEMENT OF INSPECTION TECHNIQUES / TECHNOLOGIES AS A PART OF BRIDGE MANAGEMENT SYSTEMS

A PIARC TECHNICAL REPORT

New techniques and technologies are constantly emerging and changing that affect our lives in many ways. For example, advances in communication via online tools enable us to do our work even in times of a pandemic.

When it comes to bridge inspection as part of a holistic bridge management system, new tools resulting from technological advancements allow engineers to improve their work by getting a better picture of the current condition of a bridge. Innovative inspection techniques and technologies are appropriate for modern asset management where information is needed as soon as possible and in large quantity to efficiently manage an aging bridge stock.

These new and innovative techniques and technologies have been proven to offer better solutions than what has been previously available. They provide all the necessary information to support regular maintenance of a bridge and to justify rehabilitation, when needed. It is also worth noting that traditional methods have worked generally well for the basic function of bridge inspection. However, they include limitations that often required labor intensive activities or traffic restrictions that currently pose challenges to the surrounding built and natural environments.

This technical report provides a compilation of innovative and advanced techniques and technologies for bridge inspection gathered from 14 different countries in Europe, North America, and Asia. The information from the respective countries was collected through systematic survey forms and questionnaires as well as related case studies. The responses were analyzed and categorized by inspection area, function, and components of a bridge. Therefore, it gives an insight perspective of inspection techniques and methods that are used by the asset owners and operators to better manage their bridge stock. The adaptability of bridge inspection to the current challenges of climate change is also addressed in this report.

The focus of the report is on modern techniques and technologies which should not be considered as unique solutions but as alternatives and complementary to traditional ones. It is the expectation of the working group that this technical report will disseminate a useful and up-to-date source for anyone charged with the task to inspect and assess bridge infrastructure.

CONTENTS

1. INTRODUCTION

PIARC, also referred to as the World Road Association, was established in 1909 as a non-profit and non-political organization with the broad aim of promoting international cooperation on issues related to roads and road transport. It has over 100 members of which around two thirds are developing countries or countries in transition. Its vision is to be the world leader in the exchange of knowledge on roads, road transport policy and road transport practices within an integrated sustainable transport context.

The World Road Association achieves its vision through a series of technical committees established within four themes as part of its Strategic Plan. The themes for the 2020 – 2023 cycle were:

- ST1. Road Administration.
- ST2. Mobility.
- ST3. Safety and Sustainability.
- ST4. Resilient Infrastructure.

The goal of Strategic Theme ST4 was to improve the quality of road infrastructure through the effective management of assets in accordance with user expectations and managers' requests. While new technologies, social and environmental developments are expanding the sphere of interest for road authorities, infrastructure and asset management remains their core business. The need for more efficient use of funds requires constant improvement in techniques in terms of the design, management, and maintenance of assets.

Technical Committee (TC 4.2), Road Bridges, was divided into 2 working groups to satisfy the strategic plan themes dealing with the five issues it was assigned. This report presents the contribution of Working Group 2 of TC 4.2 to address the third assigned issue, Advancement of Inspection Techniques/Technologies as a Part of Bridge Management Systems.

1.1. PURPOSE

Technologies have an ever-increasing presence in our lives, homes, and jobs. In this sense, the use and knowledge of new inspection techniques and technologies that can be applied to the inspection of bridges acquires increasing importance.

In that context, this effort was about identifying techniques and technologies that can produce not only more detailed, comprehensive, and precise information on the state of conservation of a bridge, but also the possibility of knowing the state of an element of the bridge that, with traditional techniques of inspection and without technological aids, was previously hidden and unknown, or where only very limited and partial knowledge could be developed.

The prevailing globalization of advancement in our lives allows us to think about the use of these new techniques and the technologies they rely on in almost any country around the world. To that end, countries can learn from the best practices included in the responses obtained from both the general questionnaire and the collection of case studies what these techniques are and through what technologies they can be applied, to improve the methods and scope of bridge inspection in their bridge management programs.

1.2. Scope

The scope of this work was to present new bridge inspection techniques and the technologies that support improvement of the quality of the information obtained in bridge inspections, and that is used to justify actions within a bridge management system. Also included are those techniques and technologies that make it possible to obtain information on elements and areas of the bridges that were previously inaccessible.

1.3. Limitations

The inspections contemplated in this document for the application of new techniques and technologies are typically the periodic principal inspections of bridges within a bridge management system, but also special inspections for those more sophisticated or complex techniques.

The types of bridges considered in this study are conventional concrete or steel, non-composite or composite bridges, but also include cable stayed, cable suspended, masonry arch, and timber bridges.

1.4. Methodology

The methodology used in this investigation was to seek out and gather information from member countries of TC 4.2 on experiences and practices applying new inspection techniques and technologies as a part of bridge management systems. This was accomplished through a survey based on a specifically developed questionnaire and case study template that invited the member countries to describe their experiences and practices and to share examples. The responses received were then compared and analyzed, the result of which was the production of this technical report containing a consolidated set of best practice guidelines and recommendations.

2. REQUIREMENTS OF INSPECTIONS

The following chapter gives a brief outline of the general context into which the present investigation is placed. A concise compilation of the basic principles, terms, and interrelations in the broad field of bridge inspection is presented. Based on this overview, a set of fundamental requirements are identified which relate to the future inspection of bridges and which should be considered when the actual techniques and technologies are applied in each country.

The general objectives of bridge inspection are:

- the preservation of sufficient safety (comprising structural, road, operational, road user, and environmental safeties),
- the securing of sufficient serviceability,
- the conservation of basic bridge elements,
- the conservation of both the cultural and economic values of the construction, and
- the management of risk during the bridge's service life.

The inspection of bridges involves activities related to:

- the management or administration of a bridge (including periodical targeted surveillances and inspections, if needed, also check measurements or monitoring),
- the implementation of urgent safety measures, if needed,
- the examination of the elements of a bridge (including condition surveys, condition evaluations and subsequent recommendations of intervention measures), and
- the planning and execution of intervention measures.

As stated in Chapter 1.3, this report is limited to the consideration of those activities related to the inspection of bridges. These include principal inspections - done every 4 to 5 years in some countries – and special inspections, carried out to investigate a specific problem or issue on a bridge.

This report attempts to illustrate the most advanced inspection techniques and the technologies which support those techniques, as a part of a bridge management system.

3. QUESTIONNAIRE AND CASE STUDY – DEVELOPMENT AND REVIEW OF RESPONSES

1.1. DEVELOPMENT OF THE QUESTIONNAIRE AND CASE STUDY TEMPLATE

A questionnaire and case study were developed to gather the practices and examples from PIARC member countries of TC 4.2. The questionnaire was divided into four parts:

Part 1: Standards & Codes

> This part of the questionnaire inquired about the references for inspection techniques and technologies in the Standards and Codes used in each country. There were 3 questions in this part.

Part 2: Techniques & technologies

> This part of the questionnaire inquired about the details of any new inspection techniques and technologies for different bridge elements (e.g., post-tensioning anchorages) or the application of specific techniques (e.g., robotized solutions). There were 11 questions in this part.

Part 3: Climate change

> This part of the questionnaire aimed to identify the relation, if any, between the new inspection techniques and technologies and climate change. There were 3 questions in this part.

Part 4: Case Study

> A case study template was used to collect examples from member countries on appropriate techniques and technologies that facilitate the inspection of a bridge and/or bridge elements.

For each question, examples of responses were provided to aid in the understanding of the question considering the potential for differences in interpretation due to the primary language of the different nationalities polled. Respondents were also asked to provide references for their answers if the answer was established in documented design codes, standards, procedural manuals, guidelines, and/or national legislation. Due to time constraints, the questionnaire and case study were produced only in English. However, from the responses received, this did not prove to be a deterrent in responding.

Refer to Appendix A for the questionnaire and case study template developed.

1.2. Overview Of Responses

In response to Parts 1 to 3 of the questionnaire, 14 responses were received from the same number of countries, while 28 responses from 10 different countries were received for the case study (Part 4). Table 1 below presents a summary of the responses to the questionnaire and case study.

Country	Person	Organization	Description of Organization	Questionnaire	Case Study
Austria	Peter Augschöll	ASFINAG	Austrian infrastructure company for managing all motorways in Austria	Yes	Yes (1)
Belgium – Wallonia	Patrice Toussaint	Direction de l'Expertise des Ouvrages	We carry out expert appraisals and specialized controls on engineering structures managed by the Walloon Region	Yes	Yes (1)
Chile	Marcelo Marquez	Ministerio de Obras Públicas	Public Entity in charge of the Bridges in Chile	Yes	Yes (1)
Estonia				Yes	No
France	French mirror group 4.2.3 (facilitator DABERT Jean-luc) HOUEL Adrien; GODART Bruno; SCHMIDT Franziska; ORCESI André; BOUVET AGNELLI Cecile; PLASSARD Florent; LOPEZ Sylvain; FASQUEL CLEMENT; PAYAN Raymond; ROIBET Adrien; LECONTE Renaud; BESSOULE Nicolas; COLLIN Bertrand	French mirror committee WG 4.2.3 / ASFA APRR animation French organizations contributing actors	Grouping of French players in the field of civil engineering structures, led by the Association des Sociétés Françaises d'Autoroutes (Association of French Motorway Companies). Ministry of ecological transition / transport infrastructure department; Gustave Eiffel University UGE including IFSTTAR; Centre for technical study and testing in the field of civil engineering CEREMA; concession motorway companies (APRR, Vinci autoroutes, CCI Seine estuaire); local authority in charge of the departmental road network (Gers); private engineering offices (Quadric, Diades, Sixense, Sites)	Yes	Yes (12)
Italy	Ing. Maurizio Deiana	Autostrada dei Fiori SpA - A6 Highway	The Concessionary *Autostrada dei Fiori* manages the motorway A6 since 2014. The A6 connected Torino ring road to Savona	Yes	Yes (2)
Japan		Honshu-Shikoku Bridge Expressway Company Limited (HSBE)	One of 6 expressway companies in Japan. Especially, it operates long span bridges including Akashi Kaikyo Bridge, Seto-Ohashi Bridges, Tatara Bridge, and Kurushima Kaikyo Bridges	Yes	Yes (4)

Country	Person	Organization	Description of Organization	Questionnaire	Case Study
South Korea	Heungbae GIL	Korea Expressway Corporation (KEC)	KEC is the public corporation to construct and maintain paid expressway networks in South Korea	Yes	No
Portugal	Sérgio Pereira	IP – Infraestruturas de Portugal	IP is a public company that manages road and rail infrastructure. The purpose of IP is the conception, design, construction, financing, conservation, operation, requalification, enlargement and modernization of the national road and rail networks, including the command and control of circulation	Yes	Yes (2)
Slovenia	Matej Kušar	DRI Investment Management Ltd.	DRI is the largest consulting and engineering company in Slovenia. It is state owned. We provide services of investment engineering, management of investments in public infrastructure and other consulting services according to the "in-house" contract model	Yes	Yes (1)
Spain	Gonzalo ARIAS HOFMAN (indep. consultant commissioned by MITMA)	Ministerio de Transportes, Movilidad y Agenda Urbana (MITMA)	MITMA is the Ministry for the construction and maintenance of the road and railway infrastructure in Spain National network	Yes	No
Switzerland	Laurent Meyer Dimitrios Papastergiou	Swiss Federal Roads Office (FEDRO)	Asset owner of the swiss national roads network, 2254,5 km	Yes	Yes (1)
USA – FHWA	Joseph Hartmann	Federal Highway Administration	National level governmental agency.	Yes	No
Poland	Prof. Jan Bień Dr Mieszko Kużawa	Wroclaw University of Science and Technology	WUST Training Center for Bridge Inspectors for 25 years is organizing special courses for inspectors of road and railway bridges - on various levels of specialization	Yes	Yes (3)
TOTAL				**14**	**28**

Table 1: Summary of Organizations responding to questionnaire.

Tables 2 to 4 below reveal how Parts 1 to 3 of the questionnaire were answered. A full summary of all the answers is given in Appendix B. A review of the answers indicates that there may be variation in some instances due to an explicit interpretation of the question.

Each answer is assigned as « 0 », « 1 » or « 2 », and the meaning for each value is explained under each question in the following tables.

	1.0 Questions related to Standards & Codes		
	1.1 Inspection Strategy. Do you use a known repository[1] and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?
	0: Nothing but visual or simple items 1: some advanced technologies 2: many advanced technologies	0: Not mandatory 1: Not mandatory, but performed in singular bridges 2: Mandatory and/or performed in all bridges	0: Nothing is considered 1: in some environments or just considering accessibility problems 2: in several environments
Austria	1	0	0
Belgium - Wallonia	1	0	1
Chile	0	2	1
Estonia	1	0	0
France	2	1	1
Italy	1	0	1
Japan	1	1	1
South Korea	1	2	1
Portugal	2	1	1

[1] Repository means a data base for storage the information

	1.0 Questions related to Standards & Codes		
	1.1 Inspection Strategy. Do you use a known repository[1] and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?
	0: Nothing but visual or simple items 1: some advanced technologies 2: many advanced technologies	0: Not mandatory 1: Not mandatory, but performed in singular bridges 2: Mandatory and/or performed in all bridges	0: Nothing is considered 1: in some environments or just considering accessibility problems 2: in several environments
Slovenia	1	1	1
Spain	1	1	1
Switzerland	2	1	1
USA - FHWA	2	1	0
Poland	1	0	1
0	7%	36%	21%
1	64%	50%	79%
2	29%	14%	0%

Table 2: Summary of how Part 1 of the questionnaire was answered regarding Standards & Codes

	2.0 Questions related to techniques & technologies (1/4)		
	2.1 Which techniques or technologies are commonly used within the inspections of visible areas of the bridge (drones, scan 3D, photogrammetry, pattern recognition, automatic damage detection, digital mock-up, satellite monitoring,…)	2.2 Which techniques or technologies are commonly used within the underwater inspection of submerged bridge components (scanner, underwater drones, detection of scouring…)	2.3 Is construction monitoring extended and converted to long-term monitoring to facilitate the bridge surveillance (topography, corrosion monitoring, instrumentation…)? Use of RFID -Radio Frequency Identification- sensors embedded during construction and used during operation?
	0: no technologies commonly used (only visual) 1: up to 3 technologies commonly used 2: more than 3 technologies commonly used or automatic detection	0: no technologies used or just divers 1: visual helpful technologies 2: other advanced technologies	0: use of monitoring but in construction period and no RFID sensors used 1: use of monitoring after construction period or RFID sensors used 2: use of monitoring after construction period and RFID sensors used
Austria	1	2	1
Belgium - Wallonia	1	0	0
Chile	2	2	1
Estonia	1	0	1
France	1	2	1
Italy	2	1	1
Japan	2	1	1
South Korea	0	1	1
Portugal	0	2	1
Slovenia	0	2	1
Spain	2	0	1
Switzerland	1	2	0

	2.0 Questions related to techniques & technologies (1/4)		
	2.1 Which techniques or technologies are commonly used within the inspections of visible areas of the bridge (drones, scan 3D, photogrammetry, pattern recognition, automatic damage detection, digital mock-up, satellite monitoring,…)	2.2 Which techniques or technologies are commonly used within the underwater inspection of submerged bridge components (scanner, underwater drones, detection of scouring…)	2.3 Is construction monitoring extended and converted to long-term monitoring to facilitate the bridge surveillance (topography, corrosion monitoring, instrumentation…)? Use of RFID -Radio Frequency Identification- sensors embedded during construction and used during operation?
	0: no technologies commonly used (only visual) 1: up to 3 technologies commonly used 2: more than 3 technologies commonly used or automatic detection	0: no technologies used or just divers 1: visual helpful technologies 2: other advanced technologies	0: use of monitoring but in construction period and no RFID sensors used 1: use of monitoring after construction period or RFID sensors used 2: use of monitoring after construction period and RFID sensors used
USA – FHWA	1	2	0
Poland	2	0	0
0	21%	29%	29%
1	43%	21%	71%
2	36%	50%	0%

Table 3.1: Summary of how Part 2 of the questionnaire was answered regarding techniques & technologies

	2.0 Questions related to techniques & technologies (2/4)		
	2.4 Instrumented bridge (BWIM -weight in motion-, predictive monitoring, overload)	2.5 How it is managed the inspection of inaccessible parts (operation of traffic lanes, …)?	2.6 It is frequent the use of buried control samples (e.g. reinforced earth, shallow foundations, deep foundations…)?
	0: no BWIM in any bridge 1: BWIM at an experimental stage 2: BWIM working in bridges	0: no remote technologies or traffic lanes deviation used 1: use of remote technologies and traffic restrictions in night or weekend periods 2: use of remote technologies with no traffic restrictions	0: non systematic use of buried control samples 1: use of buried control samples in some cases 2: systematic or mandatory use of buried control samples
Austria	1	1	0
Belgium – Wallonia	0	0	0
Chile	0	0	2
Estonia	1	0	2
France	1	1	0
Italy	2	0	0
Japan	1	0	2
South Korea	2	0	2
Portugal	1	0	0
Slovenia	2	0	0
Spain	0	0	1
Switzerland	2	0	0
USA - FHWA	1	0	2
Poland	1	1	0
0	21%	79%	57%
1	50%	21%	7%
2	29%	0%	36%

Table 4.2: Summary of how Part 2 of the questionnaire was answered regarding techniques & technologies

	2.0 Questions related to techniques & technologies (3/4)		
	2.7 How it is done the geometric characterization of hidden parts of bridges?	2.8 Inspection of post-tensioning anchorages? Methods and means?	2.9 Do you use high efficiency testing and monitoring techniques? (example with waterproofing layer)? (new technologies are used for testing bridge elements or not)
	0: non systematic method 1: use of shafts 2: combination of shafts and new technologies	0: no inspection at all 1: aleatory inspection 2: systematic inspection	0: new technologies are not applied on the knowledge of existing bridges 1: it is possible to use new technologies in deeper investigations of elements 2: new technologies are widely used in testing elements
Austria	1	1	0
Belgium - Wallonia	0	0	0
Chile	2	0	0
Estonia	1	2	0
France	1	2	0
Italy	0	2	0
Japan	2	2	0
South Korea	0	0	0
Portugal	0	1	0
Slovenia	0	2	1
Spain	0	0	1
Switzerland	0	2	0
USA - FHWA	0	2	1
Poland	1	0	0
0	57%	36%	79%
1	29%	14%	21%

	2.0 Questions related to techniques & technologies (3/4)		
	2.7 How it is done the geometric characterization of hidden parts of bridges?	2.8 Inspection of post-tensioning anchorages? Methods and means?	2.9 Do you use high efficiency testing and monitoring techniques? (example with waterproofing layer)? (new technologies are used for testing bridge elements or not)
	0: non systematic method 1: use of shafts 2: combination of shafts and new technologies	0: no inspection at all 1: aleatory inspection 2: systematic inspection	0: new technologies are not applied on the knowledge of existing bridges 1: it is possible to use new technologies in deeper investigations of elements 2: new technologies are widely used in testing elements
2	14%	50%	0%

Table 5.3: Summary of how Part 2 of the questionnaire was answered regarding techniques & technologies

	2.0 Questions related to techniques & technologies (4/4)		
	2.10 Use of robotized solutions for bridge inspection?	2.11 Use of SHM in link with traditional inspection strategies	
	0: no use 1: it is used just in a few elements 2: it is used for the whole bridge	0: no SHM is used 1: if there is an SHM no visual inspection are carried out 2: SHM and visual inspections are used combined	
Austria	0	1	
Belgium - Wallonia	0	0	
Chile	2	0	
Estonia	0	0	
France	1	1	
Italy	2	2	
Japan	0	1	
South Korea	1	1	
Portugal	0	2	
Slovenia	0	0	
Spain	2	1	
Switzerland	0	1	
USA - FHWA	1	1	
Poland	1	2	
0	50%	29%	
1	29%	50%	
2	21%	21%	

Table 6.4: Summary of how Part 2 of the questionnaire was answered regarding techniques & technologies

	3.0 Questions related to climate change		
	3.1 The use of advanced inspection techniques & technologies has increased due to the climate change evidences? e.g. More frequent extreme natural hazards	3.2 Is there any specific advanced inspection technique or technology that can confirm climate change evidence? e.g. monitoring of scour at substructure, temperature records...	3.3 Do you specifically monitor bridges with regard to an exceptional climatic event (flood, strong wind, landslide, drought, etc.) in order to verify its behavior and the maintenance of its performances? Explain one of these equipments to us
	0: no increment of use of new technologies due to CG evidences 1: some technologies are used for specific hazards 2: there is a wide use of new technologies for any kind of CG evidence	0: no new technologies are uses to confirm CG 1: the use of new technologies is applied for specific hazards confirmation 2: the use of new technologies is applied for any kind of hazards confirmation	0: no monitoring system is used regarded to an exceptional climate event 1: monitoring system are used regarded to specific climate event 2: monitoring system are used regarded to all kind of climate event
Austria	0	1	0
Belgium - Wallonia	0	0	0
Chile	2	2	2
Estonia	2	0	0
France	1	0	1
Italy	1	1	1
Japan	0	0	2
South Korea	1	0	2
Portugal	0	0	0
Slovenia	0	0	0
Spain	0	0	2
Switzerland	0	1	2
USA - FHWA	0	0	1
Poland	0	1	0
0	64%	64%	43%

	3.0 Questions related to climate change		
	3.1 The use of advanced inspection techniques & technologies has increased due to the climate change evidences? e.g. More frequent extreme natural hazards	3.2 Is there any specific advanced inspection technique or technology that can confirm climate change evidence? e.g. monitoring of scour at substructure, temperature records…	3.3 Do you specifically monitor bridges with regard to an exceptional climatic event (flood, strong wind, landslide, drought, etc.) in order to verify its behavior and the maintenance of its performances? Explain one of these equipments to us
	0: no increment of use of new technologies due to CG evidences 1: some technologies are used for specific hazards 2: there is a wide use of new technologies for any kind of CG evidence	0: no new technologies are uses to confirm CG 1: the use of new technologies is applied for specific hazards confirmation 2: the use of new technologies is applied for any kind of hazards confirmation	0: no monitoring system is used regarded to an exceptional climate event 1: monitoring system are used regarded to specific climate event 2: monitoring system are used regarded to all kind of climate event
1	21%	29%	21%
2	14%	7%	36%

Table 7: Summary of how Part 3 of the questionnaire was answered regarding Climate Change

Sections 3.3 to 3.5 discuss the individual responses to the questionnaire from each country in further detail.

1.3. Part 1: Standards & Codes

The majority of respondents (64%) to the first question (the use of technologies as a part of the inspection strategy) confirmed that they consider the use of some advanced technologies in their Standards & Codes, while 29% confirmed that the use of many technologies is a common practice during a bridge inspection.

Regarding the monitoring of long-span bridges, half of the countries answered that the instrumentation of these bridges is mandatory only for specific bridges, 36% answered that it is not mandatory for any bridge, and only 14% confirmed that it is mandatory for all bridges.

Finally, regarding the inspection in specific environments in the Standards & Codes, a high majority of the answers (79%) indicated that these aspects are only considered in some cases, while the rest of the answers conclude that they are not considered at all for any case.

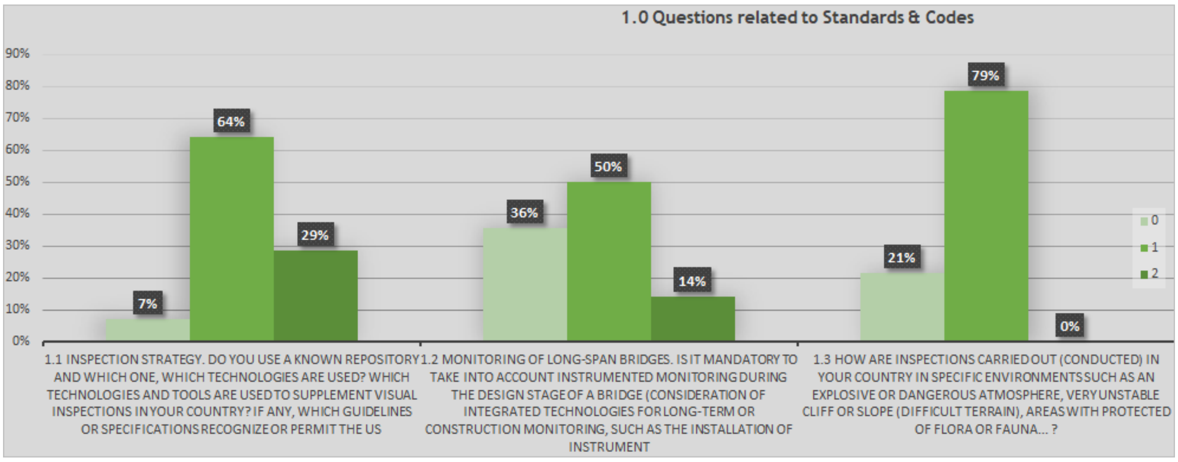


Figure 1. Summary of how Part 1 of the questionnaire was answered regarding Standards & Codes (for each question, the percentage shown in the first column is assigned to option '0', the middle column to option '1', and the column on the right to option '2', according to the criteria included in the headers of tables 2 to 4)

1.4. Part 2: Techniques & Technologies

The majority (79%) of the road authorities use different Techniques & Technologies (T&T) for the inspection of the visible areas of bridges, such as drones, scan 3D / Lidar, photogrammetry, pattern recognition, automatic damage detection, digital mock-up, or satellite monitoring.

Regarding underwater inspections, 71% of the countries use different T&T.

A high majority of the countries (71%) answered that they use monitoring systems not only during the construction period but during the life cycle of a bridge, and that the use of RFID (Radio Frequency Identification sensors) is common.

The weigh-in-motion technique is in use at an experimental stage in half of the countries, while in 29% it is currently common practice.

The use of remote technologies to avoid traffic interruptions or restrictions during an inspection is not in use in any country yet, and a high majority (79%) still need to close the lanes on or under a bridge to traffic to provide access for inspection instead of using remote technologies.

The use of buried control samples is relatively frequent as a systematic or mandatory technique (36%) but still the majority (57%) of the countries don't use this technique.

No systematic methods for the geometric characterization of the hidden parts of a bridge are being used by the majority of countries.

Post-tensioning anchorages are systematically inspected in half of the countries, and an additional 14% of them inspecting anchorages in a non systematic or aleatory way. Still 36% of the countries don't perform a systematic inspection of these critical parts of a bridge.

The use of new technologies for testing bridges is not in use widely, and only for more rigorous inspections in a small number of countries.

The use of robotized solutions is not in use for half of the countries, and only in 21% of the cases were these solutions identified for use on the whole bridge.

The combination of SHM and traditional inspection strategies are used in combination in 21% of the countries, while half of countries use one or the other option.

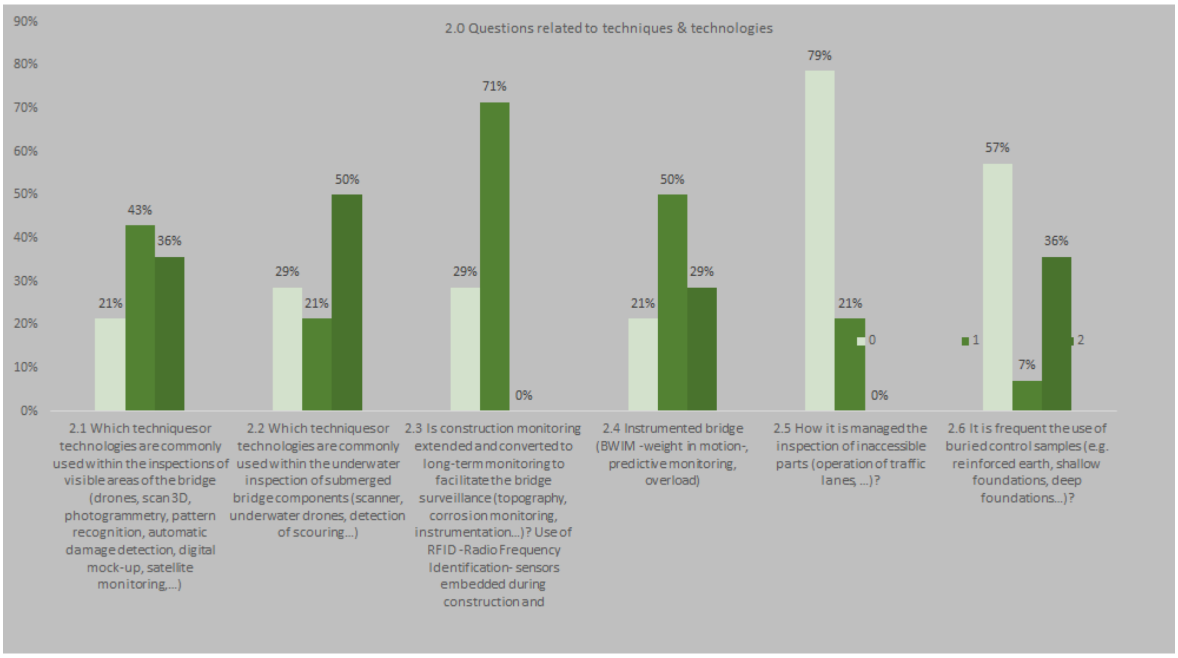


Figure 2.1. Summary of how Part 2 of the questionnaire was answered regarding techniques & technologies (1/2) (for each question, the percentage shown in the first column is assigned to option '0', the middle column to option '1' and the column on the right to option '2', according to the criteria included in the headers of tables 2 to 4)

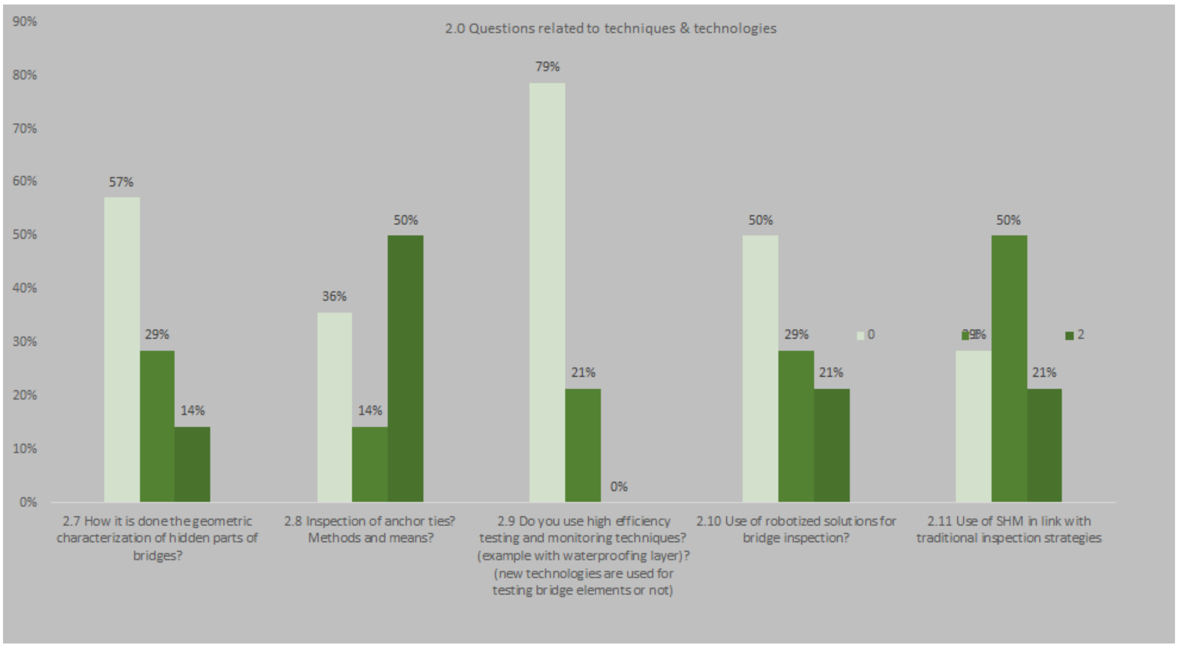


Figure 3.2. Summary of how Part 2 of the questionnaire was answered regarding techniques & technologies (2/2) (for each question, the percentage shown in the first column is assigned to option '0', the middle column to option '1' and the column on the right to option '2', according to the criteria included in the headers of tables 2 to 4)

1.5. PART 3: CLIMATE CHANGE

64% of the countries answered that the use of advanced techniques and technologies has not increased due to climate change, while 21% confirmed that they have increased their use for specific hazards, and only 14% answered that there is a wide use of these techniques and technologies as a result of climate change.

Similar percentages were reported regarding the confirmation of climate change effects using advanced inspection techniques and technologies.

The use of specific monitoring during extreme climate events had a similar percentage of responses in terms of the dissemination of these techniques (43%, not at all; 21% in some cases, and 36% in all cases).

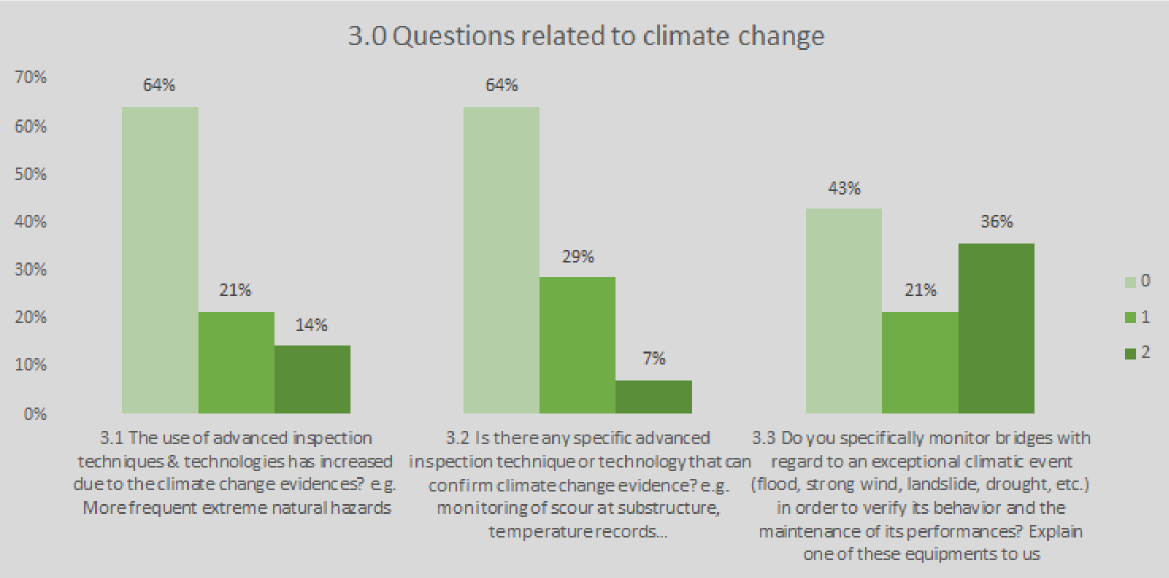


Figure 3. Summary of how Part 3 of the questionnaire was answered regarding Climate Change (for each question, the percentage shown in the first column is assigned to option '0', the middle column to option '1', and the column on the right to option '2', according to the criteria included in the headers of tables 2 to 4)

1.6. PART 4: CASE STUDIES

The case studies provide an overview of essential characteristics for the considered inspection methods. To make it easier for the reader to identify the appropriate method(s) to best address their concern(s), the inspection methods are categorized depending on the damage type that can be inspected (Table 5), and by technique for the structural element being inspected (Table 6).

Table 5: Proposed inspection methods with respect to damage type

case study	method	tool	corrosion	crack	deformation	delamination	general surface damage	inadequate structural performance	scour	stagnant (undrained) water	traffic load
Austria-01	digital twin	drone, laser scanner, high resolution camera	no	yes	no	no	yes	no	no	no	no
Belgium-01	stay cable modal frequency	accelerometer, solar panel	no	no	yes	no	no	yes	no	no	no
France-01	controlled loading	interferometric radar	no	no	yes	no	no	yes	no	no	yes
France-02	digital twin, cartography	drone, high resolution camera	no	yes	no	no	yes	no	no	no	no
France-03	geometric satellite tracking	Geocube sensors - GNSS stations	no	no	no	no	no	yes	no	no	no
France-04	photogrammetry	high resolution camera	no	yes	yes	yes	yes	no	no	no	no
France-05	scour monitoring	ultrasonic sensor, accelerometer, bathymetry, camera	no	no	no	no	no	no	yes	no	no
France-06	weigh-in-motion	optical strings	no	no	no	no	no	no	no	no	yes
France-07	gammagraphy	radiation source, scanner	yes	no	no	yes	no	no	no	no	no
France-08	magnetic flux leakage	magnetic flux leakage detector	yes	no	no	no	no	no	no	no	no
France-09	acoustic monitoring	fibre optic sensors	yes	no	no	no	no	no	no	no	no
France-10	optical fibre monitoring	fibre optic instrumentation	no	yes	no	no	no	no	no	no	no
France-11	sound waves reflectometry	transmitting, receiving and analysis units	yes	no	no	no	no	no	no	no	no
Germany-01	remote monitoring	information system	no	no	no	no	no	yes	no	no	yes
Germany-02	road traffic management system - RTMS	strain gauge, displacement sensor, acceleration sensor,...	no	no	no	no	no	yes	no	no	yes
Germany-03	instrumented exp. joint	force sensor, load cell, wire sensor, acceleration sensor	no	no	no	no	no	yes	no	no	yes
Germany-04	Instrumented bearing	pressure sensor, distance sensor, inductive displacement sensor	no	no	no	no	no	yes	no	no	yes
Italy-01	dynamic monitoring	accelerometer	no	no	no	no	no	yes	no	no	no
Italy-02	thermography	thermal camera	yes	yes	no	yes	yes	no	no	no	no
Italy-03	videoendoscopy	endoscope	yes	yes	no	no	no	no	no	no	no
Japan-01	EM waves	electromagnetic wave radar	no	no	no	no	no	no	no	yes	no
Japan-02	ultrasound	semi-automatic ultrasonic instrument	no	yes	no	no	no	no	no	no	no
Japan-03	steel decks crack detection	infrared camera	no	yes	no	no	no	no	no	no	no
Portugal-01	SHM	strain gauge, inclinometer, displacement transducer, thermometer, ...	no	no	yes	no	no	yes	no	no	no
Portugal-02	LIDAR, thermography	laser scanner, thermal camera	no	yes	yes	yes	yes	no	no	no	no
Slovenia-01	vibration method	accelometer, laser	no	no	no	no	no	yes	no	no	no
Slovenia-02	video monitoring	cameras, reflectors	no	no	yes	no	no	yes	no	no	no
Switzerland-01	GPR	ground penetrating radar	no	no	yes	yes	yes	no	no	no	no

Table 6: Proposed inspection techniques with respect to structural element being inspected

case study	method	tool	structural behaviour	foundation	sub-structure	super-structure	deck	expansion joint	bearing	external cable	drainage	railing
Austria-01	digital twin	drone, laser scanner, high resolution camera	no	no	yes	yes	yes	no	no	no	no	no
Belgium-01	stay cable modal frequency	accelerometer, solar panel	no	no	no	no	no	no	no	yes	no	no
France-01	controlled loading	interferometric radar	yes	no	no	no	no	no	no	no	no	no
France-02	digital twin, cartography	drone, high resolution camera	no	no	yes	yes	yes	no	no	no	no	no
France-03	geometric satellite tracking	Geocube sensors - GNSS stations	yes	no	no	no	no	no	no	no	no	no
France-04	photogrammetry	high resolution camera	yes	no	yes	yes	yes	yes	yes	yes	no	no
France-05	scour monitoring	ultrasonic sensor, accelerometer, bathymetry, camera	no	yes	no	no	no	no	no	no	no	no
France-06	weigh-in-motion	optical strings	yes	no	no	no	no	no	no	no	no	no
France-07	gammagraphy	radiation source, scanner	no	no	no	yes	no	no	no	yes	no	no
France-08	magnetic flux leakage	magnetic flux leakage detector	no	no	no	no	no	no	no	yes	no	no
France-09	acoustic monitoring	fibre optic sensors	no	no	no	no	no	no	no	yes	no	no
France-10	optical fibre monitoring	fibre optic instrumentation	no	no	yes	yes	yes	no	no	no	no	no
France-11	sound waves reflectometry	transmitting, receiving and analysis units	no	no	no	no	no	no	no	yes	no	no
Germany-01	remote monitoring	information system	yes	no	no	no	no	no	no	no	no	no
Germany-02	road traffic management system - RTMS	strain gauge, displacement sensor, acceleration sensor,…	yes	no	no	no	no	no	no	no	no	no
Germany-03	instrumented exp. joint	force sensor, load cell, wire sensor, acceleration sensor	yes	no	no	no	no	yes	no	no	no	no
Germany-04	Instrumented bearing	pressure sensor, distance sensor, inductive displacement sensor	yes	no	no	no	no	no	yes	no	no	no
Italy-01	dynamic monitoring	accelerometer	yes	no	no	no	no	no	no	no	no	no
Italy-02	thermography	thermal camera	no	no	yes	yes	yes	no	no	no	no	no
Italy-03	videoendoscopy	endoscope	no	no	yes	yes	yes	yes	yes	no	no	no
Japan-01	EM waves	electromagnetic wave radar	no	no	no	no	yes	no	no	no	no	no
Japan-02	ultrasound	semi-automatic ultrasonic instrument	no	no	no	no	yes	no	no	no	no	no
Japan-03	steel decks crack detection	infrared camera	no	no	no	no	yes	no	no	no	no	no
Portugal-01	SHM	strain gauge, inclinometer, displacement transducer, thermometer, ...	yes	no	no	no	no	yes	no	yes	no	no
Portugal-02	LIDAR, thermography	laser scanner, thermal camera	no	no	yes	yes	yes	no	no	no	no	no
Slovenia-01	vibration method	accelometer, laser	no	no	no	no	no	no	no	yes	no	no
Slovenia-02	video monitoring	cameras, reflectors	yes	no	no	no	no	no	no	yes	no	no
Switzerland-01	GPR	ground penetrating radar	no	yes	yes	yes	yes	no	no	no	no	no

4. CONCLUSION

The aim of this investigation was to seek out and gather information from member countries of TC 4.2 on the provisions and practices regarding the use of new techniques and technologies for bridge inspection. This was accomplished through a survey based on a specifically developed questionnaire and case study template that invited the member countries to describe their experiences and practices and to share examples. Responses were received from 14 different countries to the questionnaire that included 28 examples of case studies (already summarized in a previous report). The responses received were then compared and analyzed and the output of this investigation was a review of each country's provisions and practices and the production of a consolidated set of best practice guidelines and recommendations on the subject.

It seems that for most of the countries, techniques or technologies which can be considered as new are used in some cases but not as a mandatory or regular practice. New techniques and technologies require time and experience to become a common and systematic procedure for bridge inspection, not only in the Standards and Codes, but in application.

Evidence of climate change did not promote the use of new techniques and technologies, although there is a common use of monitoring for specific climate events.

All the innovative inspection techniques discussed have proven their usefulness for the inspection of bridges. Particularly, inspections by means of high-resolution images from drones, infrared cameras and ground penetration radar are more suitable for surface defects detection in the reinforced concrete mass where a high image accuracy is needed; whereas magnetic flux, vibrations and ultrasound are helpful to detect damage in post-tensioning tendons and stay cables. Finally, accelerometers have a multi-purpose use, are very promising, and can be used even more efficiently in the future combined with BIM and asset management through digital twins.

5. RECOMMENDATION

Corrosion, cracks, delamination, various deformations, and other types of damage are all signs of bridge degradation. In some cases, their intensity cannot be determined by visual inspection only and use of advanced inspection techniques is necessary. The application of advanced inspection technologies and techniques provides valuable information for road authorities regarding the condition of their bridge stock. Based on inspection findings, appropriate remedial measures can be prescribed.

For LMIC (Low- and Middle-Income Countries), it is important to highlight that not all the techniques and technologies summarized in this report are highly complex or expensive. As such, their application should be consider as pragmatic or reasonable. In the case studies collection, information is included that addresses these issues.

6. REFERENCES

[1] *“Bridges – Planning and Design – Planning Basics – Providing for Bridge Inspection and Repair. RVS 15.02.11”, Austria, August 2017*

[2] *“Highway Bridge Structural Health Monitoring System Technical Specification” (JTT 1037-2016), China*

[3] *FEDRO Standard: ASTRA 12002 "Surveillance et entretien des ouvrages d'art des routes nationales (2005)" (in French and German). Switzerland*

[4] *FEDRO Guideline: ASTRA 22001 "Manuel technique Ouvrages d’art" (in French and German). Switzerland*

[5] *V441 – Inspection Manual for Bridges, Norway*

[6] *Guide for principal inspections in road bridges. Spain, 2012*

7. APPENDIX A: QUESTIONNAIRE AND CASE STUDY TEMPLATE

PIARC TECHNICAL COMMITTEE 4.2: BRIDGES

WORKING GROUP 2.3 *Advancement of inspection techniques / technologies as a part of bridge management systems*

GENERAL QUESTIONNAIRE & CASE STUDY

Description of your organization:

Country:	
Name of Organization:	
Description of Organization:	
Your name:	
Your e-mail address:	

This questionnaire aims to collect information from state holders worldwide concerning the already proven or innovative approaches of monitoring that are adopted in order to manage their asset of bridges. The different advancement of inspection techniques and technologies (electronic inspection techniques, remote detection, drones, Structural Health Monitoring, LIDAR, radar, thermography, big data analysis, machine learning – AI, BIM modeling, scour monitoring, …) to improve the maintenance management of bridges and the prevention of bridge failure, as collected by case studies, will be analyzed and compared to their effectiveness. The results obtained from this study would be drafted in a briefing note that helps in decision-making for process how to organize inspections – monitoring bridges. This questionnaire integrate questions related to climate change and bridges resilience.

Your input is highly appreciated and very important to the success of this project. The work required to complete the questionnaire and case study is understood and acknowledged; every effort has been made to make them as user friendly and labor effective as possible. The compiled questionnaires and case studies will be included in the final report of which you will receive a copy.

Please complete all forms electronically in Word and return the completed questionnaire and case study to the undersigned before 29th January 2021. Thanking you in advance for your participation and contribution.

Gonzalo Arias Hofman (Spain), gah@inesingenieros.com

Co-Leader – Working Group 2, TC 4.2 Bridges.

Part 1: General Questionnaire

General Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Strategy for detailed inspections, which technologies are used? Are they innovative? Which level of innovation is allowed in your country when referring to the official inspection guidelines?	
1.2 Is monitoring a mandatory in the design for long-span bridges?	
1.3 How it is managed the inspection in specific environment (hazardous explosive atmosphere, marine environment, flora and fauna…)?	
2.0	**Questions related to techniques & technologies**
2.1 Which techniques or technologies are commonly used within the inspections of visible areas of the bridge (drones, scan 3D, photogrammetry, pattern recognition, automatic damage detection, digital mock-up, satellite monitoring,…)	
2.2 Which techniques or technologies are commonly used within the underwater inspection of submerged bridge components (scanner, underwater drones, detection of scouring…)	
2.3 Is construction monitoring extended and converted to long-term monitoring to facilitate the bridge surveillance (topography, corrosion monitoring, instrumentation…)? Use of RFID -Radio Frequency Identification- sensors embedded during construction and used during operation?	
2.4 Instrumented bridge (BWIM -weight in motion-, predictive monitoring, overload)	
2.5 How it is managed the inspection of inaccessible parts (operation of traffic lanes, …)?	
2.6 It is frequent the use of buried control samples (e.g. reinforced earth, shallow foundations, deep foundations…)?	
2.7 How it is done the geometric characterization of hidden parts of bridges?	

General Questionnaire	
2.8 Inspection of post-tensioning anchorages? Methods and means?	
2.9 Do you use high efficiency testing and monitoring techniques? (example with waterproofing layer)?	
2.10 Use of robotized solutions for bridge inspection?	
2.11 Use of SHM in link with traditional inspection strategies	
3.0	**Questions related to climate change**
3.1 The use of advanced inspection techniques & technologies has increased due to the climate change evidences? e.g. More frequent extreme natural hazards	
3.2 Is there any specific advanced inspection technique or technology that can confirm climate change evidence? e.g. monitoring of scour at substructure, temperature records…	
3.3 Do you specifically monitor bridges with regard to an exceptional climatic event (flood, strong wind, landslide, drought, etc.) in order to verify its behavior and the maintenance of its performances? Explain one of these equipments to us	

Part 2: Case study

Case study	
Note to respondents: *The case study aims to obtain examples of latest* ***inspection*** *or/and* ***monitoring techniques*** *(e.g. non-destructive tests, monitoring systems, drones, robots, "intelligent bridges"…).* *Case studies should be selected in a way to represent the latest techniques used in each member country. The goal is to show the possibilities of new technologies to engineers in all member countries.* *Kindly complete one form per bridge.*	
1.0	**General data** Instructions for completing the form*:* Bridge name: *name; road; coordinates* General bridge description: *Short text regarding the bridge current state* Bridge equipment [list]: *bearings, expansion joints, railings, drainage…* Other*: possible special features description* Pictures: *bridge picture(s)*
Country	
Prepared by	
Date Prepared	
Bridge name	
General bridge description	
Bridge equipment	
Other	
Bridge pictures	
2.0	**Bridge data** Instructions for completing the form*:* Structural design: *frame, girder, arch…* Material classification: *reinforced concrete, steel, masonry…* Geometrical data: *length, width, no. of spans, no. of lanes…* Reason for using tools/techniques (e.g.): *substantial damage or deformation of bridge structural part, main inspection, detail inspection (landmark) bridge with continuous monitoring …* Tools/technique used: *list the tools and techniques used*
Structural design	
Material classification	
Geometrical data	

Case study	
Reason for using the tools/techniques presented	
Tools/technique used	
3	**Tools/technique used** Instructions for completing the form*:* Chapter 3.0 has to be completed for every type of tool/technique used individually. Tool picture: *At least one on-site picture, other images also desirable* General description: *Provide tool/technique general description and its potential specifics when used in the case study presented* Field(s) of use: *Parameter(s) that can be measured with the tool/technique under consideration* Results reliability: *Descriptive assessment of the results/measurements accuracy (excellent, good, average) and their possible sensitivity to various external factors (e.g. humidity, temperature, test micro location).* Test duration: *On-site time required for the test/measurement execution. Provide descriptive assessment (quick, moderate, prolonged)*, measurable (hours, days) if possible. Results interpretation complexity: *Undemanding when results are immediate (e.g. phenolphthalein test), moderate when short office or on sight analysis is required (e.g. cover meter requires undemanding data processing with computer software), demanding when computer equipment and highly qualified personal is required (e.g. Ground Penetrating Radar).* Cost: *Total cost of tool, additional equipment and software needed to perform the inspection (the cost of acquisition can be highly dependent on the technical characteristics of the equipment, therefore, the assessment is to some extent subjective). Provide at least descriptive assessment (high, moderate, low) with a brief explanation.* Standardization: *Inspection tool/technique has international, national or no standard. Name the standard, if any.*
3.1	**Tool/technique: Name**
Tool picture	
General description	
Field(s) of use	
Results reliability	
Test duration	

Case study	
Results' interpretation complexity	
Cost	
Standardization	

8. APPENDIX B: ANSWERS TO GENERAL QUESTIONS

Country:	Austria
Name of Organization:	ASFINAG
Description of Organization:	Austrian infrastructure company for managing all motorways in Austria
Your name:	Peter Augschöll
Your e-mail address:	Peter.augschoell@asfinag.at

General Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Strategy for detailed inspections, which technologies are used? Are they innovative? Which level of innovation is allowed in your country when referring to the official inspection guidelines?	In general the detailed inspection is based on a visual inspection of all surfaces. For surfaces they can`t be reached with inspection platforms, it is possible to use field glasses.
1.2 Is monitoring a mandatory in the design for long-span bridges?	No
1.3 How it is managed the inspection in specific environment (hazardous explosive atmosphere, marine environment, flora and fauna…)?	-
2.0	**Questions related to techniques & technologies**
2.1 Which techniques or technologies are commonly used within the inspections of visible areas of the bridge (drones, scan 3D, photogrammetry, pattern	drones

General Questionnaire	
recognition, automatic damage detection, digital mock-up, satellite monitoring,...)	
2.2 Which techniques or technologies are commonly used within the underwater inspection of submerged bridge components (scanner, underwater drones, detection of scouring...)	Sonar
2.3 Is construction monitoring extended and converted to long-term monitoring to facilitate the bridge surveillance (topography, corrosion monitoring, instrumentation...)? Use of RFID -Radio Frequency Identification- sensors embedded during construction and used during operation?	Yes, for example with Fiber-optic systems
2.4 Instrumented bridge (BWIM -weight in motion-, predictive monitoring, overload)	Temporary used to get a load spectrum of the traffic for fatigue calculations
2.5 How it is managed the inspection of inaccessible parts (operation of traffic lanes, …)?	field glasses, drones, endoscope if necessary and possible traffic lanes where bypassed
2.6 It is frequent the use of buried control samples (e.g. reinforced earth, shallow foundations, deep foundations...)?	-
2.7 How it is done the geometric characterization of hidden parts of bridges?	Construction drawings
2.8 Inspection of anchor ties? Methods and means?	Endoscope, extracting test

General Questionnaire	
2.9 Do you use high efficiency testing and monitoring techniques? (example with waterproofing layer)?	No
2.10 Use of robotized solutions for bridge inspection?	No
2.11 Use of SHM in link with traditional inspection strategies	Yes
3.0	**Questions related to climate change**
3.1 The use of advanced inspection techniques & technologies has increased due to the climate change evidences? e.g. More frequent extreme natural hazards	Not yet
3.2 Is there any specific advanced inspection technique or technology that can confirm climate change evidence? e.g. monitoring of scour at substructure, temperature records…	Measure the temperature of the bridge deck and the bottom of the box girder to get the temperature gradient. The shortly temperature changes getting higher, and so the temperature gradient of the box girder. This can cause problems especially to prestressed concrete bridges.
3.3 Do you specifically monitor bridges with regard to an exceptional climatic event (flood, strong wind, landslide, drought, etc.) in order to verify its behavior and the maintenance of its performances? Explain one of these equipments to us	No

Country:	Belgium
Name of Organization:	Direction de l 'Expertise des Ouvrages
Description of Organization:	We carry out expert appraisals and specialized controls on engineering structures managed by the Walloon Region
Your name:	Patrice Toussaint
Your e-mail address:	Patrice.toussaint@spw.wallonie.be

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	Two computer tools are used: - the BDOA (database of engineering structures), a web program developed specifically for our needs; all information related to bridges is encoded in it, including periodic and specialized inspections. - an inspection tool on android tablets; it allows the field encoding of the inspection via a specialized form and transmits the information (including photos) to the BDOA. To supplement visual inspection, few additional tests are carried out, but an inspection by specialist engineers, internal to the administration, may be requested. This may include many types of destructive or non-destructive tests. For example: mechanical tests (traction, compression), chemical tests (chloride content, carbonation depth, ...), measurement of coating depth, radar technique, 3d techniques, potentiometric mapping, ...
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential	We do not adopt any general rule for the instrumentation of new structures, a case-by-case reflection is carried out.

Questionnaire	
instrument locations)? If so, which specifications are used?	
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	When accessibility is complicated, we form a team of two people. If necessary, we use rope access technicians. In case of a confined atmosphere, we use gas detectors. The use of platforms (positive or negative) is frequent. We will soon be using drones.
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	We very frequently use 3D scanning and photogrammetry techniques, which is the only advanced technology very commonly used for inspections. We plan to have UAV inspections performed on some of our viaducts in the near future. For our most important bridges, we are considering using computerized tracking tools based on artificial intelligence for automatic detection of defects and their tracking over time.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	We do not use underwater drones, but use a team of divers, internal to the administration.
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the	When designing the bridge, attention is paid to the means of access (ladder, access corridor) at specific locations to allow inspection of the supports, the lower part of the expansion joints, the beam ends, etc. For large viaducts, facilities such as inspection walkways or lighting devices are provided.

Questionnaire	
inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	Not yet but a new project will begin soon. The aim is to control overloaded trucks.
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	Access gondolas are used if necessary. The administration has gondolas that allow inspections up to 20m high; if necessary, other gondolas can be rented by the day (for access to the underside from the top for example). If necessary, one or more traffic lanes can be temporarily cut off.
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	No, the buried parts are never inspected during periodic inspections. However, when deemed necessary, specialized inspections are organized and localized earthworks may be planned.
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	We never take such measures.

Questionnaire	
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	No.
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	No. We do not use RFID sensors.
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	No.
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	Certain structures subject to settlement or tilting are continuously monitored, as is the opening of certain cracks deemed to have an impact on stability.
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	No.
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	No.

Questionnaire	
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	No.

Country:	Chile
Name of Organization:	Ministerio de Obras Públicas
Description of Organization:	Public Entity in charge of the Bridges in Chile
Your name:	Marcelo Marquez
Your e-mail address:	marcelo.marquez@mop.gov.cl

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	Chile use AASHTO as framework, but the national code is Manual de Carreteras, in volume 7 include some inspection reference. Nowadays we are including new internal protocols for the technology use (ex. Drone). Also we is developed the I3MOP as a repository of the visual inspection.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	Yes, the supported cables bridges include in the Technical reference (ITB) request of instrumentation and monitoring. Nowadays we are including singular bridges (long length) in this category
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable	Not it is considered. But it is analyzing case by case considering the national code. Just in the heritage bridges, the inspection has to consider a permit from the Authority of Heritage and Environmental.

Questionnaire	
cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	When it is used Drone, the DGAC permit is requested (aeronautical authority).
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	**Drone (aerial), 3D scanning, Lidar (whole bridge), truck inspection (under deck), thermal camera (surrounding and under deck – seel), pachometer, CSL, PDA (foundation), spectrometer (steel rebars). Satellite image.** **Also instrumentation: acelerometers, geophone,**
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	**Sonar for Bathymetry** **ROV and camera**
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification)	**Just in long span bridges is included a whole system the equipment for O&M** **Ladders or stairs is also included in a specific traditional bridges, but it is not frequent.** **RFID is not included**

Questionnaire	
sensors integrated during construction or during operation?	
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	**WIM is not included**
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	**It is considered the closing lane, and we use the truck inspection.** **Climbing is also used.**
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	**Geophones and ground scanner are used**
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	**Scanner and pachometer is define the steel rebars.** **Scanner 3D or Lidar is used for global view of the structure**
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	**It is not included**
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during	**No**

Questionnaire	
construction to support operation or management?	
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	**Yes**
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	**Not yet, but in the cable supported bridges is considered.**
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	**Yes, we use technology due to Climate Change.** **We are increase the frequency of visual inspection with supplement of technology.**
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	**We use Drone, thermal camera, Lidar, Satellite Image, for the hazard of fire, landslide, tsunami**
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	**Yes, we monitor for seismic condition, using geophones and a national network of acelerometers.** **We have also prepared a hazard maps** **Instrumentation for river flow registration.**

Country:	Estonia
Name of Organization:	
Description of Organization:	
Your name:	
Your e-mail address:	

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	We use our own technology based on evaluating individual elements and assigning different factors to them. To supplement visual inspection we use sometimes drones, but not any technical equipment. Only visual inspection. If there is a suspicion of loss of load capacity, we order a separate study to assess the load capacity. We don't have any guidelines or recognize to difference inspections.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	In Estonia we don't have any long-span bridges.
1.3 How are inspections carried out (conducted) in	We have not yet had such a situation

Questionnaire	
your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	**drones, photogrammetry, Also a company tried to use satellite surveillance, but that was few years ago. Traditional visual inspection carried out every 4…5 years. Those methods have not occupy traditional inspection yet.**
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	**10 years ago we used divers and video cameras to inspect one bridge. After that we haven't use this kind method anymore.**
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to	**Different studies have been carried out on the dynamic determination of load capacity with decreasing gravity and oscillation method with WIM results** **In some new bridges, there are better stairs to abutment and horizontal area front of the abutment. In some bridges also the stairs and walkways trough the deck. Also ladders holder on the columns.**

Questionnaire	
facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	**no**
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	**We have used WIM solutions only to monitor different kind of traffic load and gross vehicle weight**
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	**In Estonia we don't use different kind on heavy equipment or machinery for inspection. Only some studies have used traffic closures during static loading.**
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	**Every kind on studies, what are made about bridges (or some specific bridge) are integrated systematically to management our bridges.**
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	**We are developing a system where we can hold every detail about a bridge, what we have. Starting 3d model until inspection comments.**
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	**Only visual inspection about cracks or differences.**

Questionnaire	
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	**No** **No**
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	**No**
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	**Yes** **Yes** **Yes in some cases or some bridges**
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	**No**
3.3 Do you specifically monitor bridges during an extreme	**we do not have bridges that would be affected by climate change presented here or similar**

Questionnaire	
climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	

Country:	FRANCE
Name of your organisation :	✓ French mirror committee WG 4.2.3 / ASFA APRR animation ✓ French organizations contributing actors
Description of your organisation :	✓ Grouping of French players in the field of civil engineering structures, led by the Association des Sociétés Françaises d'Autoroutes (Association of French Motorway Companies). ✓ Ministry of ecological transition / transport infrastructure department; Gustave Eiffel University UGE including IFSTTAR; Centre for technical study and testing in the field of civil engineering CEREMA; concession motorway companies (APRR, Vinci autoroutes, CCI Seine estuaire); local authority in charge of the departmental road network (Gers); private engineering offices (Quadric, Diades, Sixense, Sites)
Last name, First name :	✓ French mirror group 4.2.3 (facilitator DABERT Jean-luc) ✓ HOUEL Adrien; GODART Bruno; SCHMIDT Franziska; ORCESI André; BOUVET AGNELLI Cecile; PLASSARD Florent; LOPEZ Sylvain; FASQUEL CLEMENT; PAYAN Raymond; ROIBET Adrien; LECONTE Renaud; BESSOULE Nicolas; COLLIN Bertrand
E-mail address :	✓ Jeanluc.dabert@aprr.fr; adrien.houel@developpement-durable.gouv.fr; bruno.godart@univ-eiffel.fr; franziska.schmidt@univ-eiffel.fr; andre.orcesi@cerema.fr; Cecile.bouvet@cerema.fr; florent.plassard@cerema.fr; Sylvain.lopez@vinci-autoroutes.com; cfasquel@ponts.seine-estuaire.cci.fr; rpayan@gers.fr; adrien.roibet@quadric.arteliagroup.com; renaud.leconte@setec.com; nicolas.bessoule@sixense-group.com; bertrand.collin@sites.fr

General questionnaire	
1.0	**Issues relating to standards and codes**
1.1 Strategy for inspections: do you use a known frame of reference and which one, which technologies are used? What innovative technologies are used in your country when referring to official inspection guidelines?	In France, there are no legal or statutory provisions obliging the owners of bridges to inspect and manage their engineering structures. Nevertheless, these owners are responsible for the maintenance of their structures in the event of legal disputes. Several reference systems are available depending on the status of the roads concerned. On the National Road Network, including conceded motorways, a good number of departments and local authorities. The reference system used is the Technical Instruction for the Supervision and Maintenance of Engineering Structures(ITSEOA). The SNCF, the RATP and many local authorities have their own reference system based on the ITSEOA. The 1979 ITSEOA, recently updated in 2010, describes the inspection strategy, which includes annual visits for all structures, three-year IQOA

General questionnaire	
	assessment visits for all structures, detailed inspections for some structures (major structures, sensitive structures, pathological structures, etc.), as well as specific monitoring actions (reinforced monitoring and high surveillance). It comprises 4 basic booklets (including booklet 00 on strategy and organization and booklet 01 on the works file) and some thirty technical guides for each family of works. For detailed inspections, the ITSEOA (booklet 02) requires that all the parts that can be inspected with all possible means of inspection : ladders, platforms, inspection platforms, rope access, ..., so as to be able to touch the cladding and identify any disorders and in particular fine cracks; this also allows to somewhere the siding with a hammer and to clean the dirty surfaces. One difficulty concerns access. This requires nomadic or fixed installations, or the use of negative offset gondolas or rope access. To guarantee access to certain structures of exceptional dimensions, Cerema's Epsilon cable footbridge, owned by the French state services, remains the only prototype of a means of access allowing access to large vaults, inclined planes and high piles up to 150 m high. New remote sensing tools such as binoculars, televised means or drones are being tested for their interest and limitations, especially on parts that are difficult to access. More and more managers and service providers plan to use these tools during particular follow-up or targeted inspections or visits following regular inspections. Once the practice of these new means of inspection has been developed and feedback shared by all has been established, the ITSEOA could be modified to incorporate these new means of inspection. Beyond inspection, auscultation has been widely used in France for at least 40 years. Auscultation methods have been extensively developed by the network of public Bridges and roadways laboratories since the 1970s, and a large part of these methods are listed in ITSEOA fascicule 03 which deals with auscultation, reinforced surveillance, high surveillance and immediate security measures. In addition, there is an interactive booklet on the UGE website (formerly IFSTTAR) on the auscultation of civil engineering structures developed jointly with Cerema : https://www.ifsttar.fr/collections/CahiersInteractifs/CII1/index.html This site currently presents fact sheets on 115 auscultation methods and 24 diagnostic procedures. A call for projects has been launched by the French State relating to the automatic monitoring of structures through connected bridges, image analysis, artificial intelligence. Innovative techniques will be tested in

General questionnaire	
	full scale over the period mid 2021 - mid 2023 in order to develop techniques for monitoring a fleet of structures that can be easily deployed at low cost. 

Country:	Italy
Name of Organization:	Autostrada dei Fiori SpA - A6 Highway
Description of Organization:	The Concessionary *Autostrada dei Fiori* manages the motorway A6 since 2014. The A6 connected Torino ring road to Savona.
Your name:	Ing. Maurizio Deiana
Your e-mail address:	deiana@autofiori.it

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	Actually is used a visual inspection for controlling bridges. In particular our Company developed an own system named SIOS based on a strong defect catalogue. Together to visual inspection some new technologies are applied like: Laser Scanner, thermo scanner (together drone application). Other technologies like NDT test are used for better understanding the quality of concrete, steel rebar etc. Now days Italy Minister of Infrastructure has published a guide line for a better definition of bridge inspection: defect and classification.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential	Actually in Italy there are not any specific standard for monitoring system on bridges.

Questionnaire	
instrument locations)? If so, which specifications are used?	
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	In general viaducts inspection are conducted using by-bridge machine positioned on the top of the slab. Particular inspection in closed part of structure like box girder or piers are done with specific procedures or using cameras.
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	Nowadays a lot of technologies are useful for doing inspection on bridges like 3Dscan, automatic damage detection by artificial intelligence. Actually in Italy they are used for special inspection not in common use.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	This task is very peculiar, in special cases 3d scanner are used
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the	We use long term monitoring on different viaducts to facilitate their management. The purpose is to evaluate the behavior under loads, light and heavy ones, measuring the deflection of the deck in different points in which the sensors are present. This kind of technology can be used obviously to evaluate the behavior of specific parts of the viaducts, in case of structural deficiency due to a particular decay or a particular action, to control the parameters of the structure waiting to carry out the necessary reinforcements.

Questionnaire	
inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	The use of RFID is not very common in Italy.
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	Yes, this technology is used in Italy. The purpose is to evaluate constantly the structural behavior. There are 9 WIM equipments along the A6 highway.
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	In general all the most important part of the bridges are inspectable by bridge or structural facility. The inspection of box girder bridge can be done by using technological devices, like for example endoscopic investigations.
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	In general regular inspection are done on visible elements
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	Only in particular cases using boroscopic devices or radar survey

Questionnaire	
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	Yes actual new technique are in experimental test like xray
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	Actually are not a common approach
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	Yes
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	Yes
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	In particular we pay attention in the cases of bridges on important river or near to slope area. In case of extreme natural phenomena inspections are done more frequency.
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	Some application are used not in common way

Questionnaire	
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	Yes where there are some application due to hazard required or protocol proposed by *Emergency Management Agency*

Country:	Japan
Name of Organization:	Honshu-Shikoku Bridge Expressway Company Limited (HSBE)
Description of Organization:	One of 6 expressway companies in Japan. Especially, it operates long span bridges including Akashi Kaikyo Bridge, Seto-Ohashi Bridges, Tatara Bridge, and Kurushima Kaikyo Bridges.
Your name:	
Your e-mail address:	

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	Close visual inspection every 5 years is mainly performed. HSBE develops own inspection manual. To supplement visual inspections, NDT technologies is also utilized.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	Monitoring is not mandatory, however, most of long span bridges in HSBE are monitored to verify the design method and to identify the bridge soundness after big events.

Questionnaire	
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	Inspection for hard-to-reach area is conducted in a systematic way. For example: For outside of tower shafts of suspension bridges and cable-stayed bridge, inspection is conducted with high resolution camera. For underwater foundation, inspection by diving or measurement of electric potential are used.
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	**Several technologies, such as drones, 3D scanning, photogrammetry, shape recognition are available. Those technologies can be used when they are judged to become an alternative to close visual inspection.**
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	**Inspection by diving is mainly conducted.** **Measurement of electric potential is used to identify corrosive environment of steel underwater foundation with sacrificial anode.** **Bathymetric survey is used to identify the condition of scoring protection system.**
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers,	**Construction monitoring is not basically extended or converted to long-term monitoring to facilitate the bridge management.** **Major examples of equipment dedicated to the inspection are walkway, stairs, ladders, lifts, and gantry.** **RFID is not practically used.**

Questionnaire	
walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	**WIM is practically not used. Expressways in Japan use vehicle weight scale and axial load scale for operation.**
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	**For outside of tower shafts of suspension bridges and cable-stayed bridge, inspection is conducted with high resolution camera.** **For underwater foundation, inspection by diving or measurement of electric potential are used.**
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	**No.**
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	**No.**
2.8 Does monitoring include the inspection of post-tensioning	**No.**

Questionnaire	
anchorages (methods and means to be specified, if any)?	
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	**No.**
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	**Inspection with drone is still at a trial stage.**
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	**SHM is used, but not integrated with traditional visual inspection strategies.**
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	**Climate change has not motivated us to increase the use of innovative inspection techniques yet.**
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	**No**
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong	**Some of long-span bridges in HSBE are equipped with SHM which is composed of several sensors, such as anemometer, accelerometers**

Questionnaire	
wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	**and velocimeters, and monitored their behaviors under extreme events, such as strong winds.**

Country:	Korea
Name of Organization:	Korea Expressway Corporation (KEC)
Description of Organization:	KEC is the public corporation to construct and maintain paid expressway networks in South Korea.
Your name:	Heungbae GIL
Your e-mail address:	hgil@ex.co.kr

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	Inspections using UAVs or drones are being studied to replace visual inspections.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	It's not mandatory to install structural health monitoring systems on long span bridges. However almost all cable supported bridges in Korea have structural health monitoring systems. The cable supported bridges with the main span over 200m must have earthquake monitoring systems.

Questionnaire	
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	Bridge inspection vehicles or boom lifts are used to access
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	The adaption of new smart technologies including drones, photogrammetry, robot systems and Lidar are being studied for bridge inspections. However, the new technologies have not not fully accepted as standard inspection methodologies to replace visual inspections.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	Underwater sonar surveys are sometimes used.
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers,	- some sensors such as temperature and strain sensors are installed during the construction and used for maintenance. - inspection platforms and steps are permanently installed in abutments and piers to inspect bridge bearings. - RFID sensors are not officially employed.

Questionnaire	
walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	Weigh stations are used to control overloaded trucks. WIM systems had been installed to collect truck data. The data was used to develop Korean live load models in bridge design specifications.
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	Bridge inspection vehicles are mainly used to access the difficult-to-access areas of the bridge.
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	Exposed structures and surfaces are inspected.
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	None
2.8 Does monitoring include the inspection of post-tensioning	No

Questionnaire	
anchorages (methods and means to be specified, if any)?	
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	No
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	UAV are being used to inspect the difficult-to-access parts of the bridges such as tall piers. But the UAV inspection systems are not formally introduced into bridge inspection codes. Cable climbing robots were developed and used to inspect stay cables of cable-stayed bridges.
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	SHM is mainly used to monitor the safety of the bridge.
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	There have been reports of expansion joint failures due to a heat wave.
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	No

Questionnaire	
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	The permanent monitoring system have sensors to monitor temperature, humidity, wind speed and direction, and fog density. These sensors are used for the operation of the bridges as well as to figure out structural behavior of the bridges.

Country:	Portugal
Name of Organization:	IP – Infraestruturas de Portugal
Description of Organization:	IP is a public company that manages road and rail infrastructure. The purpose of IP is the conception, design, construction, financing, conservation, operation, requalification, enlargement and modernization of the national road and rail networks, including the command and control of circulation.
Your name:	Sérgio Pereira
Your e-mail address:	Sergio.pereira@infraestruturasdeportugal.pt

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	No. We do not use a known repository. We use internal procedures. At IP we mainly use SHM technology on special bridges (about 25 bridges), in collaboration with LNEC (Civil Engineering National Laboratory) and some universities. Each institute stores the data/results in its own database and shares it with IP (e.g. http://shm.lnec.pt/). IP receives the final reports and stores those documents in its database (IP's Bridge Management System - GOA). To supplement visual inspections we use SHM technology on bridges, laser scanner for tunnel-inspection (LIDAR and thermography), and ROV (Remote Operated Vehicle) on underwater inspections. No guidelines or specifications are known. The monitoring is individually done in special bridges, with a specific project.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or	No. It isn't mandatory. No specifications are used. The monitoring is used when is necessary to complement the diagnosis of important bridges.

Questionnaire	
accessibility to potential instrument locations)? If so, which specifications are used?	
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	In Portugal, some companies use robots with video camera for pipe inspections. At IP, we don't have those specific environments related to bridge inspections. Sometimes we use video cameras to observe some structural elements located in narrow areas (e.g. bearings). In specific bridges, we use bridge inspection vehicles or inspections using rope access (ActSafe ELR).
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	At this moment, this kind of technologies is not used. At IP, during this year, we'll start bridge inspections with drones (including thermographic camera). Our expectation is to use it to identify anomalies, at first glance (e.g. on bearings, reinforced concrete deterioration), instead of using a vehicle.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	At this moment, we use ROV (Remote Operated Vehicle - Underwater drones) and bathymetry, on underwater inspections. We intend to use sonar survey in the near future.
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the	On special bridges (e.g. cable-stayed or suspension bridges) the construction monitoring is extended to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring). Also on special bridges equipment is dedicated to the inspection of unique details. On current bridges this part is not necessary.

Questionnaire	
inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	No RFID.
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	Only on the 25th April Bridge (rail traffic weight balance) and occasionally when necessary on specific monitoring.
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	We use bridge inspection vehicles (closing traffic lanes) or inspections using rope access (ActSafe ELR) or accomplished with conditioned traffic.
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	No.
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	Rarely, when the project is not known and is indispensable for the survey.

Questionnaire	
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	On special bridges, we evaluate the external post-tensioned tendons using vibration method.
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	Our experience in visual inspections has been important in choosing the appropriate technologies for each bridge, taking into account the cost-benefit analysis. No, we don't use RFID.
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	No.
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	Yes.
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	No, directly. No, directly. No, directly. Our approach, is increasing the frequency of inspections with the increase of bridge deterioration.
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	No, directly. To resolve this issue, we recently increase the frequency of subaquatic inspections. Now they are done every 3 years.

Questionnaire	
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	No. If necessary, we do extraordinary inspections.

Country:	Slovenia
Name of Organization:	DRI Investment Management Ltd.
Description of Organization:	DRI is the largest consulting and engineering company in Slovenia. It is state owned. We provide services of investment engineering, management of investments in public infrastructure and other consulting services according to the "in-house" contract model.
Your name:	Matej Kušar
Your e-mail address:	Matej.kusar@dri.si

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	Tools used for periodic inspections: special vehicle for inspection, personal protective equipment, camera, meter, crack gauge, portable ladder, lamp, geodetic equipment, hammer, sclerometer, profometer, PPT test. Technologies: geodesy, protective layer measurements (profometer), compressive strength measurements (sclerometer), carbonation (PPT). No guidelines.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	Not mandatory. During construction design, instructions are given to designers, which SHM technologies should be integrated. Instructions are given for each long-span bridge individually.

Questionnaire	
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	Prescribed safety measures have to be followed (e.g. no metal objects in high voltage areas).
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	None of the technologies listed are used.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	Bathymetry, diving equipment (divers).
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers,	Long term monitoring is conducted for most newly built long-span bridges and some older long-span bridges. Structural behavior is monitored. Unique details are not monitored. RFID is not in use.

Questionnaire	
walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	Yes. Purposes: - axle loads and spacings of all vehicles measurements, - influence lines, - girder distribution factors (GDF), - dynamic amplification factor (DAF).
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	Use of special vehicles (MOOG) and traffic lane(s) closure for the duration of inspections.
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	No.
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded	No.

Questionnaire	
reinforcement either passive or active	
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	Yes. Methods are presented in the Slovenian case study.
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	Monitor programs are based on the data needs for each bridge individually. RFID-sensors are not used.
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	No.
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	No. They are used separately as their purposes are different. Data from both techniques is used when
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	No. (note: Special inspections were conducted for bridges near the Croatian border due to earthquake in Croatia, December 2020).
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change?	No.

Questionnaire	
For example, monitoring of subsurface scour at a foundation, temperature readings...	
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	No.

Country:	Spain
Name of Organization:	Ministerio de Transportes, Movilidad y Agenda Urbana (MITMA)
Description of Organization:	MITMA is the Ministry for the construction and maintenance of the road and railway infrastructure in Spain National network
Your name:	Gonzalo ARIAS HOFMAN (independent consultant commissioned by MITMA)
Your e-mail address:	gah@inesingenieros.com

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	Inspections using UAVs or drones are being used in cable stayed bridges and bridges with a total length over 300 m, to complement their visual principal inspections carried out every 5 years. In the ToR of the contracts for principal inspections it is included the mandatory to use drones in these bridges.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	It is mandatory to install structural health monitoring systems during construction on singular bridges, in order to control the construction stages. After the construction, part of this instrumentation continues its task during the life of the bridge, and it is supervised under a general monitoring contract controlled by the Technical Department of MITMA. Almost all cable stayed bridges and big arch bridges in Spain have structural health monitoring systems.
1.3 How are inspections carried out (conducted) in	Gangway truck are used to access

Questionnaire	
your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	New technologies such as drones, 360º images, photogrammetry, robot systems and Lidar are being used or studied for bridge inspections. The new technologies are complementary to the visual principal inspections, but only drones have become a standard nowadays.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	No new technologies such as the mentioned in the question are yet currently used for the UW inspections, which are still performed with professional divers
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to	Yes, sensors such as temperature, moisture and strain sensors and anemometers are installed during the construction and used for maintenance. If there is equipment for inspection like platforms or walkways those are permanently installed to inspect bridge certain elements of the bridge such as bearings, but it is not an extended situation. No RFID sensors are employed during construction.

Questionnaire	
facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	No
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	Gangway trucks are mainly used to access the difficult-to-access areas of the deck. For tall piers or abutments climbers is the usual option
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	Only exposed elements are inspected as part of the principal inspection campaigns. If there is a potential problem with the foundation hidden items can be unearthed
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	No
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	No

Questionnaire	
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	There are not official monitoring programs, each instrumentation on a bridge is a prototype itself. No RFID sensors are used
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	UAV are currently used to inspect the parts of the bridges with a difficult access.
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	SHM is used to monitor singular bridges.
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an increased in the frequency of extreme natural hazards required more frequent inspection?	The more frequent use of innovative inspection techniques and technologies is due to the need to carry out inspections as complete as possible, but not directly as for climate change evidences
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	No, but research projects related to flooding are being carried out to consider the impact of climate change, introducing technologies to combine information from flooding maps and bridge maps, identifying the most vulnerable assets

Questionnaire	
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	The permanent monitoring system in singular bridges can demonstrate the consequences of an extreme event on the bridge and those bridges monitored are checked after every extreme event.

Country:	Switzerland
Name of Organization:	Swiss Federal Roads Office (FEDRO)
Description of Organization:	Asset owner of the swiss national roads network, 2254,5 km.
Your name:	Meyer Laurent Spécialiste Ouvrages d'art et tunnels Gestion Patrimoine Centrale Division Infrastructure routière Ouest Papastergiou Dimitrios Head of Bridges Standards and Safety of Infrastructure Roads network division
Your e-mail address:	laurent.meyer@astra.admin.ch dimitrios.papastergiou@astra.admin.ch

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	According to FEDRO Directive 12002 Supervision and Maintenance of Structures on National Roads, Edition 2005 under Main Inspection we assign the following : The main inspection is a periodic inspection to be carried out by the competent department of the owner or on behalf him. It is to be carried out every 5 years and any deviation from this frequency must be duly justified. In principle, it is a visual inspection, which is carried out using simple means. However, the safety of the persons carrying out this work must be ensured. The main inspections cover the entire work. If certain construction elements have to be observed from a distance (e.g. high pillars), the inspection can be carried out using suitable and simple means (e.g. binoculars). Critical parts of structures (e.g. supports, Gerber joints, etc.) must be inspected from close range. The inspections are carried out using the Kuba-DB database, which is a technology that avoids the inspector having to manually draw the structures to be inspected and transfer them into a report. The

Questionnaire	
	software allows the export the drawings of the structures to be inspected directly to the inspector's tablet or laptop and the results can be retrieved after inspection without the risk of transcription errors. Advanced technologies, are not used for the routine main inspection. They apply only when a specific monitoring need is decided for individual cases.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	In general, long span bridges are not many in Switzerland. Instrumentation monitoring is quite common during the construction time. A permanent, long term monitoring is generally not required. However, for each object the design engineer sets a quality and preservation plan. If it turns out, that a long term monitoring is necessary, this is noted on the preservation plan. The department which is responsible for the preservation of the asset, assures that this preservation plan is followed. It is the case of few cable-stay bridges, which are equipped with sensors on the stay-cables, which measure the cable force. Actually, no standard exists for such a long-term monitoring. Due to aging of the infrastructure, FEDRO has recently initiated a project to verify the necessity of a more general monitoring of the road infrastructure. One of the aims of this project will be to set the basis for such a new standard.
1.3 How are inspections carried out (conducted) in your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	Generally, such environment is less common. There are though, some sectors in Highway N2, Canton Uri and in Highway N4 (Rigi Nordlehne), In case of unstable cliff, the access, for instance to piers, is assured by cranes which drive over the deck. If a cave, which presents a risk for a highway bridge, has to be investigated, groups of at least two investigators with appropriate O2 equipment perform this.
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections	Such technologies are not yet incorporated to the regular inspections that remain visual. On the other hand, when the results of the visual inspection indicates the necessity to proceed to a rehabilitation project, other techniques are used which can provide more details and can lead to a better estimation of the rehabilitation costs. Such used techniques are: • three-Dimensional Laser Scanning • Ground penetrating radar • Ultra sound impact echo

Questionnaire	
compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	The case study presented after concerns a ramp bridge that was thoroughly investigated by ground penetrating radar.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	Inspections on submerged elements of structures are generally visual. Divers or other specialists are used as required (this is stated in the monitoring plan). In some cases, the condition and use of the structure may require further underwater investigations. The evolution of the water level is also noted in order to record an eventual tendency, this is though performed by an inspection different to that of the bridge.
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	Apart from few cases, the monitoring of bridges is not extended. However, some long viaducts were designed in such way to facilitate future inspections. For instance, the Sitter Viaduct is equipped with a cableway, installed under the box deck, which allows to inspect the box girder and have secure access to the bearings of the piers. Standard configurations that also help access for inspections are the stairs in the abutments and the lighting inside the box girders.
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	Throughout Switzerland, ten weight in motion installations exist, however there are located on the pavement and not on the bridges. These WIM stations are mainly used for statistical purposes and for load-dependent adaptation of codes. Current internal discussions within the federal office indicate the necessity to install WIM stations on the deck of bridges so as to monitori dynamic effects caused by heavy traffic.
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy	Inspections of difficult to access structural parts is accomplished by using cranes equipped with inspection telescopic platforms. If it is necessary to close traffic, this may apply during the day under the

Questionnaire	
equipment or machinery) or accomplished (closing traffic lanes, etc.)?	condition that a lane remains free for each direction. If this condition cannot by fulfilled the inspection takes place at night.
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	As far as possible, an observation is mandatory for the inspectors, for instance, all sustaining walls, being part of a bridge structure, are observed to detect deformation. For some structures, like the protecting shafts of the high pillars founded deep in a steep, sliding slope are periodically measured and those results are integrated in the inspection report.
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	No, the geometry of hidden parts is obtained from the existing plans in the archives. Such an inspection takes place only when the whole road sector is the object of a general rehabilitation program or in case of doubt.
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	This is dealt by the standard: ASTRA Guideline 12005 Ground anchors. All anchored structures must be equipped with measureable anchors. The minimum number of measurable anchors is 5% of all anchors. For each anchored structure, structural deformation monitoring devices must be installed, which provide useful information on the behaviour of the structure. The “old” existing structures with soil or rock anchors have to be inspected visually; some of those have been equipped with measurable anchors far after construction time.
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	Not for regular inspection.
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	Not for regular inspection.

Questionnaire	
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	Structural Health Monitoring is foreseen only within the framework of a pilot studies.
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	So far, no need exists for such technologies for bridges. It may apply though to other structures as protection galleries and cut and cover exposed to natural hazards, such as avalanches and rock falls
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a foundation, temperature readings...	A monitoring of the temperature of the structure may apply for cases where there is a doubt about the capacity of an existing expansion joint.
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	Such a monitoring applies to individual cases: - Bridge over the Rhône River in St-Maurice. This cable-stayed bridge is equipped with various sensors for measuring the vibration frequencies, the forces of the stay-cables and the grading of the suspended deck. - Bridge over the Paudez river, Highway N9. Due to landslide the foundations shafts are equipped with inclinometers.

Country:	United States of America
Name of Organization:	Federal Highway Administration
Description of Organization:	National level governmental agency.
Your name:	Joseph Hartmann
Your e-mail address:	joey.hartmann@dot.gov

Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Inspection Strategy. Do you use a known repository and which one, which technologies are used? Which technologies and tools are used to supplement visual inspections in your country? If any, which guidelines or specifications recognize or permit the use of these technologies?	There are many sources that identify technologies that may be used to supplement visual inspections in the United States. The Federal Highway Administration's (FHWA) "Bridge Inspectors Reference Manual" discusses technologies (this document is in the process if being updated for release later in 2021). FHWA has developed a Nondestructive Evaluation Web Manual (https://fhwaapps.fhwa.dot.gov/ndep/) that includes information on technologies, too, and is periodically updated. In addition, the AASHTO's "The Manual for Bridge Evaluation" is another document that includes some technologies.
1.2 Monitoring of long-span bridges. Is it mandatory to take into account instrumented monitoring during the design stage of a bridge (consideration of integrated technologies for long-term or construction monitoring, such as the installation of instrumentation or accessibility to potential instrument locations)? If so, which specifications are used?	Instrumented monitoring is not required, but under Federal bridge inspection regulations (the National Bridge Inspection Standards), most long span bridge types would be considered "Complex" bridges that would require bridge-specific inspection and monitoring procedures. There is no specification that governs the development of those procedures.
1.3 How are inspections carried out (conducted) in	Neither the Federal bridge inspection regulation nor the FHWA's Bridge Inspector's Reference Manual specifically address these types

Questionnaire	
your country in specific environments such as an explosive or dangerous atmosphere, very unstable cliff or slope (difficult terrain), areas with protected of flora or fauna... ?	of situations. If a State had a bridge in an area that required special attention, like these situations, the State would develop bridge specific inspection plans.
2.0	**Questions related to techniques & technologies**
2.1 What techniques or technologies are available in your country and/or used to supplement the inspection of visible bridge parts (drones, 3D scanning, photogrammetry, shape recognition, automatic damage detection, digital model, satellite surveillance,...)? What places do they occupy in inspections compared to "traditional" visual inspections (How routinely are these techniques or technologies used?)	The use of technologies to supplement visual inspections are becoming more utilized in the inspection program to determine the conditions of bridge members and as part of a planning for a bridge project to better understand the scope and need of a project. Unmanned aerial systems (UAS) or drones are primarily used to deliver an established technology, primarily a camera, to get a different perspective but their use is still developing. FHWA has stated that UAS can be used as a supplemental inspection tool and that States should continue with their normal visual inspection practices until the technology becomes more mature.
2.2 Which techniques or technologies are used for the underwater inspection of bridge components or to detect scour (scanner, underwater drones…)	**Underwater Inspections** The National Bridge Inspection Standards and the AASHTO “The Manual for Bridge Evaluation” dictate and describe such underwater inspection techniques. Bridge owners enjoy a great deal of flexibility within those standards to develop techniques appropriate to their specific assets. **Scour detection** With 578,000 bridges over water, the diverse variety of hydrologic, hydraulic, geotechnical, structural and geomorphic conditions and features dictate such potential techniques. Furthermore, the examples seem to indicate some confusion between the actual devices (e.g., “scanners”) and the means to deploy them (e.g., drones). The FHWA considers scour monitoring to have four components: 1. Instrument for making the measurement 2. System for deploying the instrument(s) 3. Method to identify and record the horizontal position of the measurement 4. Data-storage device

Questionnaire	
	Generally, instrumentation may take the form of one of the following: 1. Physical probing 2. Sonar (including side beam and multi-beam) 3. LiDAR 4. Geophysical (e.g., ground penetrating radar) 5. Release or floatation devices 6. Buried or driven rods - device with sensors on a vertical support, placed or driven into streambed 7. Other Buried Devices - active or inert buried sensor (e.g., buried transmitter) Chapter 9 of FHWA's 2009 Hydraulic Engineering Circular number 23 "Bridge Scour and Stream Instability Countermeasures" has an extensive discussion of these technologies. Other literature is quite extensive on such techniques including: NCHRP Report 396, "Instrumentation for Measuring Scour at Bridge Piers and Abutments" NCHRP Report 397 A, "Sonar Scour Monitor Installation, Operation, and Fabrication Manual. NCHRP Report 397B, "Magnetic Sliding Collar Scour Monitor Installation, Operation, and Fabrication Manual." NCHRP 20-5 "Practices for Monitoring Scour Critical Bridges"
2.3 Is construction monitoring extended or converted to long-term monitoring to facilitate the bridge management (structural behavior, corrosion monitoring, WIM…)? Is equipment dedicated to the inspection of unique details (lifts or stairs in the abutments, piers or towers, walkways under the deck, ladders on columns, lighting to facilitate inspection from lifts or baskets ...)? Has your country used RFID (radio frequency identification) sensors integrated during construction or during operation?	The use of technologies for construction monitoring rarely get converted to long-term monitoring as they both serve very different purposes. Some instrumentation for longer-term monitoring may be installed during the construction of a bridge, but it isn't typically used for construction monitoring. For example, a State may add to the construction plans that monitoring devices and equipment may be installed and will leave access to connect a computer and other device to transfer data from the monitoring to the State after the construction project is completed. RFID technologies are not widely used.

Questionnaire	
2.4 Are bridges instrumented (WIM - weight in motion -, predictive surveillance, overload) in your country? If so, for what purposes?	Bridge instrumentation is not a general practice in the United States. However, States have instrumented some bridges they own for different purposes such as security surveillance, structural condition monitoring, assessing load capacity, or research to better understand long-term structural performance.
2.5 How is the inspection of difficult-to-access structural parts managed (using heavy equipment or machinery) or accomplished (closing traffic lanes, etc.)?	The Federal bridge inspection regulation require a complete inspection, but leaves the specific means of an inspection up to each State. States use a variety of means to access difficult to reach spaces. These include: climbing with rope access, under bridge inspection trucks that can be used from on the bridge deck with lane closures or from under the bridge itself, and from permanent inspection platforms that are built for the bridge and left in place.
2.6 Does inspection or management in your country systematically integrate the analysis (or observation) of buried structures and, if so, what elements (foundations, reinforced soil...)?	Inspection of bridges in the United States includes a characterization of the bridges foundations from what can be seen. If a buried structure was to fail, there are usually visible signs above ground (cracks in walls, heaving of soil, etc.). The following question and response gets to technologies that are available to assess buried structures more directly. From a management perspective, a State would use any information it has to make informed decisions. Since the technology is not systematically integrated, the management techniques to use information on buried structures is not systematically integrated.
2.7 Do you perform geometric characterization of the hidden parts of bridges, and how? This intended to ask if subsurface investigations are used to define the geometric dimensions of foundation elements (shafts, piles, etc.) or identifying the geometric dimensions of embedded reinforcement either passive or active	This is essentially a question about unknown foundations. While our technology is getting better, we still don't have the ability to completely characterize buried features of bridges. Some bridge owners have developed a risk-based, data-driven approach to such consideration. Additionally, the relative expense of the technologies per foundation element remains very high. So, identification of the type and geometry of foundations is done on a case by case depending on many factors, including access. The identification process could involve the traditional method of drilling adjacent borings or excavation of test pits for direct access to the foundation element if possible, coring for collection of a sample from concrete elements. Use of non-destructive tests (NDT) geophysical methods is also performed and the selection of the method depends on the access conditions, foundation material (concrete, steel) and other factors. NDT electrical resistivity tomography (ERT), ultra-sonic, ultra-seismic (US) and ground penetration radar (GPR) technique are examples of NDT used for identification of foundations.

Questionnaire	
2.8 Does monitoring include the inspection of post-tensioning anchorages (methods and means to be specified, if any)?	Inspection of post-tensioning anchorages is typically performed visually via borescope through a post-grouting access hole integrated into the anchorage assembly. We're not aware of other monitoring methods in use.
2.9 Has your experience of inspections allowed you to incorporate reliable testing and control techniques into your monitoring programs? Do you use of RFID-sensors embedded during construction to support operation or management?	The use of monitoring technologies and programs is limited to address or investigate known issues or to gain additional information to supplement other information to make informed decisions. It is not widely used. We are not aware of much us of RFID sensors in bridges in the United States.
2.10 Do you use unmanned aerial systems or similar remotely controlled platforms to conduct or supplement inspections?	Unmanned aerial systems and other similar technologies are allowed to be used by States to supplement visual inspection. We are waiting for the technologies to become more mature before allowing them to be used to replace typical visual inspection processes.
2.11 Do you use SHM in conjunction with traditional visual inspection strategies?	Structural health monitoring (SHM) is limited to address or investigate known issues or to gain additional information to supplement other information to make informed decisions. It is not widely used.
3.0	**Questions related to climate change**
3.1 Has climate change encouraged you to increase the use of innovative inspection techniques and technologies? Is the need for the use of innovative inspection techniques and technologies evidence of climate change? For example, has an an increased in the frequency of extreme natural hazards required more frequent inspection?	No. Climate change does not play a role in inspections. The safety of the travelling public dictates the role and frequency of inspections. However, as part of the required Asset Management plan for NHS bridges, the plan shall identify of risks that can affect conditions, performance of the NHS, including "risks associated with current and future environmental conditions, such as extreme weather events, climate change, seismic activity, and risks related to recurring damage and costs as identified through the evaluation of facilities repeated damaged by emergency events …". Part of the plan might allow, if some external factor, such as an extreme weather event, occurs, for the asset owner to take necessary steps to ensure the safety of that asset, including conducting an inspection of the asset.
3.2 Do you use a specific advanced inspection technique or technology to confirm evidence of climate change? For example, monitoring of subsurface scour at a	No.

Questionnaire	
foundation, temperature readings...	
3.3 Do you specifically monitor bridges during an extreme climatic event (flood, strong wind, slip, drought, etc.) in order to confirm behavior and maintain performance? If so, what equipment is used?	See answer to earlier questions on instrumentation. Using scour as an example, for a scour critical bridge, the required "plan of action" might require such monitoring of that bridge during those extreme weather events. Perhaps via instrumentation, perhaps using inspectors, perhaps using RADAR of the event, etc. From such monitoring the bridge owner would close the bridge during the event so that an inspection team can inspect it before re-opening. There are software packages that help bridge owners to make such assessments.

Country:	Poland
Name of Organization:	Wroclaw University of Science and Technology Training Center for Bridge Inspector
Description of Organization:	WUST Training Center for Bridge Inspectors for 25 years is organizing special courses for inspectors of road and railway bridges - on various levels of specialization
Your name:	Prof. Jan Bień Dr Mieszko Kużawa
Your e-mail address:	jan.bien@pwr.edu.pl mieszko.kuzawa@pwr.edu.pl

General Questionnaire	
1.0	**Questions related to Standards & Codes**
1.1 Strategy for detailed inspections, which technologies are used? Are they innovative? Which level of innovation is allowed in your country when referring to the official inspection guidelines?	In national regulations five types of regular and special inspections are defined: current inspections, basic inspections, extended inspections, detailed inspections and expertise. First three types of inspections are mainly based on visual observations as well as simple optical methods (including endoscopy, microscopy, geodesy) and are focused on identification of bridge defects. During detailed inspections some more advanced non-destructive (NDT) and semi-destructive (SDT) diagnostic tools are used, e.g. sclerometric tests, ultrasonic test, radiographic techniques, impact echo, electromagnetic induction, pull-out/pull-off tests, chemical and biological test. In inspections performed by external experts all available diagnostic methods can be applied, including innovative technologies – regulations do not limit range of inspection techniques.
1.2 Is monitoring a mandatory in the design for long-span bridges?	Monitoring of long-span bridges is not mandatory in Poland. Decision on permanent monitoring system located on a bridge structure depends on decision of investor and state holder.
1.3 How it is managed the inspection in specific environment (hazardous explosive atmosphere, marine environment, flora and fauna…)?	General rules of bridge inspections are generally unified for all environment conditions. Some specific regulations are defined for bridges located in mining areas.
2.0	**Questions related to techniques & technologies**

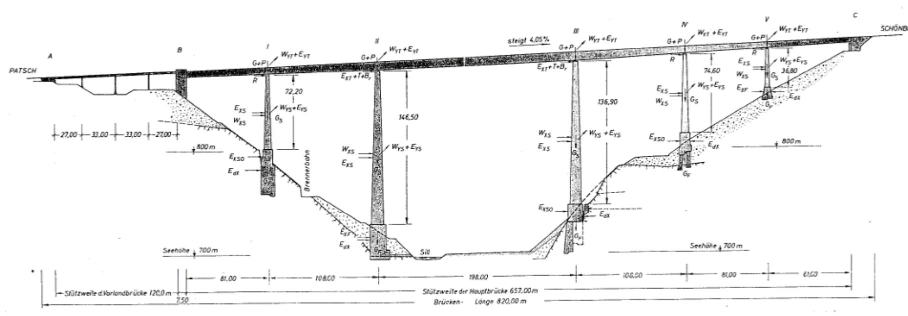
General Questionnaire	
2.1 Which techniques or technologies are commonly used within the inspections of visible areas of the bridge (drones, scan 3D, photogrammetry, pattern recognition, automatic damage detection, digital mock-up, satellite monitoring,…)	Regular basic inspections are mainly based on visual observations as well as simple optical methods (including endoscopy, microscopy, geodesy). During detailed inspections more advanced non-destructive (NDT) and semi-destructive (SDT) diagnostic tools are used, e.g. sclerometric tests, ultrasonic test, radiographic techniques, impact echo, electromagnetic induction, pull-out/pull-off tests, chemical and biological test. In inspections performed by external experts all available diagnostic methods be applied, including ultrasonic tomography, computer tomography, radar techniques, electric potential/resistance techniques, laser methods, thermographic methods.
2.2 Which techniques or technologies are commonlyused within the underwater inspection of submerged bridge components (scanner, underwater drones, detection of scouring…)	Underwater inspections are commonly performed by means of special probes as well as by professional divers equipped with specialist diving equipment. In some cases special sonars or underwater robots are used.
2.3 Is construction monitoring extended and converted to long-term monitoring to facilitate the bridge surveillance (topography, corrosion monitoring, instrumentation…)? Use of RFID -Radio Frequency Identification- sensors embedded during construction and used during operation?	Long-term instrumented monitoring is not obligatory and is used in special situations only. Monitoring goals and technologies are individually decided in each case.
2.4 Instrumented bridge (BWIM -weight in motion-, predictive monitoring, overload)	Monitoring goals and technologies are individually decided in each case.
2.5 How it is managed the inspection of inaccessible parts (operation of traffic lanes, …)?	In such a case the traffic lines can be temporarily closed or drones can be used.
2.6 It is frequent the use of buried control samples (e.g. reinforced earth, shallow foundations, deep foundations…)?	This type of inspection is rare – mainly is performed by means of the ground penetrating radar (GPR).
2.7 How it is done the geometric characterization of hidden parts of bridges?	This type of inspection is mainly performed by means of the ground penetrating radar (GPR).
2.8 Inspection of anchor ties? Methods and means?	Effective inspection of anchor ties (as well as prestressing cables) is still a problem in bridge diagnostics.
2.9 Do you use high efficiency testing and monitoring techniques? (example with waterproofing layer)?	No special techniques of waterproofing layer testing or monitoring are now used in our country.
2.10 Use of robotized solutions for bridge inspection?	Some pilot applications of drones and underwater robots were performed in last years.
2.11 Use of SHM in link with traditional inspection strategies	Bridges under the Structural Health Monitoring (SHM) with technical monitoring instrumentation are all the time

General Questionnaire	
	inspected also according to the general inspection standards.
3.0	**Questions related to climate change**
3.1 The use of advanced inspection techniques & technologies has increased due to the climate change evidences? e.g. More frequent extreme natural hazards	Up to now we do not observe clear influence of the climate changes on inspection techniques.
3.2 Is there any specific advanced inspection technique or technology that can confirm climate change evidence? e.g. monitoring of scour at substructure, temperature records…	Almost all monitoring systems register temperature, wind, etc. Results confirm climate changes.
3.3 Do you specifically monitor bridges with regard to an exceptional climatic event (flood, strong wind, landslide, drought, etc.) in order to verify its behavior and the maintenance of its performances? Explain one of these equipments to us	This type of special bridge monitoring was not applied up to now. Almost all monitoring systems register temperature, wind, etc. and results confirm climate changes.

9. APPENDIX C: CASE STUDIES

The appendix contains 28 case studies. Their arrangement is alphabetical.

Austria - 01

Case study	
1.0	**General data**
Country	Austria
Prepared by	Peter Augschöll
Date Prepared	28.12.2020
Bridge name	Europabrücke
General bridge description	The bridge was built from 1959 to 1963 and it`s a Steel bridge with orthotropic deck and reinforced concrete piers. The superstructure is a continuous beam with six spans with the maximum span of 198 m.
Bridge equipment	Roller-bearings; expansion joints (Mageba sliding fingers);
Other	
Bridge pictures	
2.0	**Bridge data**
Structural design	Continuous beam with box girder

Case study	
Material classification	Superstructure: steel Substructure: reinforced concrete
Geometrical data	Length: 657 m; maximum span: 198 m; maximum height above ground about 200 m; maximum height of pier about 150 m;
Reason for using the tools/techniques	The great height of the piers
3	**Tools/technique used: Drones**

Case study	
Tool picture	 Drone with laser scanner  Drone with high resolution camera
General description	We used two drones to capture the geometry (laser scan) and the surface (high resolution camera) of the five piers. With this data we created a 3D-model of the substructure of the bridge. With special software you can view this 3D – models and document cracks, spallings, concret pockets and so on.
Field(s) of use	For structures or surfaces which are very difficult to reach

<table>
<tr><th colspan="2">Case study</th></tr>
<tr><td>Results reliability</td><td>
Detail of pier 5 – upper left corner

Detail of pier 5 – upper left corner (zoom)</td></tr>
<tr><td>Test duration</td><td>To capture the piers lasted about 3 days</td></tr>
</table>

Case study	
Results' interpretation complexity	Of course you only get the visual defects. You can`t find local separations. But with the high resolution pictures it`s very close to an inspection on site. A great advantage is the documentation of defects directly in a 3D-Model on the exact position.  Crack in the reinforced concrete pier
Cost	26.000 €
Standardization	No (until now there were only a few pilot projects).

Belgium - 01

Case study	
1.0	**General data**
Country	Belgium
Prepared by	Auguste Thierry
Date Prepared	03/03/2021
Bridge name	Pont de Wandre; road N667; 50.673991 N 5.643546 E
General bridge description	The bridge was built in 1988-1989. It connects the highway E25 and an oil port located on the right bank of the Meuse river with the former rolling mill of Chertal and the cities on the left bank. A visual inspection of the structure and a tension determination of the stay cable is conducted on a 5-year basis. End March 2020, abnormal vibrations were observed on some stay cables.
Bridge equipment	Stay cable, expansion joint, bearings, drainage
Other	
Bridge pictures	

	
2.0	**Bridge data**
Structural design	Stay cable bridge
Material classification	Prestressed concrete
Geometrical data	Length : 505 m Width : 21.8 m Span : 7 No of lanes : 4
Reason for using the tools/techniques	To control if the abnormal vibrations observed in March 2020 led to damage to the strands of the stay cable, a new monitoring system developed in cooperation with the University of Liège and V2i (a private company specialized in vibration), has been used to monitor the tension in the cables during 2 months. This situation serves as a study case for the developed system, aimed to be placed on stay cable bridges and arch bridges to monitor the evolution of the tension in their cables.
Tools/technique used	Autonomous and wireless accelerometers. Solar station running the software for recording the measured data every hour, calculating the tension on the basis of the frequency signal and sending the values to the cloud. An automated analysis generates alerts sent by email or sms.

3	**Tools/technique used**
Tool picture	  

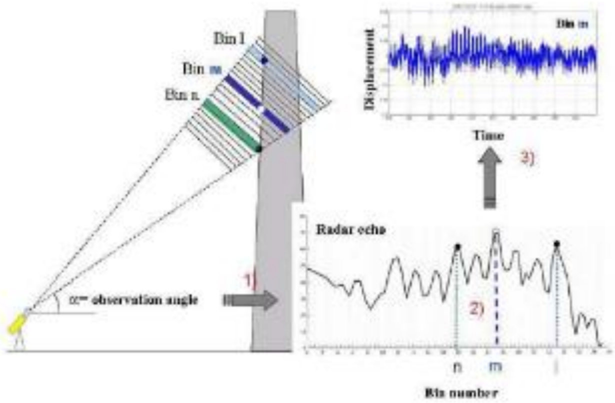
General description	The system measures the vibrations of a cable with an accelerometer fixed on it. The modal frequencies of the cable are calculated by applying a fast fourrier transform and selected by using a stochastic subspace identification algorithm. The tension is then identified by fitting the ratio curve between the identified frequencies and their mode number with this of a parametric model by means of an iterative procedure.
Field(s) of use	Limited to the determination of the tension of external cables.
Results reliability	Good. The uncertainties come from the selected frequencies, geometric parameters (length, linear mass), estimated parameters (stiffness, deformability and mass of the support). The tension varies with the temperature
Test duration	2 months
Results' interpretation complexity	The calculated stress values are good, but do not make it possible to locate or quantify possible wire breakage defects.
Cost	The cost of the material developed for these measurements is 190000 euros. This does not represent the cost of the instrumentation since it will be used on other bridges. It has been installed by administrative staff, no contract has been awarded to a private company. In estimation, it takes 5 days for an engineer and 2 days for an operator.
Standardization	No.

France – 01

Case study	
1.0	**General data**
Country	France
Prepared by	✓ Z. Belhmira, ASF – Autoroutes du Sud de La France ✓ M. Lebreton Sixense ✓ Michele Crosetto Centre Technologique de Télécommunications de Catalogne)
Date Prepared	25/01/2021
Bridge name	PI5393 sur A10
General bridge description	Reinforced concrete beam underpass built in 1963, 3 spans, approximately 65 ml long, supporting 2 x 3 lanes of the A10 motorway north of Bordeaux. On each deck the cross profile consists of a 1.90 m BAU, 3 lanes of approx. 3.5 m width and a 0.80 m BDG.
Bridge equipment	
Other	
Bridge pictures	

	
2.0	**Bridge data**
Structural design	Bridge with reinforced concrete girders.
Material classification	Reinforced concrete.
Geometrical data	Built in 1963, the PI 5393 is a reinforced concrete beam structure with the following main characteristics : • Mitre length : approx. 65.55 m with 3 bays (25.80 m, 24.40 m, 15.35 m), • Straight width : approx. 31.80 m with 2 aprons (15.90 m, 15.90 m), • Bias : 45 grades.
Reason for using the tools/techniques	Carrying out a loading test to check the transverse bending behaviour of the deck.
Tools/technique used	Measurements of deck displacements using high-frequency interferometric radar technology, allowing dynamic measurements of the boom at different points of the girder, without contact with the structure.

<table>
<tr><td>3</td><td>Tools/technique used : High-frequency radar interferometry for non-contact, dynamic displacement measurement</td></tr>
<tr><td>Tool picture</td><td>

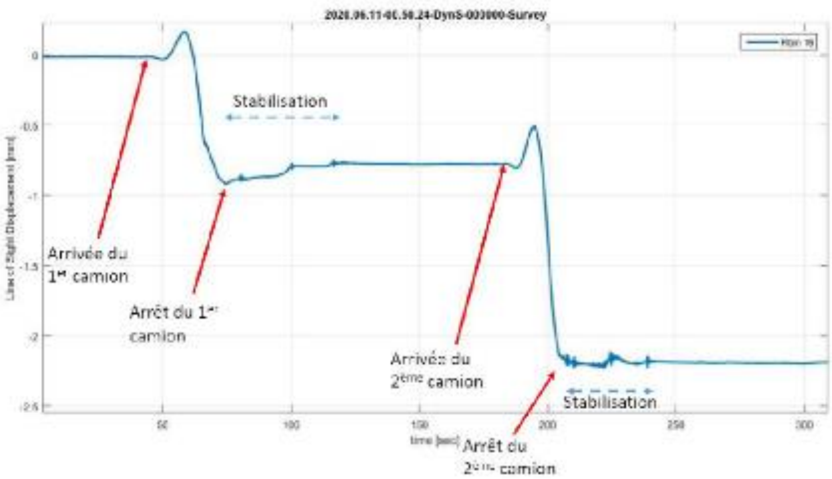

</td></tr>
<tr><td>General description</td><td>


Use of interferometric radar technology. The radar emits frequency-modulated electromagnetic waves, which allows the distance between the device to be continuously scanned (at a rate of one (1) measuring point every 75 cm).

Differential interferometric analysis of the return signals enables the determination of distance variations with an accuracy of +/-0.02 mm.

Measurements are made in the line of sight of the radar.

Measurement frequency up to 200 Hz (200 measurements in 1 second).
</td></tr>
</table>

Field(s) of use	Displacement measurement, as an alternative to the installation of sensors (no need to access the structure to install measuring instruments) or topometry. Direct determination of the structure's eigenfrequencies is possible for evaluating the dynamic behaviour of the structures.
Results reliability	Excellent. Very good adequacy with the theoretical studies and the displacements expected by the calculation.
Test duration	Radar is generally used for spot measurements, with measurements being taken in the order of ten minutes or so.
Results' interpretation complexity	Simple. Displacement measurements easily correlated with theoretical studies. Visualisation of measurements in real time, during data recording. 
Cost	Low to moderate, depending on aiming conditions and the desired duration of monitoring (one-off test, or continuous monitoring over a few days).
Standardization	No.

France – 02

Case study	
1.0	**General data**
Country	France
Prepared by	Bertrand Collin, SITES
Date Prepared	Étude réalisée en avril-mai 2018
Bridge name	Viaduc de Calix – RN 814 entre Hérouville St Clair et Mondeville (Calvados) Coordonnées : 49°11'1" N - 0°19'38" W
General bridge description	Date of commissioning: 1974 Reach : RN 184 - 2 x 2 lanes Roads crossed : RD 34, river Orne, maritime canal, several others roads, railways, port area. Maximum clearance height : 38 m above the Orne River Total length: 1180 m Total width: 15.2 m Supports: 2x 14 stacks and 2 abutments
Bridge equipment	Street lighting, TPC, guardrails, BN3, heavy pavement joints.
Other	Viaduct classified in category 3 in 2018 (IQOA reference) Crossing of a Seveso-classified port area.
Bridge pictures	

2.0	**Bridge data**
Structural design	• SETRA design • Double box girder prestressed concrete deck (internal prestressing) constructed by successive corbelling • Reinforced concrete piles and abutments
Material classification	• Pre-stressed concrete with internal prestressing • Reinforced concrete
Geometrical data	Total length : 1180 m Total width : 15.2 m Apron • double prestressed concrete caisson with variable inertia (between 1.90 m and 9.70 m) • 15 bays Maximum clearance height: 38 m above the Orne River : 38 m above the Orne River Support • 2x 14 drum type piles with variable height reinforced concrete headframe • 2 reinforced concrete abutments Reach : RN 184 - 2 x 2 lanes Roads crossed : RD 34, river Orne, maritime canal, several others roads, railways, port area.
Reason for using the tools/techniques	• Work classified 3 (IQOA reference) in 2018. • Lack of an exhaustive and objective survey of the condition of the piers and deck since the commissioning of the structure in 1974. • Difficulty of access to the apron and batteries. • Complex crossing. Need for a baseline to objectively assess the condition of the facility, target specific monitoring actions and define the urgency, nature and extent of corrective actions.
Tools/technique used	• Drone (recognition and PTHR readings).

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PTHR (Panoramic Very High Resolution) readings from the ground with motorised panoramic head and telescopic boom.
PTHR lifts with telescopic pole.
HD Mapping processing: statistical processing of data, orthophotographs, creation of digital twins and defect mapping

</td></tr>
<tr><td>3</td><td>Tools/technique used</td></tr>
<tr><td>Tool picture</td><td></td></tr>
<tr><td>General description</td><td>Realization of the photographic cover at very high resolution.
<table>
<tr><th colspan="2">DRONE M210</th></tr>
<tr><td>Payload</td><td>1.6 kg</td></tr>
<tr><td>Autonomy</td><td>13-25 min</td></tr>
<tr><td>Maximum speed</td><td>Vertical : +/- 5m/s - Horizontal : 12m/s</td></tr>
<tr><td>Dimension</td><td>887×880×378 mm</td></tr>
<tr><td>Motorization</td><td>4 motors brushless</td></tr>
<tr><td>Two vidéo returns</td><td>5.8 gHz et full HD 2.4 gHz secured</td></tr>
</table>
</td></tr>
<tr><td>Field(s) of use</td><td>

Structural elements and equipment that are difficult to access.
Complex crossings (use of negative gondolas impossible, implementation of heavy means of access with a strong impact on operations and safety or cases where the implementation of PTHR surveys by fixed stations is not suitable or even impossible).
Reduced intervention time on site.
Special conditions (secure site, various risks).

</td></tr>
<tr><td>Results reliability</td><td>

Excellent reproducibility.
Excellent completeness through the overlay of THR photographs.

</td></tr>
</table>

	• Sufficient accuracy with regard to the requirements of the readings (crack detection threshold of 0.1 mm).
Test duration	5 days for a team of two people
Results' interpretation complexity	***See tool / technique 3 - HD Mapping***
Cost	Low compared to a traditional method of surveying • reduced intervention time on site • no heavy means of access • no hindrance to the holding
Standardization	No.

France – 03

Case study	
1.0	**General data**
Country	France
Prepared by	André Orcesi, Nicolas Manzini
Date Prepared	21/01/21
Bridge name	**Pont de Brotonne & Pont d'Aquitaine**
General bridge description	Prestressed concrete cable-stayed bridge & Steel suspension bridge
Bridge equipment	
Other	Case studies considered in Nicolas Manzini's thesis (CIFRE SITES/UGE/IGN thesis defended on 4 November 2020)
Bridge pictures	
2.0	**Bridge data**
Structural design	Cable-stayed bridge (Pont de Brotonne), Suspension bridge (Pont d'Aquitaine)
Material classification	Prestressed concrete (Pont de Brotonne) Steel (Pont d'Aquitaine)
Geometrical data	Brotonne Bridge : The central span, which rises up to 50 m above the level of the Seine, is made up of 320 m long prestressed concrete segments assembled by corbelling. The two pylons reach a height of 125 m and carry the stays arranged in a fan-shaped pattern in the median plane of the roadway. Aquitaine Bridge : It is composed of a 1014 m access viaduct, a 39 m anchor block (left bank), three suspended spans: a central main span of 394 m and two symmetrical spans of 143 m; and finally a 35 m anchor block to the east (right bank). The central and right bank spans are joined, while the left bank span is independent. The bridge consists of two pairs of flexible embedded reinforced concrete pylons 103 m high.
Reason for using the tools/techniques	Taken from Nicolas Manzini's thesis manuscript (thesis CIFRE SITES/UGE/IGN defended on 4 November 2020) Context of the Brotonne Bridge : The structure is subject to regular monitoring, initially to monitor the deformation of the deck and pylons with respect to creep phenomena. Particular attention is paid to the south

	abutment of the structure, as settlements have been measured since 1987 by topographical monitoring. The settlement rate is currently around 3 to 4 mm per year. The abutment is equipped with support devices enabling the structure to be raised by 7 to 8 mm every two years by injecting silicone. Since 2010, reinforcement work has been carried out on several piers, including the filling of external cracks, the installation of reinforced concrete belts in the piers, and the installation of carbon composite strips inside and outside the piers subjected to thermal effects that were insufficiently taken into account in the design. In 2013, replacement of bearings, replacement of pavement joints and modification of the drainage and sewerage system. Context of the Aquitaine bridge : The bridge has been the subject of careful monitoring and regular maintenance and repair operations for 40 years. In 1993, a new detailed inspection revealed a total of 178 wire breaks: this represents less than 1% of the total number of wires in the suspension, so the condition of the structure is not considered "alarming" at this stage. In 1998, the structure came under the high surveillance regime, and it was decided to replace its suspension between 2000 and 2006. Since then, several repair operations have been carried out in 2010 and 2012.
Tools/technique used	In both cases, the deployment of a network of Géocube sensors aims to complete the geometric monitoring of structures with dense data distributed over various characteristic elements. Taken from the manuscript of Nicolas Manzini's thesis (thesis CIFRE SITES/UGE/IGN defended on 4 November 2020) : Both structures have been equipped with a network of Géocube sensors, compact intelligent GNSS stations. In both cases, a fixed GNSS reference station was installed close to the structures (less than 1.5km from the furthest instrumented point). The sensors transfer their GNSS observations via a radio mesh network to a local collector, and to a remote server on which a relative GNSS calculation (with the reference) is performed to obtain time series of positions (3D) with a delay of a few minutes. From May 2017, the Brotonne bridge will be equipped with 11 Geocube stations with a sampling rate of 30 seconds: • 2 stations at the tops of the pylons ; • 2 stations in the centre of the central apron, located on both sides of the roadway (upstream and downstream sides) ; • 2 stations surrounding the joint between the access viaduct and the main span, located in the centre of the joint;

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- 4 stations surrounding the joint between the south abutment and the access viaduct, divided into two pairs on either side of the roadway;
- 1 station located on the access viaduct, in the centre of the carriageway, north of the previous joint.

The structure also features a weather station collecting data on air temperature, wind speed and direction, as well as temperature sensors installed by Cerema in the main piers and in a box near the south abutment.

From February 2019, the Aquitaine bridge will be equipped with 14 Geocube sensors with a sampling rate set at 60s :
6 sensors installed on the central span, deployed in pairs on either side of the roadway;

- 2 sensors located in the centre of the right span ;
- 2 sensors located in the centre of the left span ;
- 2 sensors installed at the top of the right pylon ;
- 2 sensors installed at the top of the left pylon.

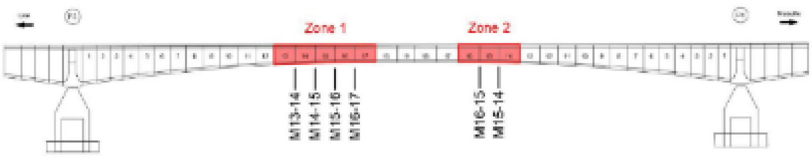
The work also includes traditional instrumentation, with temperature probes distributed in the cables, the apron, and laser displacement sensors and inclinometers at different points of the work.

</td></tr>
<tr><td>3</td><td>Tools/technique used :</td></tr>
<tr><td>Tool picture</td><td>
</td></tr>
<tr><td>General description</td><td>GNSS stations of the "intelligent sensor" type, whose data collection is ensured by a wireless mesh network, and data processing is carried out on a remote server.</td></tr>
<tr><td>Field(s) of use</td><td>3D tracking of movements in geotechnical applications: glaciers, volcanism, landslides.</td></tr>
</table>

	3D monitoring of static and quasi-static deformations and displacements on large structures, multi- centimetric order of magnitude.
Results reliability	Horizontal accuracy <1cm, vertical ~1cm. Observations validated with an accuracy of the order of 4mm in experimental tests after smoothing of the time series. Accuracy varies according to installation conditions (obstacles with the sky). No (electronic) drift over time. Possible data losses due to radio transmission (up to 5%) and calculation related to surrounding conditions (variable).
Test duration	Ø Permanent instrumentation, continuous data.
Results' interpretation complexity	Moderate: the time series obtained at the output of the treatment must be interpreted with knowledge of the precision of the material and the expected behaviour on the work. Simple smoothing or transformation into an appropriate reference frame may be necessary. Research has shown that time series models can be generated by learning from other sensors installed to identify abnormal behaviour. Note: This comment applies to time series obtained after processing GNSS observations to obtain positions. The observations themselves cannot be directly interpreted.
Cost	Approximately 2000€/station including all costs and accessories, but without subscription/processing costs.
Standardization	No.

France – 04

Case study	
1.0	**General data**
Country	FRANCE
Prepared by	N. Bessoule, P-M. Fabry (SIXENSE) C. Hechi (ASF – Autoroutes du Sud de La France)
Date Prepared	18/01/21
Bridge name	A7, PI 275 – Viaduc de Vienne
General bridge description	Structure built between 1972 and 1974 as part of the Vienne Nord / Reventin link to allow the Rhône to be crossed. The bridge consists of two independent parallel decks made of a single-cell prestressed concrete box section. Box girder bridge in prestressed concrete with variable inertia composed of 5 spans, 430m long (spans 67.4 / 98.4x3 / 67.4).
Bridge equipment	Pavement joints, Barrier type BN4.
Other	Box girder with prefabricated segments laid by successive corbelling using a launching beam.
Bridge pictures	

	
2.0	**Bridge data**
Structural design	Prestressed concrete box girder bridge with variable inertia.
Material classification	For the voussoirs : • B.A. transversally • B.P. longitudinally
Geometrical data	• 2 aprons with unidirectional carriageway with a gap of a few centimetres between them (approx. 14cm) • 5 bays • Length between supports: 430m • Ranges: 67.4m / 98.4m x3 / 67.4m • Width of the aprons: 12.16m • Thickness corbelled: 25cm on edges (VD and TPC) • Foundations: superficial for 2 abutment stacks and box for 4 stacks.
Reason for using the tools/techniques	A recalculation of the structure revealed a possible decompression of several segment joints, in the lower fibre of the box girder, under certain loading conditions. 

	A precise survey of the state of the joints in the identified sections was necessary in order to have a precise and accurate picture of the state of the joints: • an indisputable control reference system that enables the precise monitoring of the evolution of the state of the joints over time, • a high-definition digital survey that can be shared among experts, in order to compare opinions and facilitate technical exchanges.
Tools/technique used	• Very high resolution orthoimage* (0.2 mm / pixel) obtained by photogrammetry, • Web platform for data visualization and sharing. **Orthoimage: mosaic of images corrected for optical distortion and relief to make it superimposable on a plane (Image to scale)*
3	**Tools/technique used : very high resolution photogrammetry (0.2 mm / px)**
Tool picture	Conditions of access : • negative gateway Image acquisition : • digital camera Sony A7 RIV (61 MPx) • coded targets • 35mm fixed focal length lens • Led lighting system Photogrammetric processing for the production of orthoimages : • computing station • Agisoft Metashape software

	 
General description	The generation of a very high-resolution orthoimage, followed by the comparison of orthoimages over time, makes it possible to follow the evolution of disorders in the same area of interest very precisely (without bias of the human eye, and freeing oneself from errors in transferring disorders to manual mapping). The generation of an orthoimage is carried out in two stages : i. an on-site acquisition phase consisting of taking high-resolution (0.2mm/pixel) images of the facings with a high rate of overlap between images (approximately 75% in both directions); in the case study illustrated here, the images were taken with a facing setback of approximately 1m ii. a photogrammetric post-processing phase in the office to produce an orthoimage that restores the exact state of the cladding over the entire area of interest. To enable data sharing and analysis between experts, the orthoimages are tiled and then uploaded on a web platform (beMap). The platform allows the visualization of orthoimages in full resolution and the enrichment of the data with annotation, drawing and measurement tools. Illustration of an orthoimage on an area of 25m² :

Illustration of the level of detail obtained :

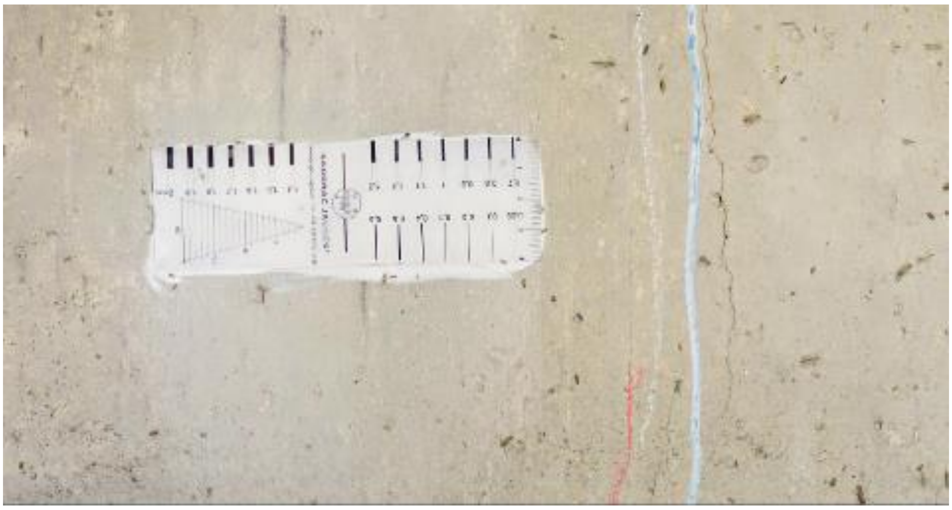


Illustration of data visualisation in the sharing platform (beMap) :

	
Field(s) of use	Assessment of the situation as part of a periodic detailed inspection or diagnosis Temporal comparison of the evolution of disorders in an area of interest
Results reliability	Reliability of the results: excellent, provided that the level of resolution of the acquisition is correctly adapted to the level of detail of the disorders sought (the level of resolution of the images - expressed in mm / pixel - conditions the threshold of detection of the defects).
Test duration	Highly variable, as it depends on : i. the level of resolution, ii. the extent of the area of interest, iii. the conditions of access for acquisition, iv. the size of the area of interest, v. the size of the area of interest.
Results' interpretation complexity	Simple. The inspector examines the orthoimage exactly as he would examine the siding on site.
Cost	Moderate to high depending on the conditions of access to the control area and the level of detail expected
Standardization	No.

France – 05

Case study	
1.0	**General data**
Country	France
Prepared by	Franziska Schmidt/Christophe Chevalier
Date Prepared	15/01/2021
Bridge name	A71_PI1001-05
General bridge description	The structure is a prestressed concrete bridge built by corbels, with a total length of 400 metres (5 spans: one of 50m, two of 75m and two of 100m), it originally had four lanes of traffic without an emergency lane. This work has 2 abutments and 4 piles (C1, P2, P3, P4, P5 and C6). The largest opening is 100 m long, connected by two neoprene supports: this length is reached for the two central spans, while the bank spans are 75 m long. At the abutments and the P5 pier there are sliding supports.
Bridge equipment	Support devices
Other	
Bridge pictures	
2.0	**Bridge data**
Structural design	Prestressed concrete box
Material classification	Prestressed concrete, reinforced concrete (piles)
Geometrical data	5 bays, total length of 400 metres. Length of the spans: 100m except those near the supports. Batteries between 85 and 86 metres high Apron width: 15.30m

Reason for using the tools/techniques	Analyse the behaviour of the structure as a function of scouring, water levels and recorded temperature
Tools/technique used	Miscellaneous sensors Case of the Vinci Motorway OA instrumented on the A71, instrumented to monitor scouring : • Water level by ultrasonic level sensor (Valeport VRS-20 limnimeter) : the water depth, combined with the flow velocity and other parameters, is involved in the prediction of scour levels (cf formula of the FHWA), • Bathymetry (bottom topography) by sonar (Kongsberg Dual Axis Sonar) and ADCP (Teledyne RDI Monitor 1200kHz) velocity profilometry, the sensors being placed on a floating frame : bathymetry measures sediment levels and therefore scour excavations. Velocity profiles are used to characterize flow conditions are involved in many formulas predicting the level of scour (in connection with the "critical speed") • Acceleration instrumentation for piers and bridge deck : monitoring of scour by the structure. There are been several publications on the subject, but work is still in progress at UGE • Room and cabinet temperature : correction of the dynamic behavior of the structure with respect to the temperature • Camera for monitoring the foot of the battery (presence of debris, ...) : allows, in addition to remote monitoring of the instrumentation, to detect the presence of debris (problematic during hydraulic phenomena of flood type or high speed), or other exceptional situations
3	**Tools/technique used**

3.1	**Tool/technology: Water level sensor**
Tool picture	Water 
General description	Radar Valeport VRS20
Field(s) of use	Limnimetre distance 1.5-20 m
Results reliability	Accuracy +/- 10 mm

Test duration	Permanent installation, instantaneous measurement (central acquisition unit required)
Results' interpretation complexity	Simple and automatic, based on the time of flight of an acoustic wave
Cost	1,800 € HT (sensor only)
Standardization	No.

3.2	**Tools/Techniques: Sonar**
Photo of the tool	  
General description	**Kongsberg Dual Axis Sonar (**on floating frame)
Area(s) of use	Bathymetry - depth 0.2 - 300 m
Reliability of results	Resolution > 1 mm
Duration of tests	Permanent installation ("quasi-instantaneous" measure)
Complexity of interpretation of results	Output data already interpreted (X,Y,Z coordinates)
Cost	28 100 eur HT (sensor only)
Standardization	No.

3.3	**ADCP (flow velocity)**
Photo of the tool	  

General description	**Teledyne RDI Monitor 1200kHz**
Area(s) of use	Depth 0.6-150 m - from 1 to 25 vertical cells - up to 5m/s
Reliability of results	Accuracy +/-0.3 cm/s
Duration of tests	Permanent installation ("quasi-instantaneous" measure)
Complexity of interpretation of results	Output data already interpreted (3 speed components)
Cost	17 000 eur HT (sensor only)
Standardization	No.

3.4	**Tool/technology: Temperature sensor**
Photo of the tool	
General description	Conventional" temperature sensor, PT100
Area(s) of use	Temperature measurement in outdoor environment
Reliability of results	Very good reliability.
Duration of tests	Continuous measurement since February 2020.
Complexity of interpretation of results	No complexity in interpreting these results. On the other hand, these data should be incorporated into the acceleration measures (Table 3.4).
Cost	Approximately 100€/sensor
Standardization	No.

<table>
<tr><th>3.5</th><th>Tools/Techniques: PCB accelerometers</th></tr>
<tr><td>Photo of the tool</td><td>

</td></tr>
<tr><td>General description</td><td>PCB accelerometers
<table>
<tr><td>Modèle</td><td>PCB 393B31</td><td>PCB 629A11(triaxial)</td></tr>
<tr><td>Sensibilité (+-5%)</td><td>10.0 V/g (1.02 V/(m/s^2))</td><td>100.0 V/g (10.2 V/(m/s^2))</td></tr>
<tr><td>Étendu de mesure</td><td>4.9 m/s^2</td><td>±490 m/s^2</td></tr>
<tr><td>Gamme de fréquence (+-10%)</td><td>0.07 à 300Hz</td><td>1.7 to 5000 Hz</td></tr>
<tr><td>Résonance fréquence</td><td>>700Hz</td><td>20 Hz</td></tr>
<tr><td>Résolution</td><td>0.000009 m/s^2 (9.10^{-6} g)</td><td>3100 $\mu m/s^2$ ($3,1.\ 10^{-4}$)</td></tr>
<tr><td>Température</td><td>-26 to +65 °C</td><td>-54 to +121 °C</td></tr>
<tr><td>Calibration</td><td>Fait le 17/01/2020</td><td>Fait le 17/01/2020</td></tr>
</table></td></tr>
<tr><td>Area(s) of use</td><td>Vibration monitoring of industrial systems</td></tr>
<tr><td>Reliability of results</td><td>For the moment, no problem with absurd data.
The accelerometers have been re-calibrated before use.</td></tr>
<tr><td>Duration of tests</td><td>There have been ongoing tests.
Currently the measurement survey has been ongoing since February 2020.</td></tr>
<tr><td>Complexity of interpretation of results</td><td>These are temporal acceleration data, so eigenmodes must be detected. The basic procedure for doing this is quite simple.
Nevertheless, since we want small differences in own values, it is a question of development/testing innovative methods.</td></tr>
<tr><td>Cost</td><td>Approximately 2000 € / sensor</td></tr>
<tr><td>Standardization</td><td>No.</td></tr>
</table>

France – 06

Case study	
1.0	**General data**
Country	FRANCE
Prepared by	BARDOU Nicolas, DE LA ROQUE Sidoine, SCHMIDT Franziska BARON Gérard, CARTIAUX François-Baptiste
Date Prepared	2019-2021
Bridge name	Bridge managed by Cofiroute, PS 123/29 on the A10, Auzouer
General bridge description	Overpass on a four-bay PRAD type motorway. The carried lane is a 2x1 lane on an exceptional convoy route.
Bridge equipment	
Other	
Bridge pictures	
2.0	**Bridge data**
Structural design	Deck made of precast concrete beams prestressed by bonded wire and cast-in-place reinforced concrete slab. Reinforced concrete sail piers.
Material classification	Reinforced and prestressed concrete.
Geometrical data	4 spans: 8.5 - 14.5 - 8.5 m (approx.), approx. 10 m wide, 10 prefabricated beams for each span.
Reason for using the tools/techniques	The extended lane is on an important exceptional convoy route: checking that the actual traffic is in line with the authorised traffic and detecting any overloaded vehicles.

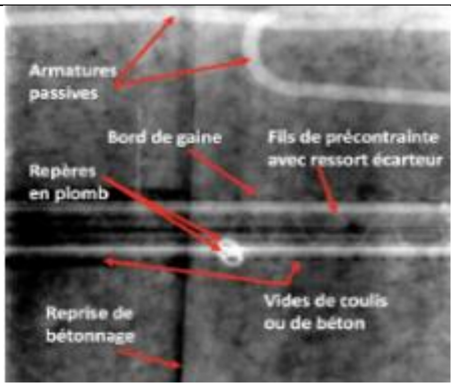
Tools/technique used	Weighing solution in operation by instrumented bridge based on deformation measurements using optical strings. These measurements could also be used for structural monitoring (anomaly detection, stress estimation, vibration analysis, etc.).
3	**Tools/technique used : On-the-go weighing solution based on an optical rope solution**
Tool picture	
General description	Between 6 and 12 long base (1 or 2 metres) Optical Rope type deformation sensors are installed at the maximum bending points of the deck, in the lower fibre of the beams or slab. Deformation measurements are acquired at a rate of 100 points per second and synchronised by an acquisition station which transmits them in real time to a server, where they are available in real time. Once the measurements have been transmitted, a dedicated algorithm reconstitutes the rolling load that generated them and provides a vehicle silhouette as well as an estimate of its total weight, its speed and the weight of each axle. This restitution is carried out in near real time (delay of about 1 minute) on a remotely accessible web page. In addition, the deformation measurements could be used to monitor the structural condition of the structure.
Field(s) of use	Weighing of vehicles on the bridge while in motion. Possible operation (but not implemented on this bridge): Continuous monitoring of the effects of road traffic on the bridge in terms of deck deflection and vibration.

Results reliability	Error between the weighing in motion and the actual weight of the vehicles, on the total weight of the vehicles: from +/-5% to +/-10%, depending on the type of apron. It should be noted that certain types of bridges are unsuitable (masonry, very rigid frames). In the case of Auzouer, the average error on the total weight is 3.4% (in absolute value) and the maximum error of 5.4% on the results of a 27-pass test. Accuracy in the order of 0.25 m for determining the number of axles and the silhouette of the vehicles. No satisfactory reliability at this stage for determining the axle load on a structure of this type (average error of about 20% and maximum error of 50% for individual axles, average error of 9% and maximum error of 20% for groups of axles. Better results have been obtained in the past on a double girder type deck). No impact of environmental conditions or electro-magnetic (fibre optic sensors).
Test duration	The system requires an initial calibration test consisting of several passes of vehicles of known weight, carried out over a minimum of half a day or night. Thereafter, it is a continuous monitoring system that is intended to remain in place permanently. In-service calibration at regular intervals may be necessary.
Results' interpretation complexity	Not very demanding for the project manager: results in the form of "passage sheets" representing the silhouette of each lorry and statistical tables on the distribution of vehicle weights.
Cost	A priori, lower than the cost of a running weighing system installed under the pavement, and moreover non-intrusive and insensitive to routine maintenance or pavement repair work. On the other hand, installations may require special means of access and operating conditions. No sufficient feedback on long-term maintenance costs and consistent reliability over time.
Standardization	European COST 323 (non-prescriptive) reference system.

France – 07

Case study	
1.0	**General data**
Country	France
Prepared by	Cécile BOUVET AGNELLI – Florent PLASSARD / Cerema
Date Prepared	Octobre 2020
Bridge name	VIPP d'Étigny
General bridge description	VIPP of 3 spans of 4 beams
Bridge equipment	Road bridge equipment
Other	
Bridge pictures	
2.0	**Bridge data**
Structural design	
Material classification	Pre-stressed concrete
Geometrical data	Spans: 3 Length: approx. 100 m Width: 8-9 m
Reason for using the tools	Gamma radiography investigations to determine the filling level of prestressing ducts.

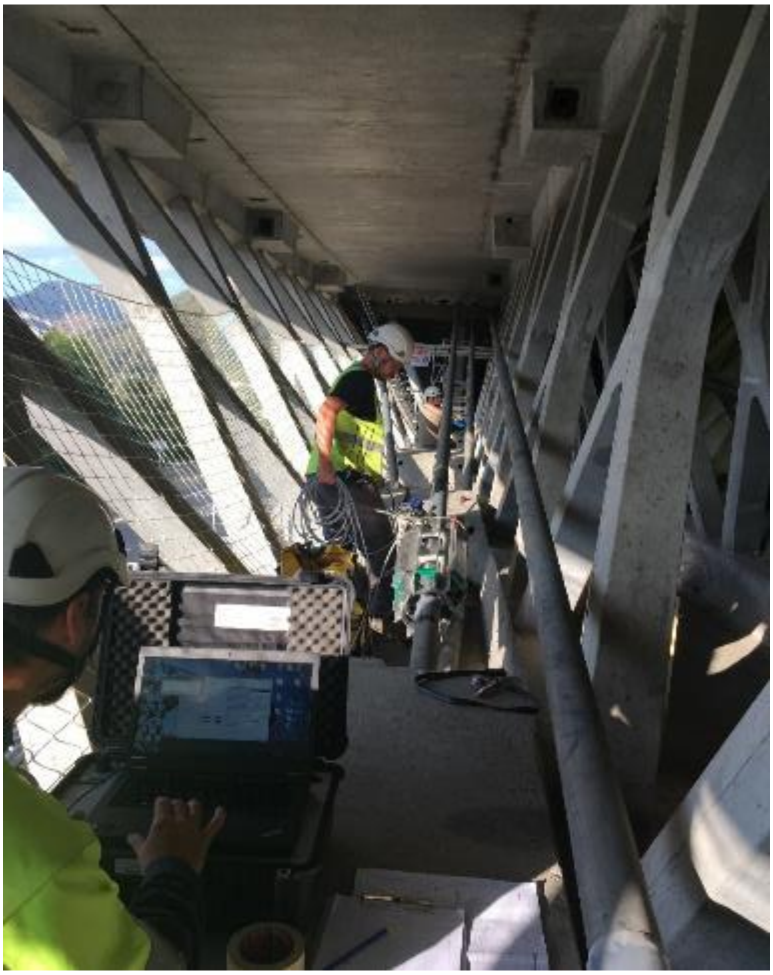
	This enables the input data for the risk analysis of VIPPs to be determined (LCPC guide 2001).
Tools/technique used	Iridium source in a GAM 120 and equipment for digital development of gamma radiography results
3	**Tools/technique used**
Tool picture	 

	
General description	Statistical method (approx. 25% of the cable length) Production of (radio) gamma radiography images by absorption of the gamma radiation emitted by the iridium source by the prestressed concrete material. The negative (30 x 40 cm) thus obtained is developed using a digital scanner. The image obtained makes it possible to observe the density of the concrete, the presence of the passive and active steels, the presence of the injection grout in the targeted prestressing sheath as well as the position of the prestressing units (or even their de-tensioning).
Field(s) of use	- Structural elements made of prestressed concrete (accessible from both sides - here beams) - Quantification of the filling level of the duct in 4 states (from well filled to slightly filled), depending on whether the grouting void is in contact with the strands or not. This method can be used for concrete thicknesses of up to 30 or even 60 cm. The question arises as to the possibility of using this technique from 2022 due to the hardening of the conditions of use of the radioactive source.
Results reliability	Excellent (repeatable and quality), visual Sensitive to concrete thickness and time of exposure to radiation
Test duration	Necessary installation time difficult to quantify (moderate) Exposure time varies from a few minutes to an hour, depending on thickness. Daily work because it is not possible to leave the source on site
Results' interpretation complexity	Demanding (scanner and necessary computer software and highly qualified personnel holding the CAMARI certificate).
Cost	Material total cost > 1M€ Availability around 8000€ per day
Standardization	Standard NF A09-202 and A09-203 for the principles of examinations with radiographic sources. The analysis of the plates is carried out according to the recommendations of the Technical Guide - Independent span viaduct with prestressed beams LCPC of 2001.

France – 08

Case study	
1.0	**General data**
Country	France
Prepared by	B.VAURIGAUD, R. PIEDNOIR, J.-F. CHERRIER
Date Prepared	12/01/2021
Bridge name	*Viaducs de Sylans et des Glacières ; A40 (Saint Martin du Fresne-Bellegarde) ; 46°09'50.8"N 5°40'00.9"E*
General bridge description	Pre-stressed motorway structure built by corbelling. The structure has an open box section with openwork corbels in the form of a cross. Corrosion of its prestressing cables in the vicinity of some electro-welded connection sleeves could be detected following non-destructive testing of the external prestressing cables.
Bridge equipment	
Other	*As the caisson is open, the prestressing inside the caisson but outside the concrete is particularly exposed to external stresses.*
Bridge pictures	

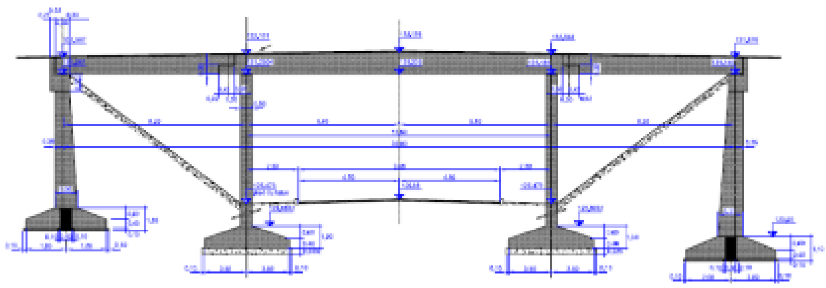
	
2.0	**Bridge data**
Structural design	Pre-stressed bridge built by corbelling with prefabricated segments with glued conjugated joints. The cores are openwork and made up of crosses which are themselves prestressed.
Material classification	Prestressed concrete. The external prestressing (internal to the box) is composed of 12T15S prestressing units with light-coloured wires injected with cement grout and 7T15S prestressing units with light-coloured wires individually sheathed and greased.
Geometrical data	Sylans: 1266m / 21 spans (55m+20x60m) Coolers: 214m / 4 bays (3x60m+32m) 2x2 channels + BAU Overall width 10.75m
Reason for using the tools/techniques	In 2015, one of the 600 external prestressing cables inside the 12T15S box with light-coloured wires and HDPE collective sheathing injected with cement grout broke off abruptly at the level of an electro-welded connection sleeve. Expertise has shown that this rupture was the result of localised corrosion following water ingress into the protective sheath and the cement grout. This corrosion gradually reduced the effective cross-section of the cable until it ruptured without any obvious external sign. In order to prevent possible future ruptures, an exhaustive visual inspection of the external state of the cables was carried out. This was complemented by a diagnosis of the internal condition of almost all the cables, particularly those under sleeves, using a magnetic control coil.

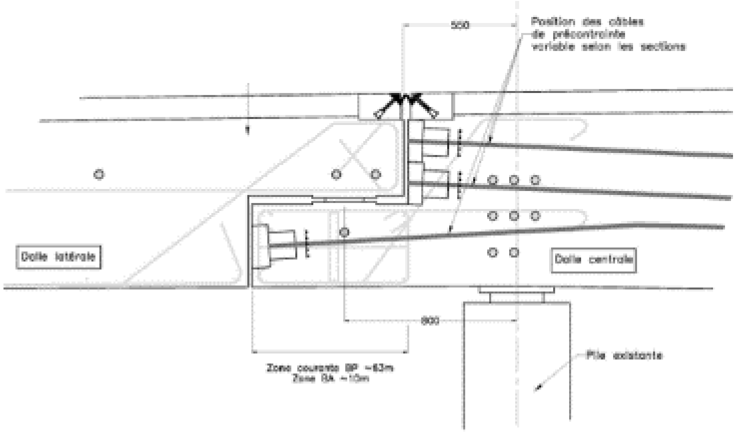
Tools/technique used	magnetic flux leakage
3	
Tool picture	 

General description	The magnetic detection equipment for cable cross-section defects is based on technology derived from the inspection of cableways. It’s a simple device with leakage field detection within the meaning of the European standard *NF EN 12927-8 : Safety requirement for cableway installations carrying persons : Câbles : Part 8 : Non destructive testing by magnetic testing.* The device consists of permanent magnets to magnetise the metal section of the cable to be inspected and a magnetic field sensor (coil) capable of measuring radial leakage fields by self-induction. The device is moved along the cable at a steady speed, and detects radial field leakage from areas with cross-sectional defects. These leakage fields result in an increase in the voltage induced in the sensor when the fault occurs. On the healthy parts of the cable, the device records a low amplitude signal called the magnetic signature of the cable. The device used was manufactured by a german company specializing in cable testing. In the case presented, this non-destructive testing was supplemented by visual destructive testing with opening of windows on the sheaths and inspection of the metal strands after possible shrinkage of the cement grout. The tool is capable of running over the entire current part of the cable, including the electro-welded connection sleeves. For reasons of geometrical dimensions, the tool does not allow the sections in the vicinity of anchors, bosses and sections too close to concrete facings to be inspected. The use of the tool requires prior preparation of the sheath with bridging of the sleeves and removal of the welding indicators for electro-welded sleeves.
Field(s) of use	This approach demonstrated the tool's ability to detect : - the presence of threading fingers in the grout - localised corrosion of stranded wires - cross-sectional losses greater than or equal to 1 wire (=1.2% of the total cross-section in this case study)
Results reliability	The reliability of the results is excellent in that minimal faults with no noticeable consequences on the resistance of the cable (corrosion of a single wire) are unambiguously detected. The method therefore allows cross- sectional faults to be detected before they become problematic for the residual capacity of the cable. Nevertheless, the results remain qualitative. The defects observed are qualified as small/medium/large with no direct relationship between the magnitude of the measured leakage field and the magnitude of the detected defect.

Test duration	The duration of the measurements cannot be evaluated on the basis of the cable length to be checked, but only on the basis of the number of assemblies/disassemblies required and the difficulties of access to the cable. A significant amount of time is spent on the handling, installation and removal of the material on the rope. The tool is made up of different heavy elements to be assembled. As the magnets are very strongly magnetised, their handling presents risks depending on the presence or absence of metal elements in the vicinity, which requires meticulous and therefore longer handling. Depending on the configuration of the cables, the installation of the device and the preparation of the measurement may require the use of specific means of access (ropes, scaffolding,...) which are time-consuming. Finally, the traction of the device along the cable to be controlled using a system of rope and pulley may require a significant installation time. The time devoted solely to carrying out the measurement is negligible compared to the time devoted to preparing the ductwork and installing and removing the control equipment. In a configuration such as that of the Sylans and Glacières viaducts considered to be easily accessible, with a deck about 4m high, the carrying out of a measurement required the intervention of a team of 2 people for the preparation of the shaft, and 3 people for the installation of the equipment and the carrying out of the measurement. Each measurement took approximately 45 minutes for these 5 people for a measured length of approximately 10m.
Results' interpretation complexity	Demanding interpretation. The operation must be carried out by experienced operators in the laboratory with experience in magnetic testing of cables in order to properly detect the full range of measurable faults. Critical faults can nevertheless be identified live on site.
Cost	High cost of acquisition of equipment and high cost of implementation on site due to the significant time spent with at least 5 people and adapted means of access.
Standardization	The tool is not subject to standardisation in the field of civil engineering structures and external prestressing control. The method and physical principles of magnetic testing of cables on which the system is based are taken from standard *NF EN 12927-8: Safety requirements for cable installations carrying persons: Cables: Part 8: Non-destructive testing by magnetic testing* used in the field of ski lifts under the name leakage field detection equipment.

France – 09

Case study	
1.0	General data
Country	France
Prepared by	Sylvain Lopez (ASF)
Date Prepared	11/01/2021
Bridge name	PI 661 ; A7 ; X = 44°58'10.78''N, Y = 4°53'07.44''E
General bridge description	Fairly good apparent condition but brittle fracture feared.
Bridge equipment	Wearing course, 4 road joint lines, safety barriers, waterways and gargoyles
Other	Single deck (1 deck carries all 6 lanes of traffic) and very biased (27 grades)
Bridge pictures	Fairly good apparent condition but brittle fracture feared.
2.0	**Bridge data**
Structural design	Slab (with cantilever)
Material classification	Prestressed concrete
Geometrical data	Length: 75 m, straight width: 28 m, angled width: 74 m, 3 bays, 6 lanes
Reason for using the tools/techniques	Putting the cantilevers under close surveillance (risk of brittle fracture) while awaiting their demolition/reconstruction (option chosen following risk analysis: hazard, consequences) 

	
Tools/technique used	Acoustic monitoring and monitoring by distributed fibre optic sensors
3.1	**Tools/technique used : acoustic monitoring**
Tool picture	
General description	Accelerometer-type sensors placed on the concrete facing detect the passage of a shock wave ("noise") that propagates along the prestressing cable and into the surrounding concrete.
Field(s) of use	Detection and location of internal prestressing cable wire breakage
Results reliability	Excellent after filtering out ambient "noise" (wheel impact on road joints, etc.).
Test duration	Fast (continuous monitoring)
Results' interpretation complexity	Demanding (requires a learning period for setting thresholds)
Cost	high
Standardization	No standard (but LCPC/IFSTTAR procedure).

3.1	**Tools/Techniques: Distributed fiber optic sensors**
Photo of the tool	
General description	Distributed fibre optic sensors (1 measuring point every 2 mm) are inserted into an existing concrete part, via a drill hole and then sealed with resin; these sensors allow deformation measurements to be taken.
Area(s) of use	Early detection of the appearance of cracks inside the cantilever (before they appear on the facing), within the framework of high surveillance
Reliability of results	Excellent after selection of the type of optical fiber (sensitivity, armed or not, ...)
Duration of tests	Fast (continuous monitoring)
Complexity of interpretation of results	Demanding (requires a period of apprenticeship)
Cost	high
Standardization	No standard

France – 10

Case study	
1.0	**General data**
Country	France
Prepared by	Cécile BOUVET AGNELLI
Date Prepared	2017-2020
Bridge name	Différents ouvrages
General bridge description	
Bridge equipment	
Other	
Bridge pictures	
2.0	**Bridge data**
Structural design	
Material classification	Prestressed concrete
Geometrical data	
Reason for using the tools/techniques	Continuous large-scale crack detection (including on parts not accessible for inspection)
Tools/technique used	Monitoring by Rayleigh backscattering distributed fibre optic sensors
3	**Tools/technique used**

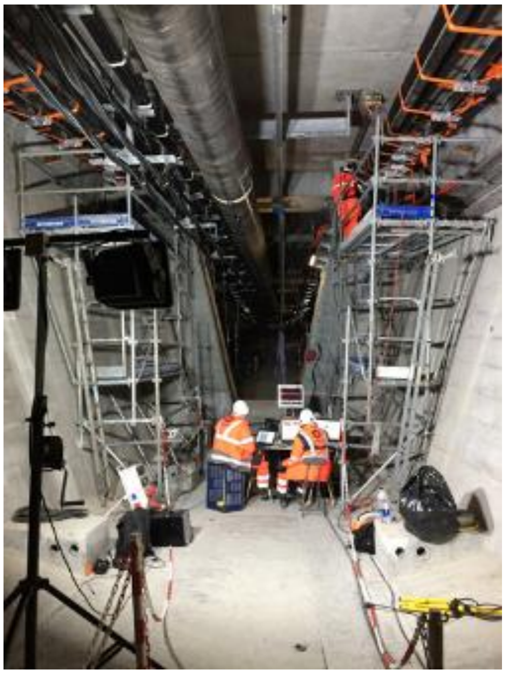
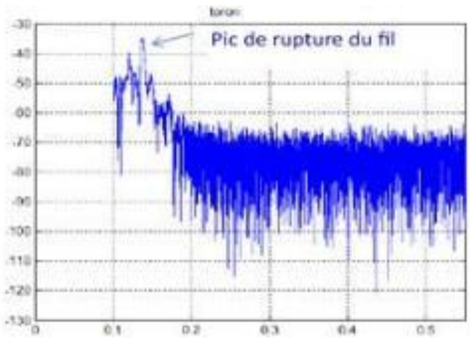
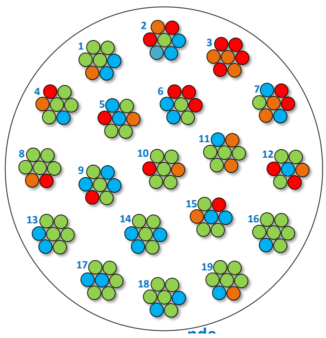
Tool picture	 
General description	Distributed fibre optic instrumentation is an instrumentation solution allowing to follow the measured phenomena with a number of measurement points (which depends on the fibre and the interrogator) which can be centimetric, which is therefore much more important than classical instrumentation (which is very punctual). Its use in particular in the context of structure monitoring would make it possible to set up a tool for detecting the appearance of cracks that is effective

	in many situations for which current solutions can only partially respond to the problem. The measurement of the variation of the Rayleigh spectrum allows to know the variation of the temperature and/or the deformations over the whole length of the optical fibre. When the optical fibre is bonded to the structure, the deformations of the part of the structure concerned are obtained. Other technologies can be used, based on Raman backscattering (which enables the temperature of the optical fibre to be determined - which makes it possible to decouple thermal and mechanical effects) or Brillouin
Field(s) of use	Crack monitoring on reinforced concrete structures during tests or over the long term.
Results reliability	Good, but in the long term, it is necessary to decouple the deformations from the thermal effects (studies are underway on this subject). Sensitivity to vibration
Test duration	The duration as such depends on the tests you want to carry out. The implementation is long and delicate in all cases (mapping to determine the optimal measurement positions, engraving of concrete and steel, placing of tubes, gluing).
Results' interpretation complexity	The results can be interpreted through extraction via the SYSADYP interface. Moderate complexity of interpretation.
Cost	
Standardization	

France – 11

Case study	
1.0	**General data**
Country	France
Prepared by	C. Ostrowski / S. Joye (SIXENSE) Anne Audouin-Dubreuil (Conseil Départemental de la Charente-Maritime)
Date Prepared	18/01/2021
Bridge name	Pont de l'ile de Ré
General bridge description	Built in 1988, the Ile de Ré bridge connects the island to the metropolis at the level of the city of La Rochelle. Almost 3km long, its 2 lanes culminate at 42m high. It is composed of 6 independent viaducts with prestressed concrete caisson supported by 28 piers.
Bridge equipment	Wearing course, pavements, road joints, railings, light fixtures
Other	
Bridge pictures	 

	
2.0	**Bridge data**
Structural design	Variable inertia box girder with external prestressing injected with cement grout
Material classification	Pre-stressed concrete pushers
Geometrical data	- Length 2926m - Width: 15m - 28 stacks and 29 bays with a range between 38 and 110m - 6 independent viaducts, each about 500 m long, separated two by two by cantilever joints 2 traffic lanes and 1 bicycle path
Reason for using the tools/techniques	Failure of an external prestressing cable in viaduct no. 2, between piers P7 and P9, at an anchorage (2018)   Need to assess the state of conservation of external prestressing tendons in anchorage areas
Tools/technique used	Auscultation by reflectometry of guided ultrasonic waves to detect wire breaks, corroded and healthy wires from the ends of the strands on the anchor block side.

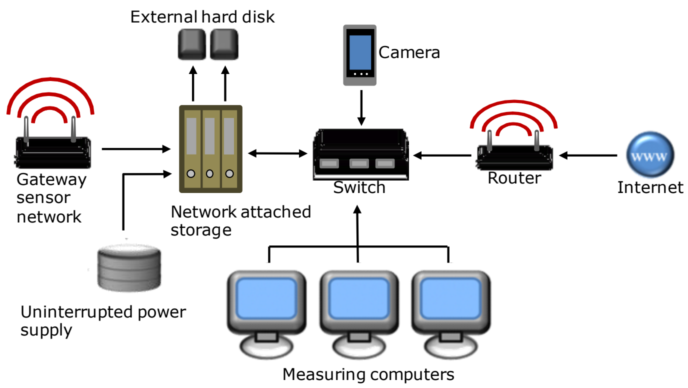
3	**Tools/technique used**
3.0	**Tool / technique: reflectometry of guided ultrasonic waves (USCAN patented process)**
Tool picture	   
General description	Measurement by reflectometry of ultrasonic waves guided from the wire ends of the strands via a coupled ultrasonic sensor connected to a signal transmitting/receiving generator and a signal processing and analysis unit.  

Field(s) of use	Detection of wire breakage over a length of 2 m after anchoring
Results reliability	Good to Excellent: classification between sound and corroded wires Average to Good: detection of broken wires (reliability depends on the degree of corrosion and the fracture face)
Test duration	Two to three anchors per day depending on the number of strands per anchor (measurement time only: excluding anchor stripping and surface preparation of the strand ends).
Results' interpretation complexity	Demanding
Cost	Moderate to high depending on the access to the anchors and strands as well as the preparation of the strand ends.
Standardization	None

Germany – 01

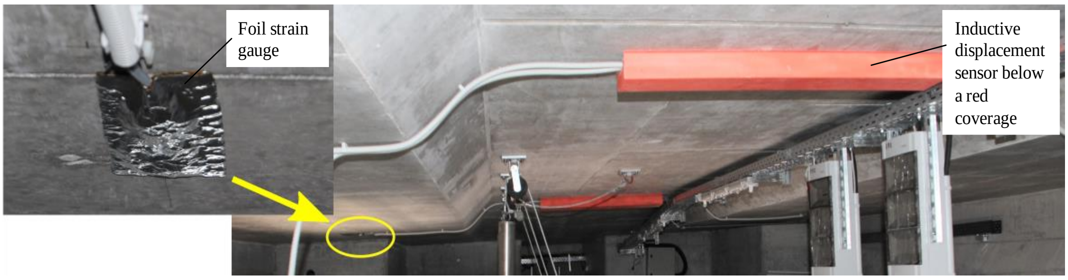
Case study	
1.0	**General data**
Country	Germany
Prepared by	Peter Haardt, haardt@bast.de
Date Prepared	01.06.2021
Bridge name	BW 402e, Highway A9, Interchange Nuremberg
General bridge description	The original overpass structure was built in 1970 and is part of the highway A 9 from Frankfurt to Munich. Because of the fatigue affected steel the bridge had to be removed. A new overpass structure was built according to the old structure in 2015/2016 and released for traffic in October 2016.
Bridge equipment	Bearings: spherical bearing and plain bearings Expansion joints: construction with sealing profile and swivel joist-expansion joint Waterproofing, pavement: single-layer bituminous waterproofing membrane, mastic asphalt Bridge caps: In-situ concrete construction
Other	Smart bridge in the “Digital Test Area Autobahn”
Bridge pictures	

	
2.0	**Bridge data**
Structural design	Single-celled box girder, longitudinally prestressed
Material classification	Reinforced concrete
Geometrical data	Length: 155.75 m Road width: 12 m (2 lanes, only one direction) Spans: 37.75, 45.0, 44.0, 29.0 m Bridge deck area: 2,445,3 m^2
Reason for using the tools/techniques	The Smart Bridge in the "Digital Test Area Autobahn" is the first new constructed bridge equipped with measuring systems that is released for traffic in Germany. The concept of the Smart Bridge is based on collecting and evaluating holistically relevant information about the structure. The "Digital Test Area Autobahn" is a test area on the German highway A 9, provided by the Federal Ministry of Transport and Digital Infrastructure. Innovations related to the topic "mobility 4.0" are tested, evaluated and further developed. The research project "Digital Test Area Autobahn" has two focuses: automated and networked driving and intelligent infrastructures. The Smart Bridge is an innovation of the focus "intelligent infrastructures". The bridge includes new developments in the field of Smart Bridges: an instrumented expansion joint (steel lamella construction), two instrumented spherical bearings and an information system for detecting loads on the bridge. The goal of a 5 year-pilot study (2016 to 2021) is to demonstrate the developed aspects on a bridge structure and to show the functionality of the whole system. By using analytical bridge models and evaluation methods the condition and the reliability of the overall bridge construction and its components as well as their remaining service life is determined. The collected information is made available online to the responsible road administration (Federal Ministry of Transport and Digital Infrastructure, Bavarian Ministry of the Interior, for Building and Transport, Highway administration of northern Bavaria).

Tools/technique used	1) Network structure 2) RTMS – Road Traffic Management System 3) Instrumented expansion joint 4) Instrumented bearing
3	**Tools/technique used**
Tool picture	
General description	**Network structure** The bridge is equipped with five information systems that collect relevant information on loads and reactions of the bridge structure. In order to ensure the reliability of measured data as well as to optimize the measuring systems, three measuring systems for determining traffic data were installed. The picture shows the scheme of the network structure. Some measuring systems have their own measuring computers, on which sensor data are stored temporarily. There is a network attached storage (NAS) for storing all sensor data for the whole project duration. A switch ensures the connection of different components with the NAS. The uninterrupted power supply ensures that the NAS shuts down in case of power interruption and restarts automatically after the power interruption in order to minimize not collected data. Furthermore, the Smart Bridge has an internet access which is important for the sensor network and for remote monitoring in the future.
Field(s) of use	See above
Results reliability	Excellent
Test duration	2016-2021
Results' interpretation complexity	Demanding
Cost	Bridge construction costs: 15 Mio € Hard- and software, Installation of measurement and analyzing systems, operation and research (2016 – 2021): 1,1 Mio €
Standardization	No standard, ongoing research

Germany – 02

Tool picture



General description

RTMS – Road Traffic Management System

The information system RTMS (Ingenieurbüro Prof. Dr. U. Freundt) is used for determining all relevant loads and bridge reactions as well as the condition of a bridge structure. The system consists of the following sensors, shown in Table 1.

Table1 : Sensors of RTMS

Sensors	No.	Location	What is measured?
Foil strain gauges	16	Below the bridge deck	Concrete strain
	4	In concrete	Reinforcement strains, displacements
	6	Expansion joint	Strains
Inductive displacement sensors	2	Below the pavement	Displacements
	4	Bearing	Rotation of the bearing -> Deduction of the deformation of the superstructure
Temperature sensors	2	In concrete	Temperature of bridge components
Acceleration sensors	4	External tendons	Acceleration -> Deduction of tension force progression

The following traffic data are determined: Vehicle type, velocity, gross weight, static and dynamic axle load, distance of axles and the number of axles of a vehicle. The vehicle velocity is determined by strain measurements of two foil strain gauges arranged one behind the other. The numbers of vehicle axles and axle distances are determined by the evaluation of local measuring points with regard to the measurement signal peaks and allocation of a vehicle. By comparing determined measuring diagrams due to traffic with calculated diagrams, vehicle weights are derived. The RTMS has two measuring cabinets with media converters, measuring amplifiers, a network technology and a power supply in order to keep the signal paths short. All measuring data are stored on the measuring computer of the measuring cabinet 1 which is connected to measuring cabinet 2 by glass fibre.

Germany – 03

<table>
<tr><td>Tool picture</td><td></td></tr>
<tr><td>General description</td><td>
Instrumented expansion joint
Expansion joints are components of a bridge structure which are used between the bridge and the adjoining roadway in order to compensate the bridge movements due to temperature and traffic loads. They are wear parts of a bridge because they are exposed to high dynamic effects resulting from direct crossing by vehicles. The Smart Bridge is equipped with a modified Swivel Joist-Expansion Joint, DS 320 GO, developed by Maurer SE. The equipment of the expansion joint is shown in Table 2.
Table 2 : Equipment of the expansion joint.
<table>
<tr><th>Sensors</th><th>No.</th><th>Location</th><th>What is measured?</th></tr>
<tr><td>Foil strain gauges</td><td>16</td><td>Below the bridge deck</td><td>Concrete strain</td></tr>
<tr><td></td><td>4</td><td>In concrete</td><td>Reinforcement strains, displacements</td></tr>
<tr><td></td><td>6</td><td>Expansion joint</td><td>Strains</td></tr>
<tr><td>Inductive displacement sensors</td><td>2</td><td>Below the pavement</td><td>Displacements</td></tr>
<tr><td></td><td>4</td><td>Bearing</td><td>Rotation of the bearing -> Deduction of the deformation of the superstructure</td></tr>
<tr><td>Temperature sensors</td><td>2</td><td>In concrete</td><td>Temperature of bridge components</td></tr>
<tr><td>Acceleration sensors</td><td>4</td><td>External tendons</td><td>Acceleration -> Deduction of tension force progression</td></tr>
</table>
The figure shows the instrumented expansion joint of the Smart Bridge. The sensors listed in the table are not visible because they are in the inside of the expansion joint. Cables for powering sensors and forwarding data to the
</td></tr>
</table>

	measuring computer are protected by protective tubes against damage. The foil strain gauges of the RTMS, compare Table 1, are highlighted in the picture. They were glued on the surface of the beams of the expansion joint. Cables in the protective tubes connect the foil strain gauges with the measuring cabinet of the RTMS. By determining the total joint gap and the distance between the 1st and 3rd beam the condition of the expansion joint is monitored. The following traffic data are determined by the measuring values of the instrumented expansion joint: number, velocity and weight of vehicles, axles of vehicles, distance between axles and axle load.

Germany – 04

<table>
<tr><td>Tool picture</td><td></td></tr>
<tr><td>General description</td><td>

Instrumented bearing

Bridge bearings are one of the basic components of a bridge, since these allow displacements, rotations and defined load transfers between bridge components. Usual displacements of bridge structures are due to effects such as traffic and temperature. Permissible displacements, rotations and load transfers of the bearing for certain directions can be realized by the choice of the bearing type. The Smart Bridge contains two modified and instrumented MSM® spherical bearings type KGA 18436 kN, developed by Maurer SE. The equipment of the two bearings is shown in Table 8.

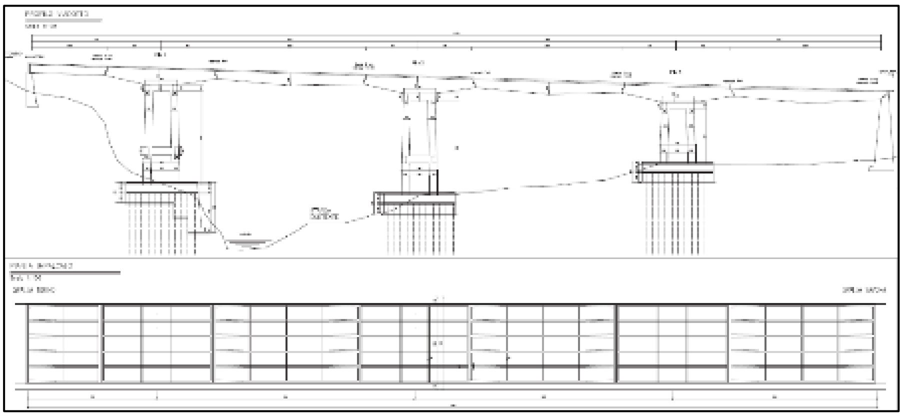
Table 8. Equipment of the bearings

<table>
<tr><th>Sensor</th><th>No.</th><th>Location</th><th>What is measured?</th></tr>
<tr><td>Pressure sensor</td><td>3</td><td>In the bearing transverse to the longitudinal axis of the bridge</td><td>Pressure -> Deduction of bearing load by calibration curves</td></tr>
<tr><td>Distance sensor</td><td>2</td><td>In the bearing in the direction of the longitudinal axis of the bridge</td><td>Distance between two bearing surfaces -> Rotation of the bearing</td></tr>
<tr><td>Inductive displacement sensor</td><td>1</td><td>Below the bearing scale in the direction of the longitudinal axis of the bridge</td><td>Bearing path and gap</td></tr>
</table>

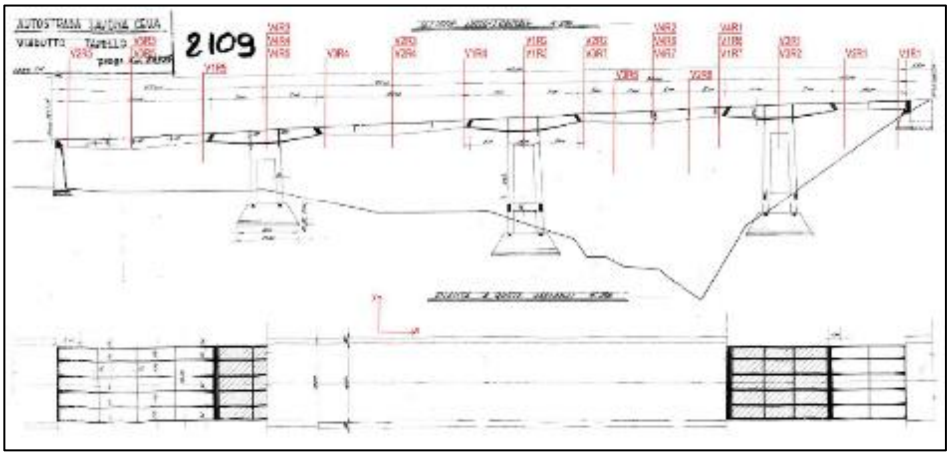
The collected data permit a self-monitoring of the bearings and a determination of the number of vehicles on the bridge. The figure shows an instrumented bearing of the Smart Bridge.

</td></tr>
</table>

Italy – 01

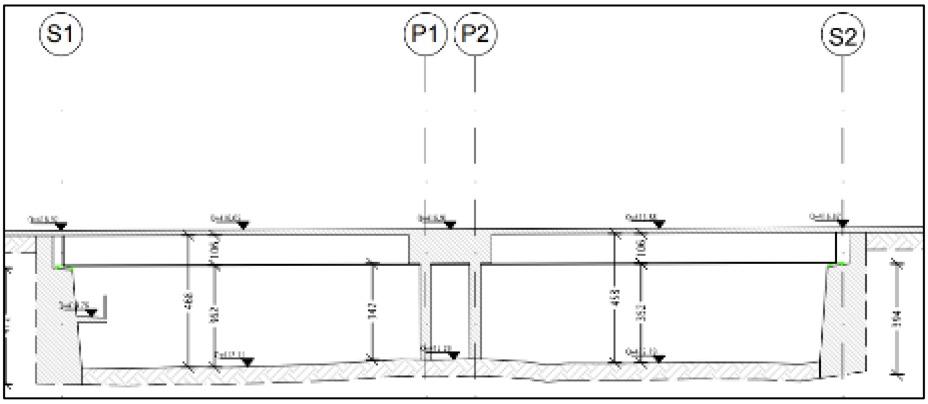
Case study	
1.0	**General data**
Country	Italy
Prepared by	ADF (Autostrada Dei Fiori) and SINA (Engineering society for design, realization and management of infrastructures)
Date Prepared	May 2018
Bridge name	*Tapello Viaduct; A6 highway (Torino-Savona direction); initial latitude: 44,367061_initial longitude: 8,2569933_initial altitude: 482,64m*
General bridge description	The bridge was built in 1960. The deck of the bridge has been subjected to maintenance (finished on july 2020), in which the beams have been reinforced and the bearings replaced.
Bridge equipment	Bearings (fixed and sliding, reinforced rubber typology), expansion joints, barriers, drainage
Other	
Bridge pictures	 

	
2.0	**Bridge data**
Structural design	Generally we can say that is a girder bridge. The static scheme is made with a cantilever deck with a box section on the piers, and between the piers there are simply supported decks with a girder section made of 6 longitudinal beams and 3 transverse beams for each span. There are 3 piers made with 2 frames each.
Material classification	Reinforced concrete
Geometrical data	Length: 112m; width: 12,10m; n° spans: 4; 3 lanes
Reason for using the tools/techniques	The aim is: -to determine the first natural frequencies of the structure; -to evaluate the modal deformations; -to allow the calibration of the analytical model.
Tools/technique used	Dynamic monitoring
3	**Tools/technique used**

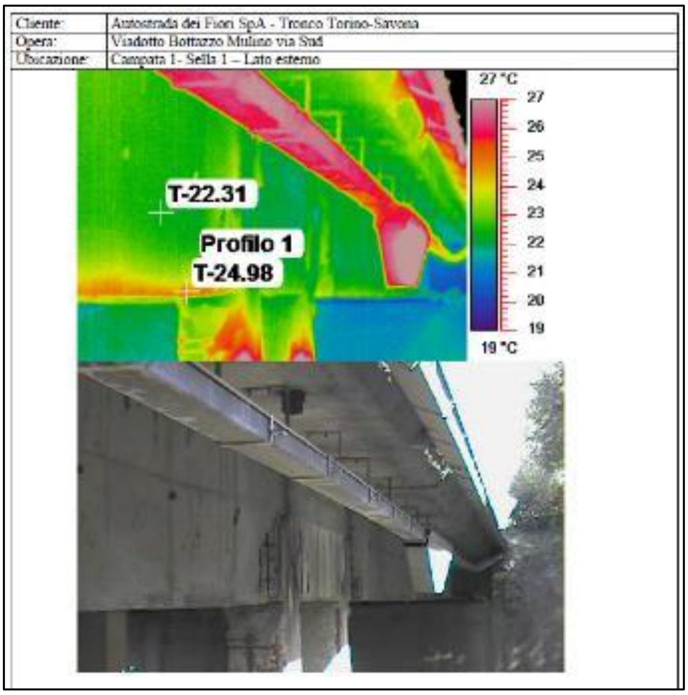
Tool picture	 *Test equipment*  *Measurements points*
General description	The test phases are: - installation of an accelerometric network made with 4 triaxial accelerometers arranged according to different configurations and an automatic acquisition equipment; - recording (in continuous) of the vibration induced on the structure due to the passage of traffic and environmental noise. The operating procedures in based on the installation of accelerometers and the continuous recording of the response in all the measuring points for a few minutes; then the instrumental configuration is changed and other measurements are done.

	The signals were recorded with a sampling rate of 250 Hz and a filter fixed at 125 Hz. The electrical signals coming from the response measurement transducers were sent to a personal computer. The measurements were recorded by a high resolution digital acquisition system. The triaxial accelerometers have these features: - nominal sensitivity: 2.5 V / g - frequency range: 0.0 ÷ 200 Hz
Field(s) of use	For all the structure which are subjected to vibration
Results reliability	Good reliability
Test duration	It depends on: -the typology of the bridge; -the dimensions of the structure; -the typology of monitoring (continuous or not).
Results' interpretation complexity	
Cost	7.000 euro\each
Standardization	Yes.

Italy – 02

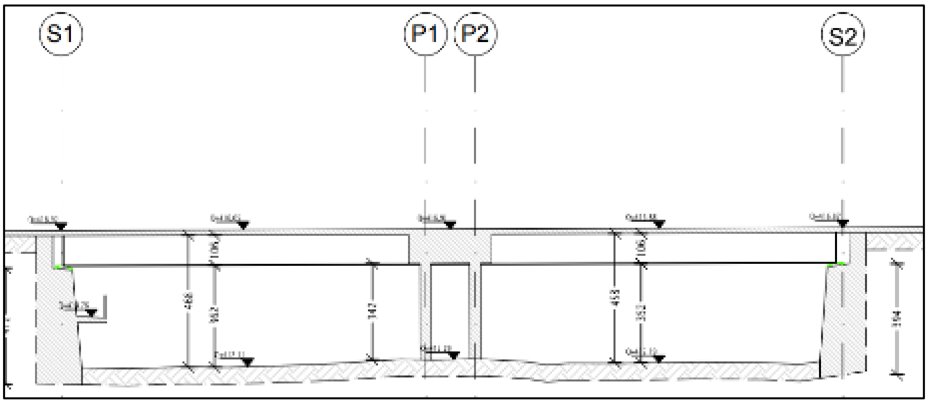
Case study	
1.0	**General data**
Country	Italy
Prepared by	ADF (Autostrada Dei Fiori) and SINA (Engineering society for design, realization and management of infrastructures)
Date Prepared	May 2021
Bridge name	*Bottazzo Mulino Viaduct; A6 highway (Torino-Savona direction); initial latitude: 44,35214_initial longitude: 8,283783_initial altitude: 411,12m*
General bridge description	The bridge was built in 1960. A part of the deck has been subjected to maintenance.
Bridge equipment	Bearings (fixed and sliding), expansion joints, barriers, drainage
Other	
Bridge pictures	

	 
2.0	**Bridge data**
Structural design	Girder bridge, with a simply supported static scheme made of 6 longitudinal beams and 4 transverse beams for each span. There is 1 pier made with 2 frames.
Material classification	Reinforced concrete
Geometrical data	Length: 30 m; width: 12,10 m; n° spans: 2;

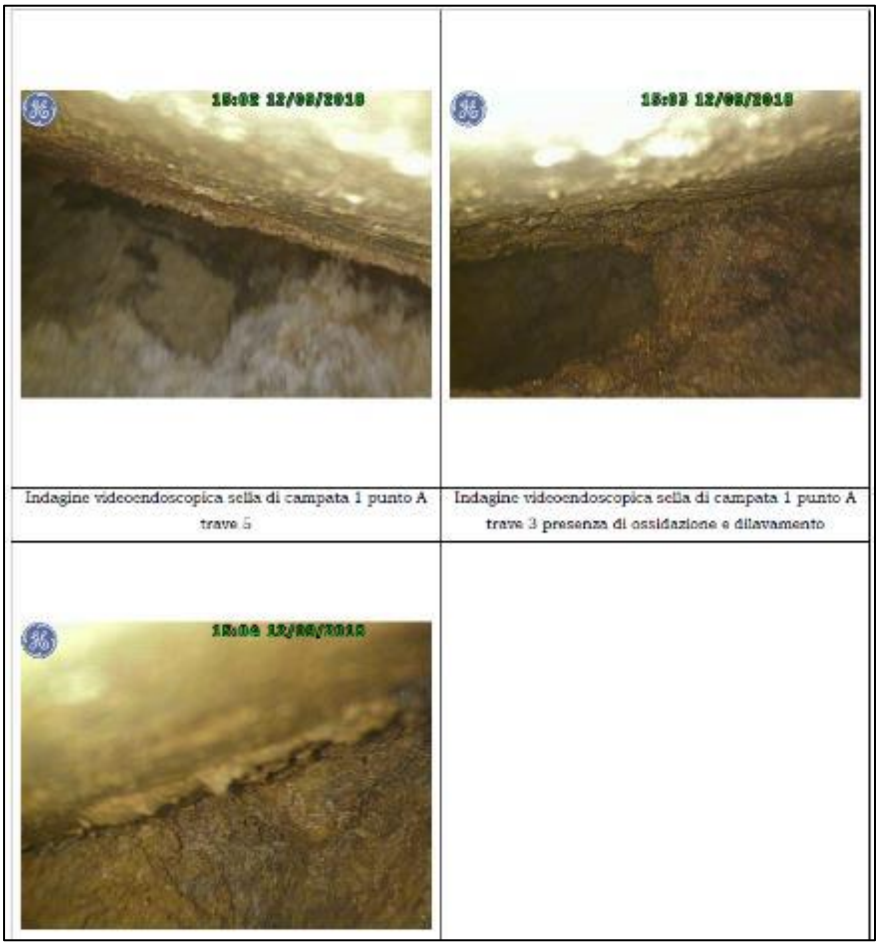
	3 lanes
Reason for using the tools/techniques	The aim is: - to evaluate the decay of the structural elements, also the ones which are not accessible.
Tools/technique used	Thermography
3.1	**Tools/technique used**
Tool picture	 *Test equipment*  *Test result*

General description	The operator takes a photo of the part of the structure to investigate the presence of corrosion and cracks. By evaluating the different temperatures recorded it's possible to know if there are problem in the materials. The peak of temperatures increases in the zone with decay of the concrete cover, probably due to corrosion of the reinforcement.
Field(s) of use	Every structure
Results reliability	Good reliability
Test duration	It depends on the typology of the bridge and the dimensions of the structure
Results' interpretation complexity	
Cost	5 euro\ m + general costs (worker)
Standardization	Yes.

Italy – 03

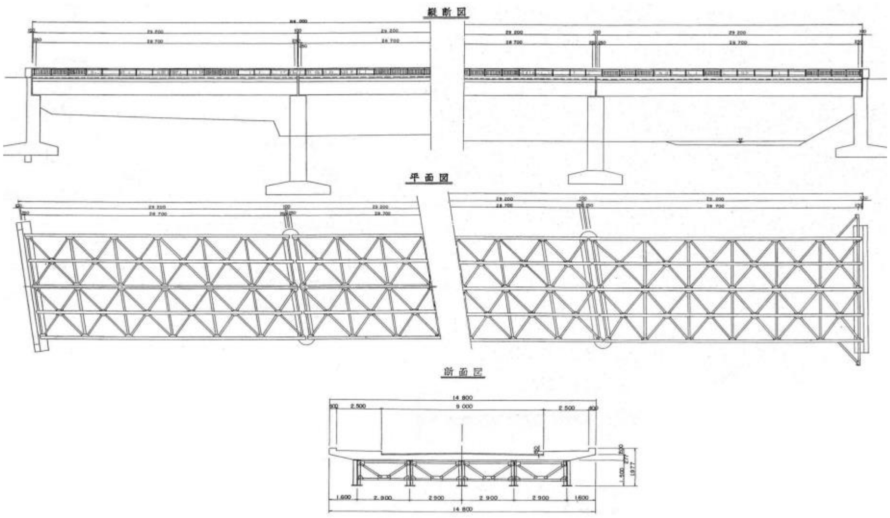
Case study	
1.0	**General data**
Country	Italy
Prepared by	ADF (Autostrada Dei Fiori) and SINA (Engineering society for design, realization and management of infrastructures)
Date Prepared	May 2021
Bridge name	*Bottazzo Mulino Viaduct; A6 highway (Torino-Savona direction); initial latitude: 44,35214_initial longitude: 8,283783_initial altitude: 411,12m*
General bridge description	The bridge was built in 1960. A part of the deck has been subjected to maintenance.
Bridge equipment	Bearings (fixed and sliding), expansion joints, barriers, drainage
Other	
Bridge pictures	

	 
2.0	**Bridge data**
Structural design	Girder bridge, with a simply supported static scheme made of 6 longitudinal beams and 4 transverse beams for each span. There is 1 pier made with 2 frames.
Material classification	Reinforced concrete
Geometrical data	Length: 30 m; width: 12,10 m; n° spans: 2;

	3 lanes
Reason for using the tools/techniques	The aim is: - to evaluate the decay of the structural elements, also the ones which are not accessible.
Tools/technique used	Videoendoscopy
3.2	Tools/technique used
Tool picture	 Test result
General description	The operator by using an endoscopic probe can investigate the presence of corrosion and cracks inside structural elements that are not accessible, and can make videos and take photos.
Field(s) of use	Structure that are not accessible

Results reliability	Good reliability
Test duration	It depends on the typology of the bridge and the dimensions of the structure
Results' interpretation complexity	
Cost	65 euro/ each+ general costs (worker)
Standardization	Yes.

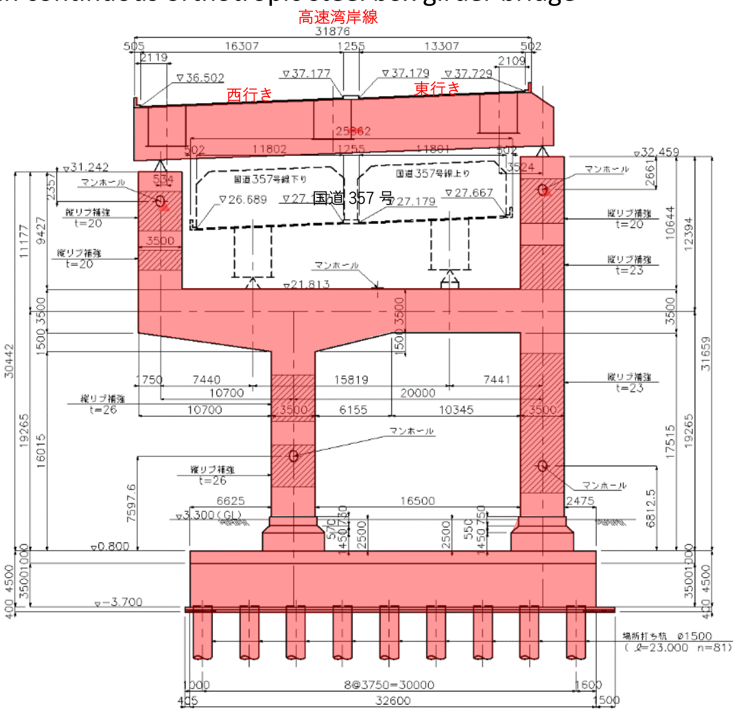
Japan – 01

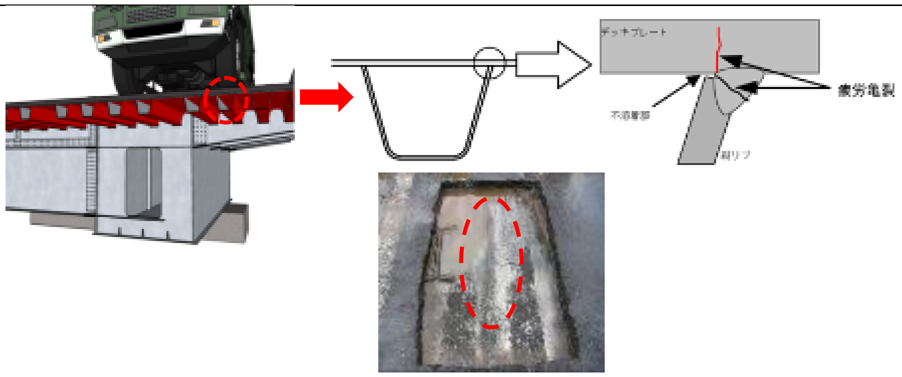
Case study	
1.0	**General data**
Country	Japan
Prepared by	Public Works Research Institute
Date Prepared	2021/3/19
Bridge name	Yatsuo bridge
General bridge description	It is a bridge in Toyama city road Kagamimachi - Mizutani line located in Kagamimachi, Yatsuocho, Toyama. It is a three simple composite steel girder bridge with RC slab and 48 years old after opening.
Bridge equipment	Bearings, Expansion joints, Railings, Pedestrian roads.
Other	
Bridge pictures	
2.0	**Bridge data**
Structural design	 Three simple composite steel girder bridge
Material classification	Reinforced Concrete

Geometrical data	Bridge length: 88.0m Number of lanes: 2 Width: 14.8m Number of spans: 3
Reason for using the tools/techniques	The cause of crumbling at the upper part of RC slabs is considered to be undrained water on the slab, which can not be found from road surface. An electromagnetic wave rader was used to detect water at the upper part of RC slab without cutting pavement and to prevent crumbling of the slabs in advance.
Tools/technique used	The electromagnetic wave rader is a machine which sends electromagnetic waves into concrete and receive waves reflected at bars, voids, etc. A method to detect existence of undrained water was examined by analyzing strength of waves reflected at the boundary face between pavement and concrete slabs. The rader was mounted on a vehicle so that the measurement was easily implemented without traffic regulation.
3	**Tools/technique used**
Tool picture	
General description	The electromagnetic wave rader is a machine which sends electromagnetic waves into concrete and receive waves reflected at bars, voids, etc. A method to detect existence of undrained water was examined by analyzing strength of waves reflected at the boundary face between pavement and concrete slabs. The rader was mounted on a vehicle so that the measurement was easily implemented without traffic regulation.
Field(s) of use	A nondestructive detecting method of undrained water is being examined by analyzing strength of waves reflected at the boundary face between pavement and concrete slabs.
Results reliability	Evaluation is impossible as this moment since it is still being studied technology toward practical use.
Test duration	From 4 to 6 bridges a day. It depends on bridge length and number of lanes.
Results' interpretation complexity	Demanding. Machines like computers and technical knowledge are needed in processing obtained data.
Cost	Maybe moderate. Detailed evaluation is not possible at this moment since it is still being studied technology toward practical use.
Standardization	Not yet.

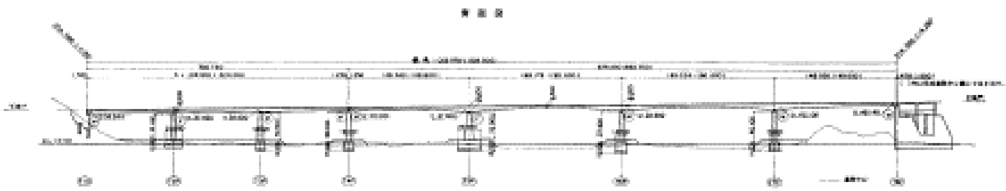
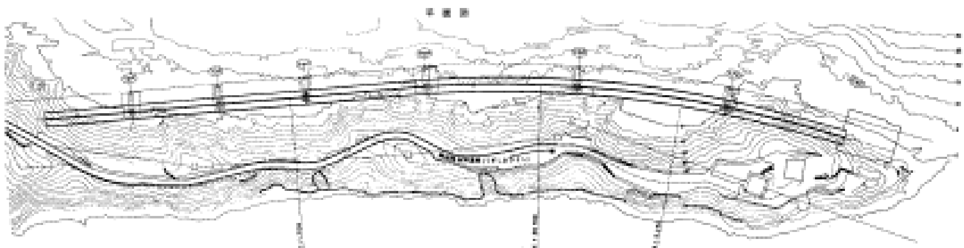
Japan – 02

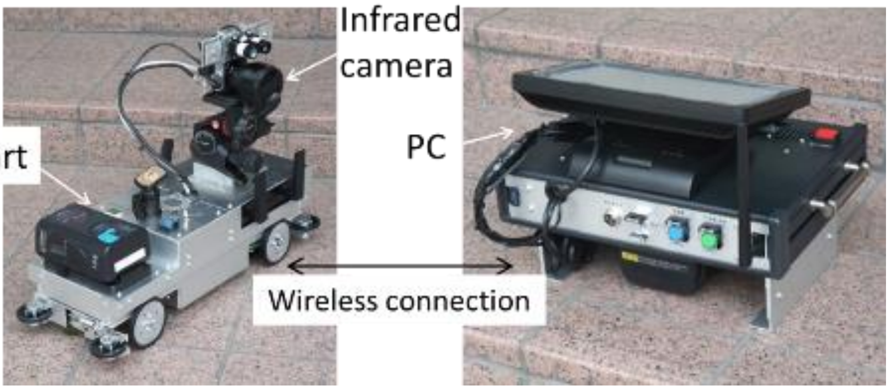
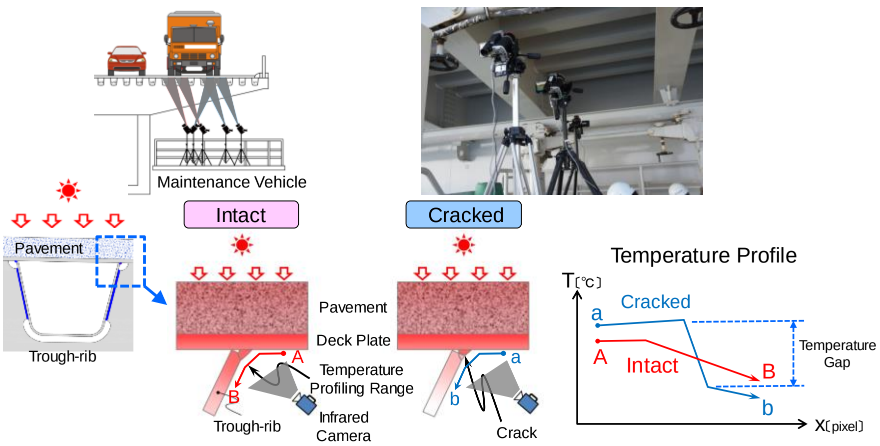
Case study	
1.0	**General data**
Country	Japan
Prepared by	Moto HISANO, Metropolitan Expressway Company Limited (MEX)
Date Prepared	19th March 2021
Bridge name	Metropolitan Expressway Bay Shore Route Note: Bridges in Metropolitan Expressway do not have individual names except for special bridges such as long-span bridges since Metropolitan Expressway is network roads in the urban area.
General bridge description	Bay Shore Route is a motorway of total length of 64km with 3 lanes on each direction at bay shore area in the metropolitan area. It is a heavy traffic route that from 50,000 to 120,000 vehicles, mainly heavy vehicles, use a day. The route consists of bridges, tunnels, half-underground structure, and earth structure, and its total length of bridges is about 37km.
Bridge equipment	*Bearings, expansion joints, RC railings, lighting poles, safety nets, and drainages*
Other	A 4-span continuous orthotropic steel box girder bridge opened in 1989 at Yokohama area is shown here. Upper deck of this bridge is for the Bay Shore Route, while lower deck is for national route No. 357. Superstructure for the Bay Shore Route consists of orthotropic steel and 3 steel box girders, and is rigidly connected with horizontal beam of pier. The substructure type is steel rigid flame with hinge on cast-in-place pile foundation.
Bridge pictures	

<table>
<tr><td>2.0</td><td>Bridge data</td></tr>
<tr><td>Structural design</td><td>4-span continuous orthotropic steel box girder bridge

</td></tr>
<tr><td>Material classification</td><td>Steel</td></tr>
<tr><td>Geometrical data</td><td>Bridge length: 344.5m
Lanes: 6 lanes (3 lanes on each side)
Spans: 4 span
Standard width: 28.75m
Lanes: 21.0m (3.5m/lane*3lanes*2 directions)
Outer shoulder: 5.0m (2.5m/direction*2 directions)
Inner shoulder: 1.0m (0.5m/direction*2 directions)
Central reserve: 1.25m
Railings: 0.5m (0.25m/direction* 2 directions)</td></tr>
<tr><td>Reason for using the tools/techniques</td><td>Welded joints between trough rib and deck plate in orthotropic steel bridge are susceptible to fatigue crack. Since its detection had been done by close visual inspection which needs large amount of labor, more efficient detection method is necessary. Deck penetrating crack needs urgent actions because it may affect third parties due to caving of road surface. Accordingly easy and simple inspection method to detect a “deep crack” possibly leading to deck penetrating crack in short time has been anticipated.</td></tr>
</table>

	 Example of deck penetrating crack
Tools/technique used	Semi-Automatic Ultrasonic Testing Developer: Metropolitan Expressway Company Limited and Shutoko Technology Center
3	**Tools/technique used**
Tool picture	  Testing from the underside of the deck
General description	Cracks deeper than 6mm can be detected with angle probe of 70 degree with focusing the diameter of ultrasonic beam. This system can detect only existence of cracks deeper than 6mm and their location by scanning special probe holder along deck plate by hand. It is an effective way for screening deep cracks in short time since it can automatically locate crack positions and record waveforms. Depth of detected cracks have to be confirmed by detailed ultrasonic testing by hand.
Field(s) of use	Crack deeper than 6mm
Results reliability	Good
Test duration	Quick. 130m-long inspection a day is possible
Results' interpretation complexity	Undemanding - moderate
Cost	Low. Total cost is cheap. It can be conducted in short time as well as in a simple manner.
Standardization	A company-specific manual was developed.

Japan – 03

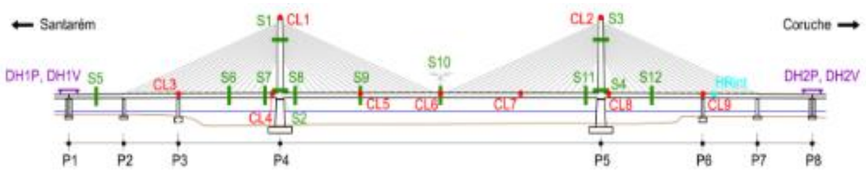
Case study	
1.0	**General data**
Country	Japan
Prepared by	Kazuo Endo, Honshu-Shikoku Bridge Expressway Company Limited (HSBE)
Date Prepared	22th March 2021
Bridge name	Tozaki Viaduct
General bridge description	Tozaki Viaduct is a part of Kobe Awaji Naruto expressway which connects Honshu and Shikoku islands. It is orthotropic steel box girder bridge of 35 years old. It is located in sever corrosive environment, and heavy duty paint system is applied on it.
Bridge equipment	bearings, expansion joints, railings, drainage, inspection vehicles
Other	
Bridge pictures	  
2.0	**Bridge data**
Structural design	3 +4 spans continuous orthotropic steel box girder bridges

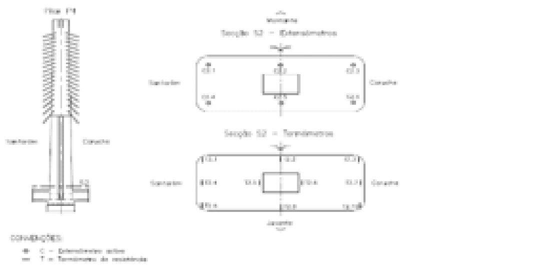
Material classification	Steel
Geometrical data	Length: 1,009.50m 3*108.00m+149.60m+2*190.40m+149.60m Width: 18.25m, 4 lanes
Reason for using the tools/techniques	Long span bridges in HSBE have orthotropic steel decks with trough rib to reduce their girder weight, and have long length of welded joint. Orthotropic steel bridges have possibility of fatigue cracks by traffic weight. Fatigue crack detection at welded joints often needs a lot of work and cost such as setting scaffoldings to approach and removing paint film. Especially, the joints between trough rib and deck plate have long welded length, and fatigue cracks are often found there. Therefore, development of an effective inspection method with low cost to detect fatigue cracks is required.
Tools/technique used	Crack detection system for orthotropic steel deck with trough rib
3	**Tools/technique used**
Tool picture	
General description	Cracks can be detected with infrared thermography without destroying or touching. In the process of heat conduction from pavement to trough rib through deck plate from sunlight, when there is a bead penetrating crack at the welded joint between trough rib and deck plate, the conduction is prevented by the crack. By measuring temperature gap through infrared camera, fatigue cracks in the welding connection of steel deck can be detected. 

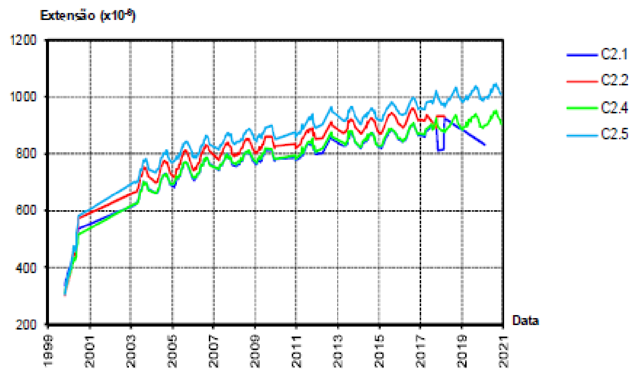
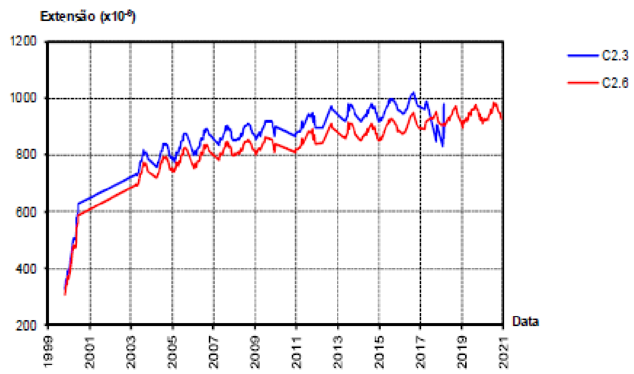
Field(s) of use	Measuring distribution of temperature and its differential value around welded joint
Results reliability	Crack of 40mm can be detected in the temperature field where the temperature difference between trough rib and deck plate is more than 0.5C.
Test duration	1.5km of welded joint can be inspected a day. It depends on the speed of inspection vehicles, where the infrared camera is installed.
Results' interpretation complexity	Moderate
Cost	Infrared thermography, laptop PC, and analysis software on the condition that there is a facility (vehicle or cart) with/on which the thermography can move along the welded joint keeping the resolution needed for the analysis.
Standardization	A company-specific manual was developed.

Portugal – 01

Case study	
1.0	**General data**
Country	Portugal
Prepared by	LNEC
Date Prepared	Since 1998 (beginning of construction of the bridge); last data – Dec 2020
Bridge name	Salgueiro Maia Bridge; 39° 11' 33.04" N 8° 39' 13.21" W
General bridge description	Cable Stayed bridge; main span length - 250m; total length - 570m. The bridge was built in 2000. It is located on the highway IC10, over the Tagus River. Regular and main inspections were conducted biannually. No major damage was recorded.
Bridge equipment	Bearings (pot, elastomeric), expansion joints (Freyssinet Multiflex SX Joint), New jerseys, rails, drainage
Other	-
Bridge pictures	  
2.0	**Bridge data**
Structural design	Cable-stayed bridge with semi-fan system; Post-tensioned concrete box girder
Material classification	Concrete
Geometrical data	Length: 570 m Width: 28,2 m Spans: 7 (40,5 m + 42 m + 78 m + 246 m + 78 m +42 m + 40,5 m)

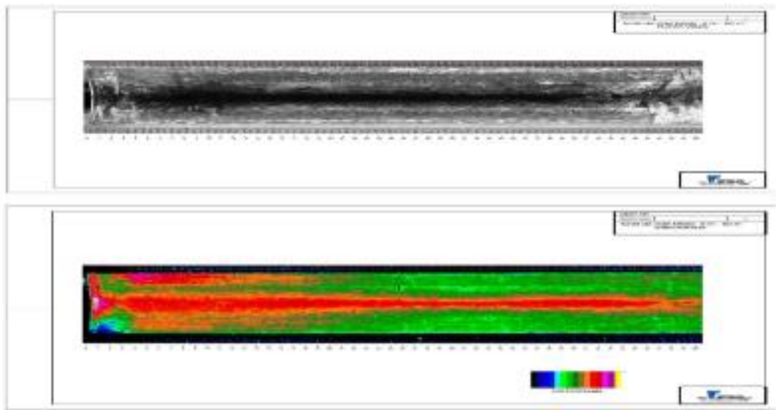
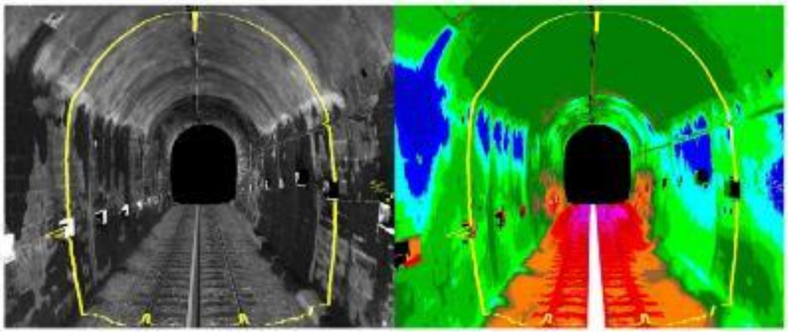
	No. of Lanes: 2 + 2
Reason for using the tools/techniques	The main objective of the SHM applied on the Salgueiro Maia Bridge is to detect anomalies that cannot be detected by the simple visual observation of the bridge structural elements and to complement the information collected during the main inspections. SHM is carried out by LNEC (Civil Engineering National Laboratory).
Tools/technique used	During and immediately after the bridge's construction (from 1998 to 2000), an automatic monitoring system comprising more than two hundred sensors was deployed *in situ* with the objective of studying its behavior and of controlling its safety in mid and long term (10 datalogger network and 243 measuring devices). At same time, a 3D structural model has been made in a program called "ARPA" (specific for rheological analysis of bridges built by cantilever method). The structural model included the properties of concrete based on samples taken during the bridge's construction. Over the last 20 years, this bridge has been regularly observed and a continuous comparation has been made between the expected values of the structural model and the acquired data from the monitoring system (which includes alarms based on real-time data acquisition). In 2017 an update has been made in the system to modernize real time acquisition and control of data. Automatic structural health monitoring system is currently making regular readings of the various quantities under observation, namely: strains, temperatures, rotations, horizontal and vertical displacements (including in expansion joints), forces on cables and the environmental conditions.
3.0	**Tools/technique used**
3.1	**Tool/technique: Automatic structural health monitoring system**
Tool picture	

	   
General description	The sensorial system comprises: • vibrating wire embedment strain gauge (S1-S12); • embedded resistance temperature detectors (RTDs; S1, S2, S8, S10); Regarding the long-term behaviour, strains and temperatures were also recorded in prisms with two long faces unsealed. Some prisms were used for shrinkage measurements (S5, S6, S8, S10-S12) while other prisms were used for creep measurements (S6, S10, S11) • inclinometer Schaevitz T233 (since 2017; previously it was used Huggenberger air-bubble clinometer; CL1, CL2); • magnetostrictive displacement transducer (since 2017; previously it was used telescometer; DH1P, DH1V, DH2P, DH2V); • hydrostatic levelling system with Druck UNIK 5000 Pressure Sensing Platform; • stay-cables' load cells; • Temperature and Humidity Sensors (outside and inside the box, S12). (For detailed explanation contact: LNEC (Civil Engineering National Laboratory - Structural Observation Nucleus NOE).

	LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL | DEPARTAMENTO DE ESTRUTURAS | NÚCLEO DE OBSERVAÇÃO DE ESTRUTURAS Figura 2.1 B - Secção S2. Extensões ativas medidas no mastro do pilar P4  
Field(s) of use	Automatic readings of the various quantities under observation, namely: strains, temperatures, rotations, horizontal and vertical displacements (including in expansion joints), forces on cables and the environmental conditions.
Results reliability	Good (possible sensitivity to temperature variations throughout the day; main measurements observed at 6:00 am to control the mid-term structural behavior). Some tools had to be replaced due to malfunction (e.g. hydrostatic levelling system).
Test duration	Quick
Results' interpretation complexity	Demanding
Cost	Total cost: around 10.000 € per year (a contract with LNEC in currently underway that includes inspection and monitoring of special bridges of IP).
Standardization	No.

Portugal – 02

Case study	
1.0	**General data**
Country	Portugal
Prepared by	IP – Infraestruturas de Portugal (previously named as REFER)
Date Prepared	More or less in 2004 (the date when the inspection was done in this case study).
Bridge name	Tunnels of Meão and Vale de Meão
General bridge description	Masonry tunnels (length – 62 m and 91 m). Located at the PKs 168+561 and 169+830 in The Douro Railway Line. Built between 1882 and 1887. Regular inspections are conducted in every 18 months, and main inspections in every 6 years. Damages detected in 2004: abutments walls deformed; water seepage; cracking in masonry walls; longitudinal drainage problems.
Bridge equipment	-
Other	-
Bridge pictures	
2.0	**Bridge data**
Structural design	Masonry tunnel
Material classification	Stone masonry
Geometrical data	Length: 62 m and 91 m Width: 7 m No. of Lanes: 1
Reason for using the tools/techniques	Laser scanner is used mainly for railway tunnel-inspection (also used in road tunnels of IP since 2015). In this example, this technique was used on tunnels

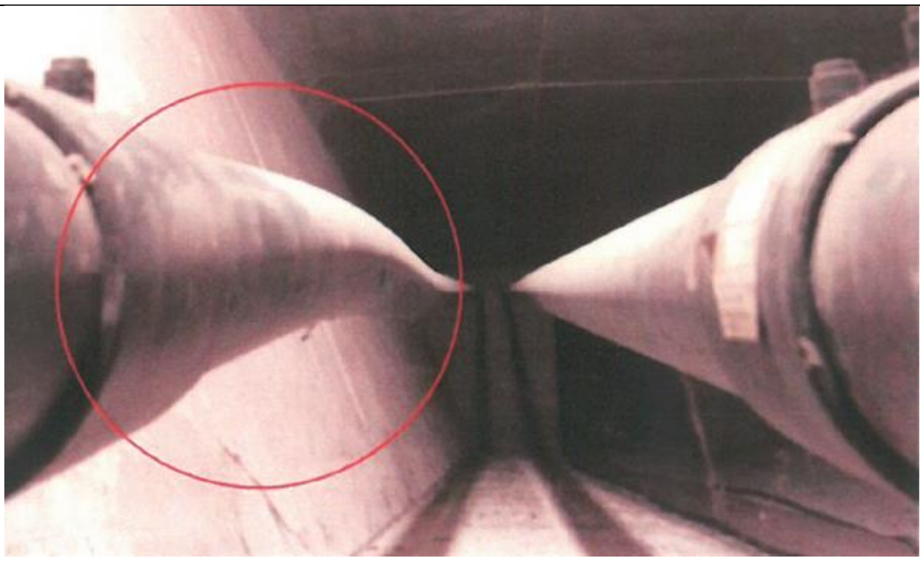
	rehabilitation project (Tunnels of Meão and Vale de Meão). Damages detected in 2004: abutments walls deformed; water seepage; cracking in masonry walls; longitudinal drainage problems. The rehabilitation works were finally done in 2013/2014. This technique is carried out by SPACETEC (company hired by IP) on-site and data treatment, and the final results evaluation is handled by IP (with the software Tunnel-Inspection).
Tools/technique used	Laser scanner (LIDAR; thermography; profilometry).
3.0	**Tools/technique used**
3.1	**Tool/technique: Laser scanner (LIDAR; thermography)**
Tool picture	   
General description	SPACETEC – TS3 system Scanner survey (visual, thermal, profile) Activities: • Measuring on-site (includes preparation/calibration, system transport to the site and set-up);

	• Data treatment (provision of data on appropriate carrier, backup copy stored at SPACETEC and quality control; automatic data comparison with the data recorded in the previously inspection) The results of this calculation are used by Tunnel-Inspector for display and evaluation of the two scans matching each other perfectly. NOTES: For detailed explanation contact IP – Infraestruturas de Portugal; in the near future IP intends to use the new SPACETEC TS4 system (TS3 scanner + additional sensors for high resolution colour imaging).
Field(s) of use	This is a very useful tool for example to recognize and evaluate cracks, spalling, detachment of parts of shotcrete, deformations or other damages which are manifested by change of the 3D surface.
Results reliability	Excellent. Highly Accurate
Test duration	2h on-site activities (Scan speed more or less 4km/h) More or less 1 week on data treatment and evaluation (it depends)
Results' interpretation complexity	Demanding
Cost	Total cost at that time unknown. A contract with SPACETEC in currently underway that includes inspection of many road and railway tunnels of IP (average cost around 700 € per 100m of tunnel length). On-site activities and data treatment are carried out by SPACETEC but the final evaluation is handled by IP.
Standardization	No.

Slovenia – 01

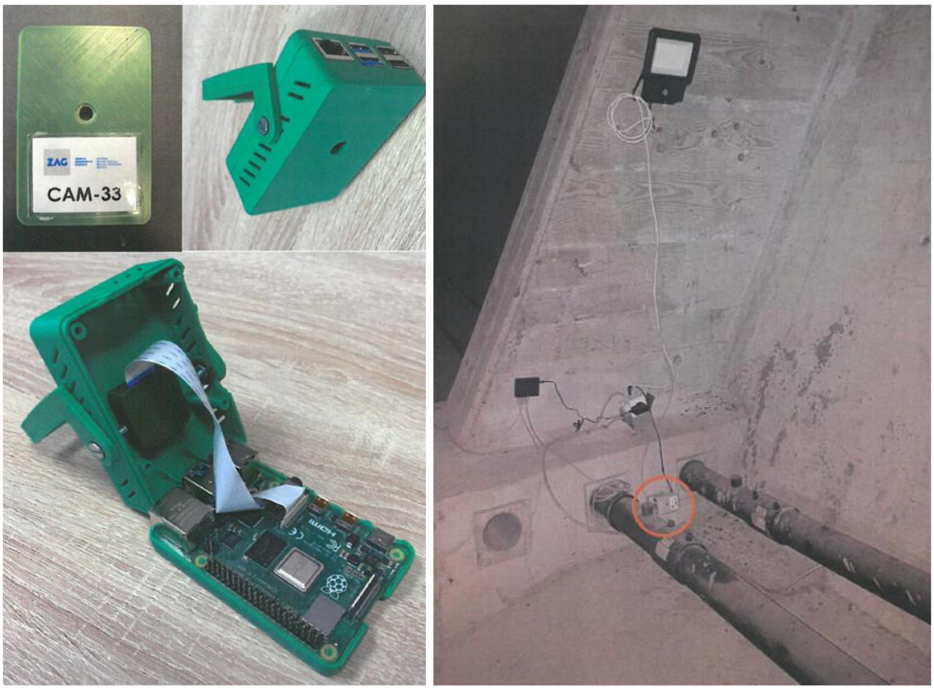
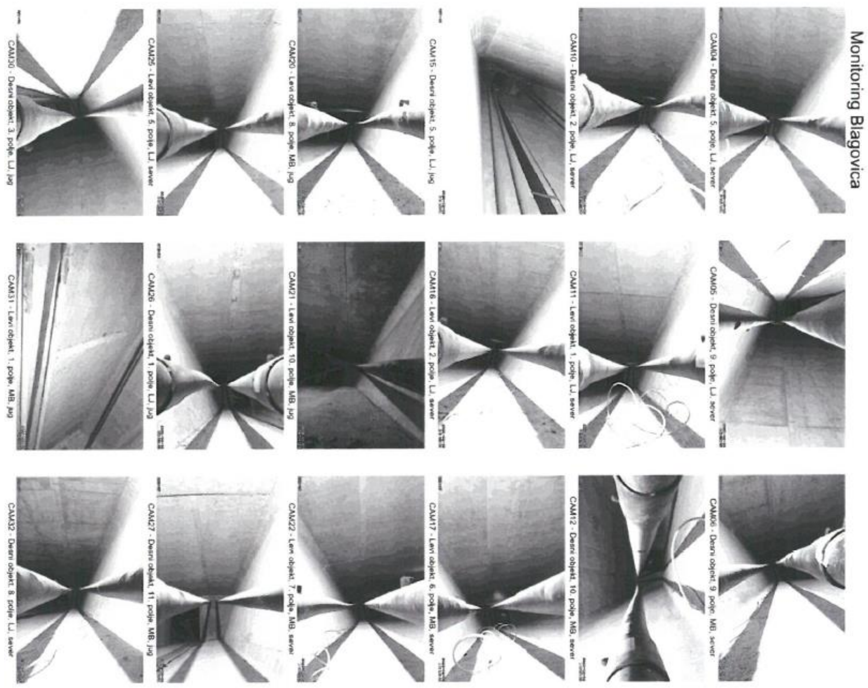
Case study	
1.0	**General data**
Country	Slovenia
Prepared by	Matej Kušar (DRI – Company for infrastructure development) Andrej Anžlin (ZAG – National building and civil engineering institute)
Date Prepared	28.10.2020
Bridge name	Blagovica; Highway A1; 46°,10',28'' N, 14,48',6'' E
General bridge description	The bridge was built in 2005. It is located on the highway with the highest traffic volume in the country. Regular and main inspections were conducted biannually. Apart from smaller delaminated areas of superstructure, no major damage was recorded. In 2019, during the main inspection, deformation of two prestressed cables was recorded.
Bridge equipment	Bearings (sliding, spherical), expansion joints (Maurer D 320), noise barriers, drainage
Other	
Bridge pictures	

	
2.0	**Bridge data**
Structural design	Post-tensioned concrete box girder bridge
Material classification	Concrete
Geometrical data	Length: 449m Width: 1,6 m Spans: 11 No. of Lanes: 3
Reason for using the tools/techniques	Principal inspection in 2019 revealed deformation of two prestressed external cables. In the first phase, the condition of the cables was determined by estimating the tensile force using vibration method. In the second phase, autonomus video monitoring was placed inside box girder to detect any additional deformation in real time.

	 Fig. Deformed prestressed cable
Tools/technique used	1. External cables prestressed force estimation using vibration method 2. Video monitoring of external prestressed cables
3	**Tools/technique used**
3.1	**Tool/technique: External cables prestressed force estimation using vibration method**
Tool picture	
General description	Tensile force in the external cables was estimated using the analytical expression derived from differential equation of tensile cable. In order to estimate tensile force in the pre-stressed cables the first few mode periods of cables were measured with accelerometer. The length of the cables was measured with laser distance meter. The following equipment was used: - linear scale Mitutoyo - laser measure Disto Leica D510 - accelerometer DYTRAN 3192A - data acquisition system Dewesoft Sirius-i - software Dewesoft X3, Python (v. 3.7.6)

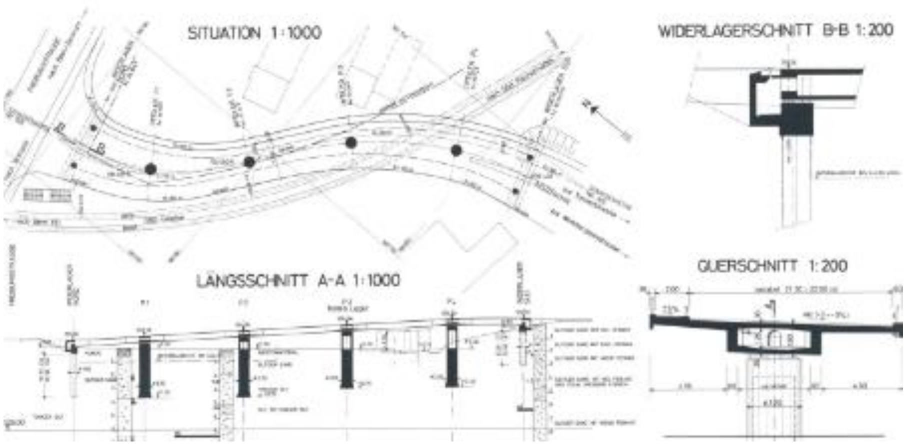
	(For detailed explanation contact: ZAG – National building and civil engineering institute, Structures department)
Field(s) of use	Limited to testing of external pre-stressed cables
Results reliability	Results reliability: good, especially for engineering purposes when compared with the tensioning protocols Sensitivity to external factors: some error derives in estimating the effective length of the cables (the transition of cable from fix to free area cannot be always clearly identified), calculation of true flexural stiffness of the external cables can be difficult, therefore two extreme situations are considered, i.e. stiff connection between all components of cables (HDPE pipes, cement paste, cables), no connection is provided between the components
Test duration	Equipment installation: 1 days (1 senior engineer, 1 assistant) On-site test duration: 1 day (1 senior engineer, 1 assistant) Results interpretation (in office): 12 days (1 senior engineer)
Results' interpretation complexity	Demanding
Cost	Total cost of inspection: 8.000 € (note: Country GDP per capita in 2019: 26.000 $)
Standardization	No

Slovenia – 02

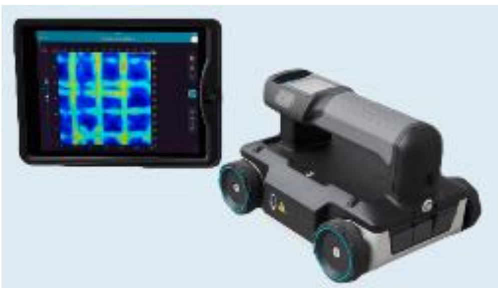
3.2	**Tool/technique: Video monitoring**
Tool picture	 
General description	Sixteen cameras are installed and each camera takes on photo per hour. The cameras are controlled by software that coordinates their operation in a way that not more than one reflector and camera is switched on at any time. The software automatically converts photos into 24 fps video. The weekly recording of an

	individual camera is 7 seconds long, which provides a quick overview and a better ability to detect possible movements. The following equipment is used: - camera Raspberry Pi V2.1 NoIR - LED reflector MISTRAL R LED/50W/230V - computer Raspberry Pi Model 4 - software MotionEyeOS (For detailed explanation contact: ZAG – National building and civil engineering institute, Structures department)
Field(s) of use	Deformation or displacements detection
Results reliability	Results reliability: excellent Sensitivity to external factors: none
Test duration	Equipment installation: 10 days (considering that permanent electric power is provided) Test duration: Continuous Results interpretation (in office): once per 2 weeks
Results' interpretation complexity	Undemanding to moderate. Short office analysis once per week required.
Cost	Total cost of equipment installation and first results interpretation: 20.000 € (note: Country GDP per capita in 2019: 26.000 $)
Standardization	No

Switzerland – 01

Case study	
1.0	**General data**
Country	Switzerland
Prepared by	Dimitrios Papastergiou Head of Bridges, Standards and Safety of Infrastructure Roads network Division Federal Roads Office (FEDRO)
Date Prepared	04.02.2021
Bridge name	Bridge over GBS, F 02D, N12.84 Anschluss 12 Bern-Bümplitz
General bridge description	The ramp bridge over GBS is longitudinally a continuous girder over 5 spans forming an “S” type clothoid. The width transversally is variable; the deck is shorter in the middle and wider approaching the abutments.
Bridge equipment	Bearings, expansion joints, , drainage, handrail walkway, road restrain systems (steel bridge railings), single portal, pipeline
Other	
Bridge pictures	

	 
2.0	**Bridge data**
Structural design	Post-tensioned concrete box girder bridge. Its cross section is a box with the upper slab presenting transversally cantilever parts at both sides. The crossbeams are formed inside the cross box over each of the 4 piles and at the two abutments. The box girder is prestressed longitudinally. Prestressed transversally are the upper slab of the box girder and the crossbeams over the piles.
Material classification	Prestressed and reinforced concrete

Geometrical data	Total length: 134.00 m Largest width: 17.37 m Spans: 5 Lanes: 4
Reason for using the tools/techniques	The regular inspection carried out in the end of 2013 revealed, besides other, extended humid zones and water infiltration inside the box girder at the cross beams both over the piles and the abutments as well, due to broken drainage and defective expansion joints respectively. Furthermore, spalling was also observed at some zones inside the box girder at the underneath surface of the upper slab. Finally, sintering is formed along small transversal cracks at the underneath surface of the cantilever slabs. This finding have revealed the following questions: - Are post-tensioning cables of cross beams affected by water infiltration? - Are the cracks on the intrados (underside) of the cantilever slab presenting sintering superficial or do they reach the transversal post-tensioning cables? - Is spalling at the underneath surface of the upper slab inside the box girder due to local disorders or the result of a general delamination of the slab? - Since asphalt layers and sealing membrane are to be renewed, it is important to know also the state of the deck slab with regard to chloride contamination so as to optimize costs and intervention and estimate an accurate budget. In order to provide answers for those questions it was decided to perform : Non-destructively mapping, using Ground Penetrative Radar, of asphalt layer thicknesses, concrete cover, determination of level of contamination by chlorides and major disorders of upper slab. Non-destructively mapping, using Ground Penetrative Radar, of concrete cover, determination of level of contamination by chlorides of cross beams and of the underneath surface of the cantilever slab.
Tools/technique used	**Ground penetrative radar**
3	**Tools/technique used**
Tool picture	 
General description	**Ground Penetrating Radar** is a non-destructive methodology similar to a scanner. The device emits electromagnetic waves that reflect within the inspected

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structure at each interface. This allows GPR to cover large surfaces in a short time**,** which makes it efficient in civil engineering applications**.** The device possesses an emitting and a receiving antenna. With moving the device along the investigated object, the radar will stack measurements one after the other enabling defect location. The raw images are called radargrams. A radargram is the sum of all recordings (traces) along the measured path. It must be processed using **digital signal processing** techniques, then it must be **interpreted** with knowing that artefacts might be presents.

The **Depth of investigation** as well as the **image resolution** depends of the antenna **central frequency**. Between 100 to 900 MHz the depth will be important but the image will be rough. Oppositely, with high central frequencies from 900 MHz to 2.5 GHz the image will be detailed but the depth will be smaller. Choosing the GPR antenna must consider these parameters to focus on the goal of the survey. The **optimal** bandwidth for **bridges** is within **1GHz** and **2GHz**.

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<td>Field(s) of use</td>
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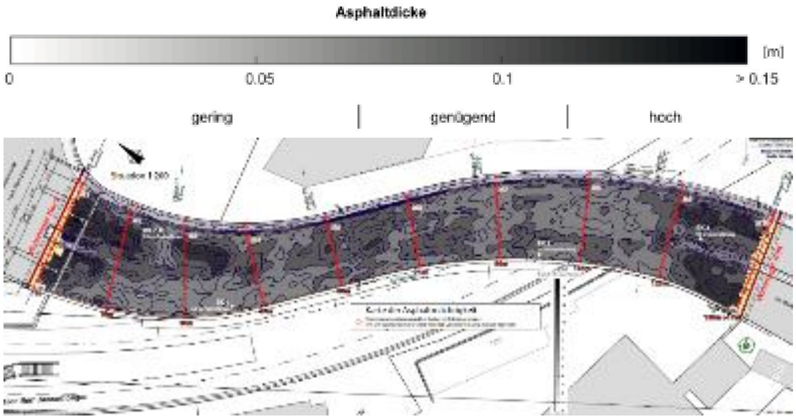
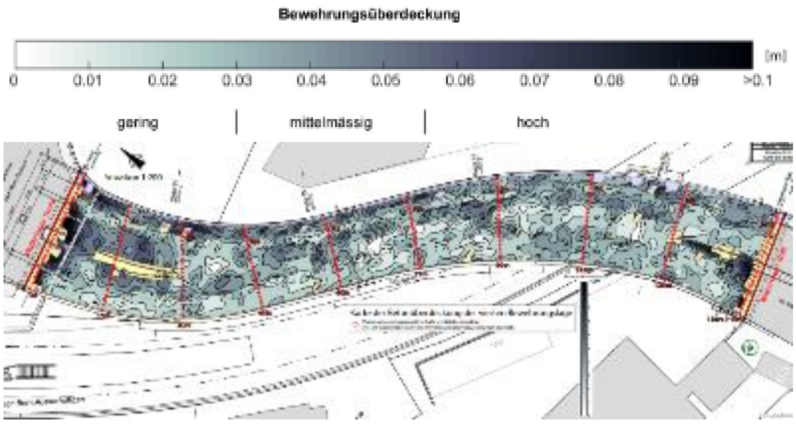
In this particular case study, took place almost all possible investigations with a GPR:

- **Mapping of asphalt thickness**



- **Mapping of concrete covering**



- **Mapping of apparent electric conductivity**

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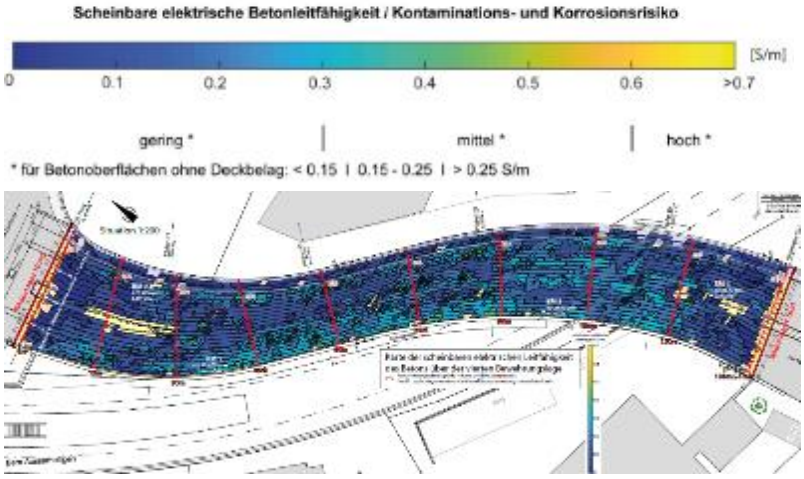
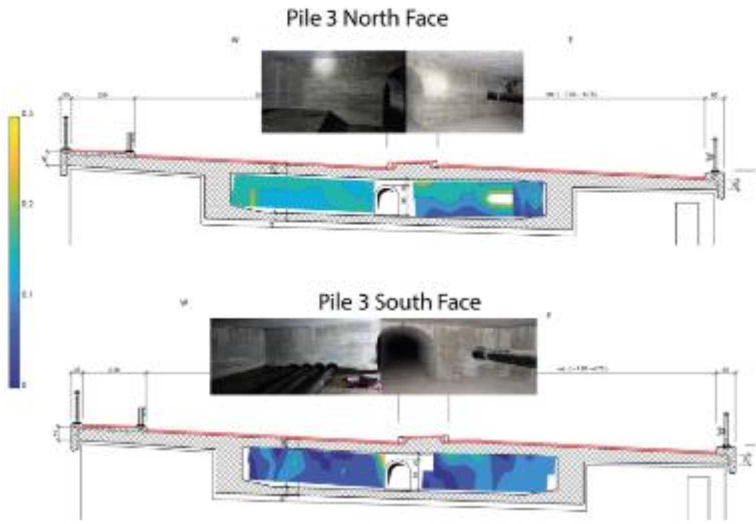
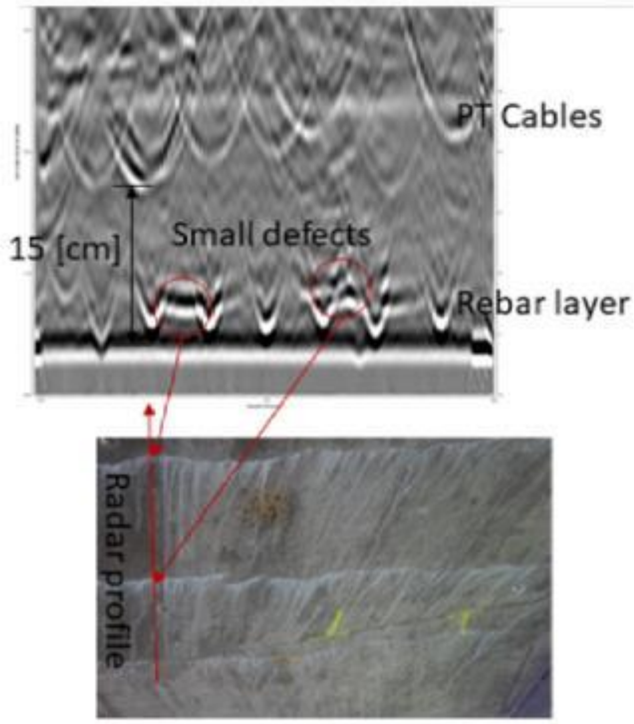




The mapping allowed to limit the costs of the intervention by proposing rehabilitation measures only where it was necessary. It was proven that spalling at the underneath surface of the upper slab inside the box girder was due only to local disorders and it was not the result of a general chloride contamination of the slab. So as to create a proper support to the new sealing, it was decided to replace the concrete of the upper slab to a depth less than 3 cm. Furthermore, it was proved that the post-tensioning cables of cross beams were not affected by water infiltration.

- **Mapping of local disorders**
  The scanning of the underneath surface of the cantilever slabs, allowed to verify that the transversal cracks with sintering were only superficial and the post-tensioning cables, being more than 10 cm higher than the cracks, were consequently not affected. Thus, the cantilever slabs do not present a static deficiency.

	
Results reliability	Very good reliability of the results confirmed by investigation openings and samples extracted from pavement and concrete members (slab, cross beams). The method is though limited and cannot predict corrosion of post-tensioning cables with plastic ducts when chlorides penetrate enough to reach the cables.
Test duration	On-site test duration: 4 days (1 senior engineer, 1 assistant) Results interpretation (in office): 30 days (1 senior engineer and partly assistant)
Results' interpretation complexity	The interpretation of the data requires special knowledge and expertise. The contactor uses self-developed algorithms to facilitate interpretation and the production of the results.
Cost	Cost of mapping inspection by GPR: 48.000 € The total cost of the rehabilitation project including replacement of expansion joints, bearings, steel bridge railings, sealing and asphalt layers is estimated to 3.0 million € , from which the repair of concrete parts is limited to 0.7 million (mostly for abutments, replacement of edge curbs, curbs of island separation, and sidewalks and much less for repairing bearing slabs and beams, thanks to results from GPR mapping). (note: Country GDP per capita in 2019: 82.000 $)
Standardization	No.

World Road Association (PIARC)

La Grande Arche, Paroi Sud, 5e étage, F-92055 La Défense cedex