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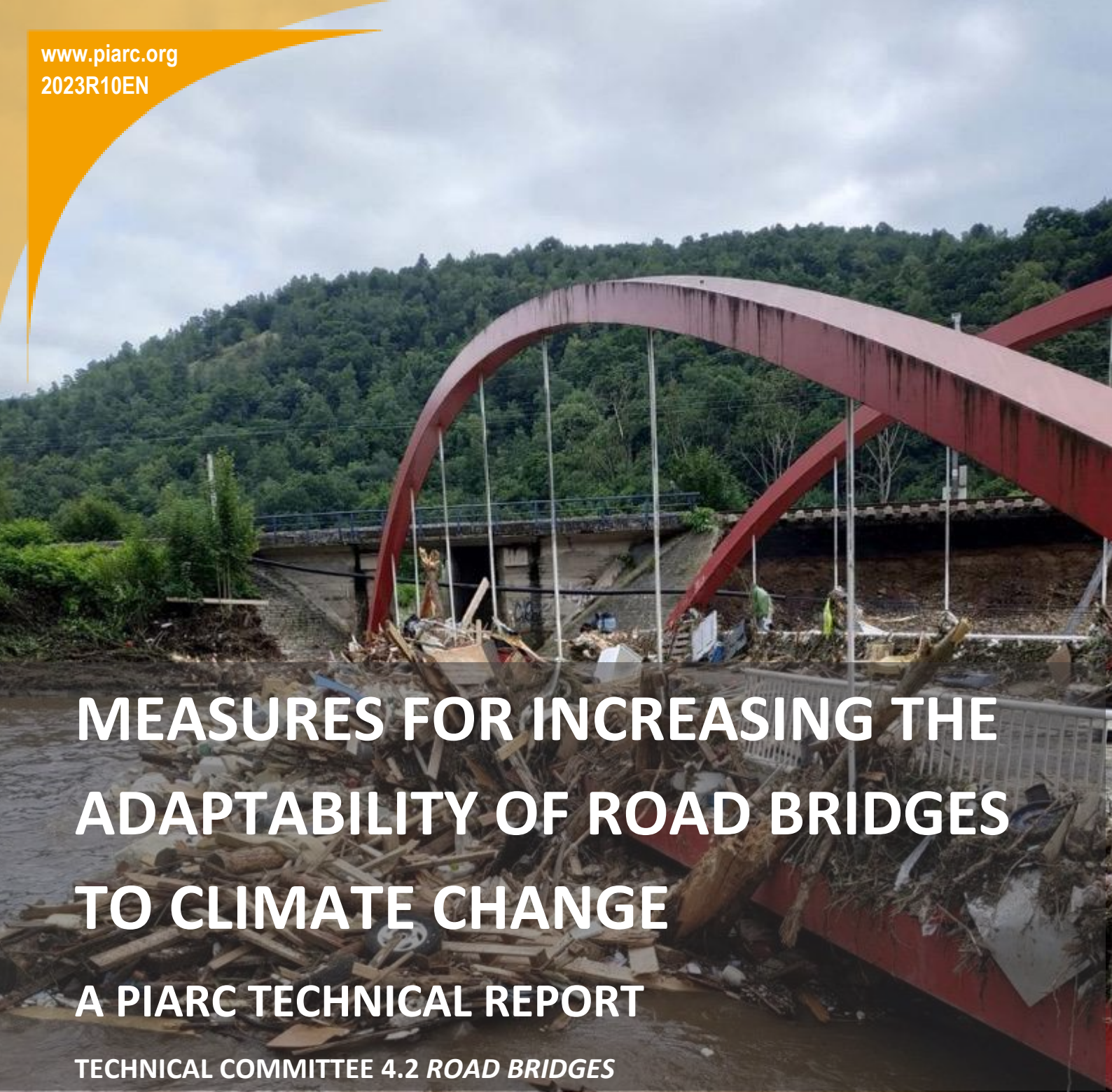

MEASURES FOR INCREASING THE ADAPTABILITY OF ROAD BRIDGES TO CLIMATE CHANGE

A PIARC TECHNICAL REPORT

TECHNICAL COMMITTEE 4.2 *ROAD BRIDGES*

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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A PIARC TECHNICAL REPORT

TECHNICAL COMMITTEE 4.2 *ROAD BRIDGES*

AUTHORS/ ACKNOWLEDGEMENTS

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

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EXECUTIVE SUMMARY

2023R10EN

MEASURES FOR INCREASING THE ADAPTABILITY OF ROAD BRIDGES TO CLIMATE CHANGE

A PIARC TECHNICAL REPORT

There are already signs of climate change driven extreme weather events in certain parts of the world including heavy rain, flooding, tropical storms, drought, high temperatures and so on. The frequencies of some of these events are also increasing. In general, there are extreme natural events being experienced in many countries resulting in loss of lives and loss or damage to infrastructure. Climate change has become a global issue of concern and it is for this reason that PIARC has incorporated it into the strategic themes and technical committee bridges for the terms of 2008-2011 and 2012-2015.

PIARC's International Climate Change Adaptation Framework for Road Infrastructure was produced by PIARC T.C E.1 - Adaptation Strategies and Resiliency (SP 2016-2019). Outputs associated with the issue "Measures for increasing resilience to climate change" were expected to provide several measures which will be options for road owners within this Framework.

In order to collect information and case studies associated with measures for increasing resilience to climate change, TC 4.2 collected fifteen sets of answers to general questions and nineteen case studies. Responses to the general questions are mainly from Europe, but they include Africa, Asia, North America, and South America. Case studies are also mainly from Europe, but there is one case study from South America as well as Africa and three case studies from Asia.

According to the general question responses, all countries have experienced different effects of climate change. A majority of the countries that responded believe that bridges are also being affected by flooding and scour driven by climate change. The Netherlands, which is low in elevation, has raised the issue of sea level rise as an impact on bridges from climate change, while Japan and China, which are affected by tropical storms, have raised the issue of wind effects. To address these impacts, it is necessary to revise and/or adjust current bridge design codes so that bridges can better accommodate these changes. However, to date, no countries responded that they have revised and/or adjusted their design codes although several are conducting research projects in that regard.

The content of each case study submitted was carefully reviewed and evaluated and then a cover sheet was created by TC 4.2 members. Contents of the cover sheet include Photos, Description of bridge, and Impact due to Climate change. In addition, in order to classify each case study, it was carefully evaluated by applying the same categories with respect to Climate, Hazards, and Impacts on bridges.

EXECUTIVE SUMMARY

Based on the classification results of nineteen case studies, a mind mapping analysis of the current state of climate change was conducted. This mind mapping was organized in terms of climate, hazards, and impacts on bridges. Among the responses to general questions, climate, hazards and impacts have been captured at the same level. However, we believe that mind mapping analysis results will make it easier for bridge engineers to understand the impacts of climate change on bridges considering causes and consequences. It is recommended that in order to adapt to climate change in the future, it is important to understand the impacts on bridges due to climate change within a cause and consequence framework since the impacts on bridges due to climate change are different from region to region.

CONTENTS

1. INTRODUCTION

There are already signs of climate change driven extreme weather events in certain parts of the world resulting in heavy rain, flooding, tropical storms, drought, high temperatures and so on. The frequencies of some of these events are also increasing. In general, there are extreme natural events being experienced in many countries resulting in loss of lives and loss or damage to infrastructure.

Climate change has become a global issue of concern and it is for this reason that PIARC has incorporated it into the strategic themes and technical committee bridges for the terms of 2008-2011 and 2012-2015.

PIARC's International Climate Change Adaptation Framework for Road Infrastructure was produced by PIARC T.C E.1 - Adaptation Strategies and Resiliency (SP 2016-2019). Outputs associated with the issue "Measures for increasing resilience to climate change" are expected to provide several measures for options that road owners can use within this Framework.

In order to collect information and case studies associated with measures for increasing resilience to climate change, Technical Committee 4.2 Bridges (TC4.2) decided to collect Case Studies through questionnaires associated with "Issue 4.2.3: Advancement of inspection techniques/technologies and bridge management" and "Issue 4.2.4: New rehabilitation materials and technologies". However, only five case studies were collected with respect to Issue 4.2.4.

Due to this outcome, TC 4.2 discussed and concluded that it is difficult to find and provide "Advancement" and/or "New" case studies since climate change is a new issue. So, TC 4.2 decided to prepare general questions and a case study template in order to collect more general information as well as more case studies, and distributed them in January 2022.

Finally, fifteen sets of answers to the general questions and an additional fourteen case studies were received through April 2022. Responses to the general questions were mainly from Europe (9 answers), but they include Africa (1 answer), Asia (3 answers), North America (1 answer) and South America (1 answer). Case studies were also mainly from Europe (14 case studies), but there is one case study from South America (Chile), one case study from Africa (Niger) and three case studies from Asia (China and Japan).

This report first summarizes the work done by the technical committee on bridges for the terms of 2008-2011 and 2012-2015 and then presents the summary of PIARC's International Climate Change Adaptation Framework for Road Infrastructure produced by Special projects (SP2012-2015) as well as the proposal by PIARC T.C E.1 - Adaptation Strategies and Resiliency (2016-2019).

Secondly, this report presents current recognition as well as the practice of bridge engineers and owners with respect to Climate Change which were obtained through the general questionnaires and then introduces a collection of case studies with connections to other issues including 4.2.3 and 4.2.4.

2. BACKGROUND

Climate change has become a global issue of concern and it is for this reason that PIARC has incorporated it into the strategic themes and technical committee bridges for the terms of 2008-2011 and 2012-2015.

PIARC's International Climate Change Adaptation Framework for Road Infrastructure was produced through Special Projects (2012-2015) by PIARC. Then PIARC launched the activity to improve and refine this International Climate Change Adaptation Framework for Road Infrastructure as one Issue for T.C 1.5 (2016-2019).

This chapter summarizes this background in order to ensure a common understanding of this previous work.

2.1. OUTPUTS FROM BRIDGES TECHNICAL COMMITTEE OF 2008-2011 AND 2012-2015

2.1.1. Outputs from the Bridge Technical Committee of 2008-2011 [1]

The scope of the Bridge Technical Committee of 2008-2011 was to investigate how the various countries define climate change and associated policies were developed. To do so, the committee prepared and distributed a questionnaire to the various countries.

Thirteen countries or states from five continents responded to this study. In general, there were extreme natural events being experienced in many countries resulting in loss of lives and loss or damage to infrastructure. Importantly, however, most countries could not qualify that these events were as a result of climate change.

The main outputs from the study were as follows:

- The most common events that have an impact on the bridge stock in most countries were flooding, higher rainfall intensities and higher temperatures. Table 1 provides a summary of the climate changes experienced by the different countries.
- Climate change takes place over extended timeframes (i.e., decades, centuries). It seems to be clear that both natural ("internal") and human activity-based ("external") forces influence the range of the effects mainly linked with climate change. The present result of the classical question and answer framework showed that for more or less that for "new" issues new ways in gaining information should be tested. Workshops in collaboration with international experts generated better findings.
- It is a goal of bridge owners worldwide to provide bridges with the capability to adapt to the effects of climate change. However, the different ages within a bridge stock makes it very difficult to decide how to adapt existing bridges and how to design new ones. Deficiencies of existing structures are almost never caused by effects of climate change only, whereas design rules for new construction often do not treat the effects of climate changes separately. Preventive measures for new construction seem to be easier to develop. Nevertheless, exposure to climate change will certainly lead to a need of a deeper understanding of its different effects on existing bridge structures.

Table 1. Climate change experienced by various countries

Country	Rain		Temp.	Wind	Flooding	Storms	Earthquake	Snow	Sea Level
	high	low	high	high	severe	severe	increased intensity	high falls	rise
Western Australia		✹							
Belgium	✹		✹						
Finland	✹		✹			✹			
Germany	✹		✹	✹					
Italy	✹		✹	✹					
Japan							✹		
Lithuania			✹						
Norway	✹		✹						
Slovenia					✹	✹			
South Africa				✹	✹				
Spain		✹							✹
Switzerland	✹		✹						
USA – Virginia	✹							✹	

2.1.2. Outputs from the Bridge Technical Committee of 2012-2015 [2]

The Bridge Technical Committee of 2012-2015 reviewed documents on climate change and its effects on road bridges. However, limited information is available on the quantitative effects of climate change. The Intergovernmental Panel on Climate Change (IPCC) report and other documents does point out that bridges can be affected by climate change. Scour due to increased sea level and flooding due to heavy precipitation was cited as the most common impact on highway bridges. Heavy precipitation can also cause land movement and settlement that can result in damage to bridge foundations as well as the entire bridge structure.

The costs to adapt bridge infrastructure to climate change are expected to be substantial. To effectively deal with on-going climate change, design guidelines considering the effects of increased flooding and sea level rise may need to be developed and implemented. Local extreme climatic events have more influence on the vulnerability of a bridge so site-specific impacts of climate change must also be considered in the design stage. The additional uncertainty that climate change brings, and the nature of these changes makes effective risk management and monitoring of bridge deterioration even more important.

2.2. PIARC'S INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK

2.2.1. International Climate Change Adaptation Framework for Road Infrastructure, 2012-2015 [3]

Through Special Projects (2012-2015), PIARC had developed a framework to guide road authorities through identifying relevant assets and climatic variables for assessment, identifying and prioritizing risks, developing a robust adaptation response and integrating assessment findings into decision-making processes. The framework was developed through extensive research and consultation with road authorities globally. The framework provides a life-cycle and iterative approach to climate change adaptation.

The proposed framework guides road authorities through the process of increasing the resilience of their networks and assets through the following stages:

- Stage 1 - Identifying Scope, Variables, Risks and Data;
- Stage 2 - Assessing and Prioritizing Risks;
- Stage 3 - Developing and Selecting Adaptation Responses and Strategies; and,
- Stage 4 - Integrating Findings into Decision Making Processes.

It was concluded that the framework facilitates the identification and replication of lessons learned from other countries and takes account of the varying levels of preparedness, adaptive capacity and knowledge from country-to-country and region-to-region. It is also designed to be applicable at any scale (such as national, regional, local or asset specific.)

2.2.2. Refinement of PIARC's International Climate Change Adaptation Framework for Road Infrastructure, 2012-2015 [4]

PIARC launched the activity to improve and refine this International Climate Change Adaptation Framework for Road Infrastructure as one Issue for PIARC Technical Committee (TC) E.1. TC E.1 collected 59 case studies to evaluate this Framework. Through this study, the Framework was evaluated with respect to its applicability for various purposes, comparison with other adaptation frameworks and compliance with ongoing adaptation work.

Based on this evaluation, proposals for refinement of the Framework were formulated. These included (1) structural changes, (2) added steps and sub-steps and (3) added content. The main proposals from this investigation were as follows:

- In general, the PIARC Framework is most suitable for road agencies that have enough basic knowledge for carrying out a climate impact assessment and implementing adaptation measures, that already have good communication with other stakeholders, but that have not done much adaptation work to date. Therefore, some simplifications (short-cuts) in the procedure were proposed in order to satisfy different levels of analysis or scope.
- The Framework provides a combination of the structure of tasks for adaptation to climate change and a methodology for risk assessment. It was proposed that these two aspects should be treated separately. The structural aspect is important because it sets out the various tasks in relation to each other. The methodology aspect is not less important but is variable and needs to be variable to suit the different existing practices of road administrations.
- Finally, the aspect of criticality needs to be included in the assessment of risks and decisions on adaptation measures.

3. METHODOLOGY

At the beginning of the activity of TC 4.2, it was decided to collect Case Studies through questionnaires associated with "Issue 4.2.3: Advancement of inspection techniques/technologies and bridge management" and "Issue 4.2.4: New rehabilitation materials and technologies". However, only five case studies were collected with respect to Issue 4.2.4.

However, TC 4.2 discussed and concluded that it was quite difficult to find and provide "Advancement" and/or "New" case studies since climate change is a new issue. As a result, TC 4.2 decided to prepare general questions and a case study template in order to collect more general information as well as more case studies. Appendix A presents the general questions and the case study template which were delivered to TC 4.2 member countries in January 2022.

Fifteen sets of answers to the general questions and an additional fourteen case studies were received through April 2022. The number of case studies became nineteen in total. Table 2 summarizes responses to the general questions as well as the case studies with respect to different countries and states.

Responses to the general questions were mainly from Europe (9 answers), but they included Africa (1 answer), Asia (3 answers), North America (1 answer) and South America (1 answer). Case studies were also mainly from Europe (14 case studies), but there is one case study from South America (Chile), one case study from Africa (Niger) and three case studies from Asia (China and Japan).

The answers to the general questions were carefully evaluated. For questions 1 and 5, responses from each country were categorized according to the type of climate change impact. Other responses were carefully analyzed by TC 4.2 members and organized into three categories: "Yes", "No" and "No answer".

Nineteen case studies were carefully reviewed and evaluated and then a cover sheet was created by TC 4.2 members to summarize the case study. The content of the cover sheet includes Photos, Description of bridge, and Impact due to Climate change. In addition, in order to classify each case study, they were evaluated by applying the same categories with respect to Climate, Hazards, and Impacts on bridges.

Based on the classification results of nineteen case studies, a mind mapping analysis of the current state of climate change was conducted. This mind mapping was organized in terms of climate, hazards, and impacts on bridges.

Table 2: Responses with respect to general questions and case studies

Country State	Continent	General question	Number of case studies (*)	
			Issue 4.2.1	Issue 4.2.4
Austria	Europe	Yes	-	-
Belgium	Europe	Yes	2 (#01, #02)	-
Chile	South America	Yes	1 (#03)	-
China Beijing	Asia	Yes	1 (#04)	-
China Wuhan	Asia	Yes	-	-
Hungary	Europe	Yes	-	-

Country State	Continent	General question	Number of case studies (*)	
			Issue 4.2.1	Issue 4.2.4
France	Europe	Yes	1 (#08)	3 (#05, #06, #07)
Germany	Europe	Yes	1 (#09)	-
Japan	Asia	Yes	2 (#10, #11)	-
Netherlands	Europe	Yes	2 (#12, #13)	-
Niger	Africa	Yes	1 (#14)	-
Norway	Europe	Yes	1 (#15)	-
Portugal	Europe	Yes	2 (#17, #18)	1 (#16)
Slovenia	Europe	Yes	-	-
Switzerland	Europe	-	-	1 (#19)
USA Utah	North America	Yes	-	-
Total		15	14	5

(*) Note: Number in the bracket indicates Case Study Number in Table 4 and appendix C.

4. RESULTS

Fifteen answers to the general questionnaire and nineteen case studies were collected. In this section the primary results from the questionnaires and case studies are summarized and presented.

4.1. GENERAL QUESTIONS

Fifteen responses from fourteen countries including Austria, Belgium, Chile, China (Beijing and Wuhan), Hungary, France, Germany, Japan, Netherlands, Niger, Norway, Portugal, Slovenia, and USA (Utah) were received to the general questions. They represent Europe, North and South America, Africa and Asia excluding Oceania. All responses are aggregated in Appendix B with respect to each question.

4.1.1. Experienced climate change, Question 1

Figure 1 presents the kinds of climate change experienced in different countries. It can be seen that a majority of responses indicated that many countries experienced “Heavy rainfall” and “Flood, Scour and Soil erosion”. The next most frequent responses indicate “Extreme wind, storms and Typhoon”, then “Temperature”, “Dry, Drought” and “Fire”.

According to the answers, concerns for rainfall are due to significant, unexpected, short duration, intense, and local heavy rains. These answers included “Significant, unexpected rain fall” (Hungary), “Significant increase in the frequency of heavy and short duration intense rain events” (Japan), “local heavy rain” (Netherlands) and “More heavy local rains” (Norway).

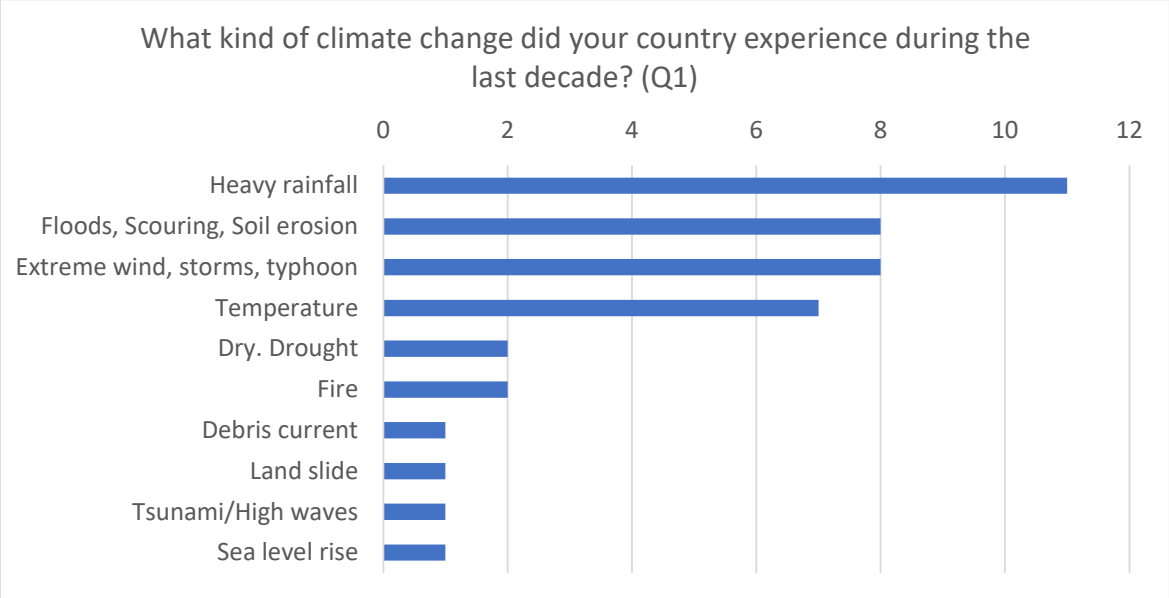


Figure 1: Country responses with respect to Question 1

4.1.2. Concerns, definition and impacts, Questions 2 to 4

Three questions were raised with regard to concerns, definition and impacts of climate change on bridge stock. The responses with respect to questions 2 to 4 are presented in Figure 2 as well as in Appendix B.

Concerns, Question 2

The second question (Question 2) dealt with concerns about the impact of climate change on a bridge stock. Eleven of fifteen countries or states indicated that they were concerned with climate change on their transportation system. It is interesting that China-Beijing indicated that over a thousand bridges were destroyed by flooding every year and, as a result, they need network-based monitoring systems including early warning and safety prevention control systems for their infrastructure. In addition, extensive repairs are required on concrete bridges due to chloride attack in coastal environments and in the north. It is also noted that within the European countries that responded, four countries, Austria, France, Portugal and Slovenia, do not have concerns but five countries, Belgium, Hungary, Germany, Netherlands and Norway, do have concerns.

Definition, Question 3

With regard to the third question (Question 3) on the definition of climate change effects on a bridge stock, six of the fifteen countries or states indicated that they have a definition of climate change effects on transportation infrastructure. In addition, Chile is defining climate change effects under a funded project. Also, China-Wuhan does not have a formal definition but some academic sectors are studying a wide range of climate change effects including temperature change, rainfall, floods, wind/typhoon, snow/ice, fire/fire storms, tropical cyclones.

Germany and the Netherlands have different definitions of climate change with respect to movable and fixed bridges. The expansion of a span due to high temperature and maintenance due to extreme strong winds and showers are considered for movable bridges. Rainwater drainage and extreme fluctuation in water levels are considered for fixed bridges. In addition to these two definitions, the Netherlands includes high water levels and fast current in its definition. Norway also has a definition including increased wind loads and increased height above water. Within the responding countries, the definition of climate change effects on bridges vary due to the different location and climate of each country.

Impacts, Question 4

The fourth question (Question 4) addressed countries or states that had been impacted by the effects due to several climate patterns including temperature changes, rainfall, floods, sea level rise, wind/tornados, snow/ice, fire/fire storms, tropical cyclones, and others. All countries indicated that they have been impacted by these effects. Table 3 shows the individual country responses with respect to the effects of climate change. The results are similar to those for Question 1, many countries had impacts due to Rainfall and Floods/Debris current/High water. A majority of countries had impacts due to temperature change. Almost one third of countries had impacts due to sea level rise, wind/tornados and tropical storms.

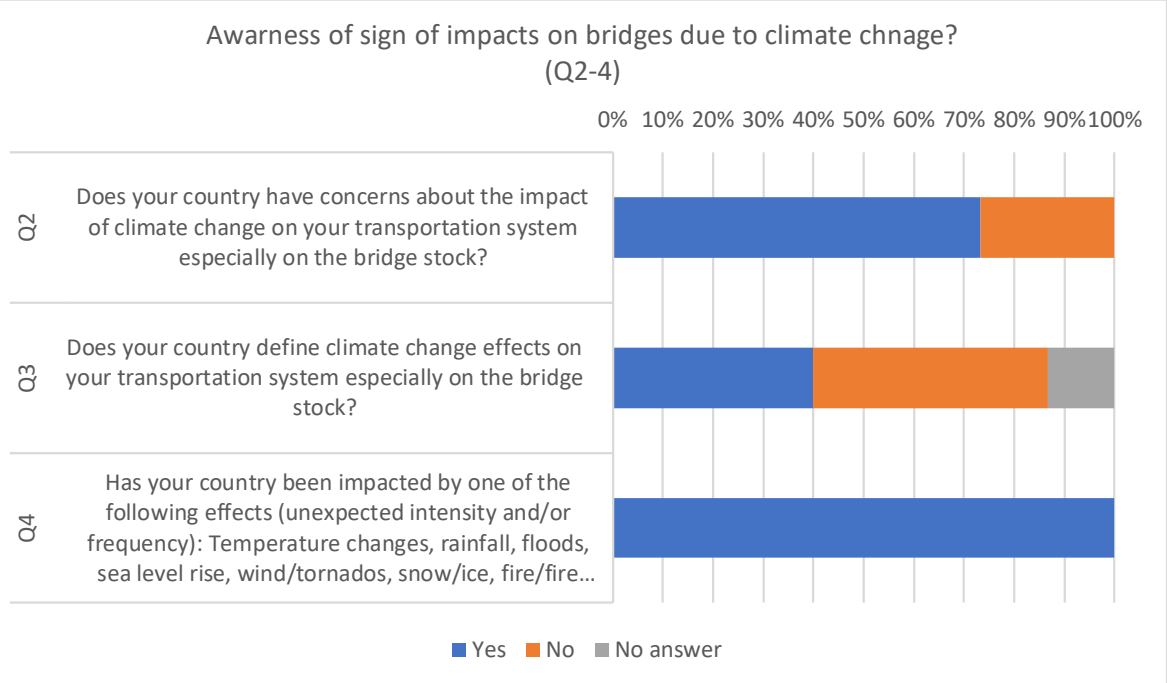


Figure 2. Country responses with respect to Question 2 to 4

Table 3: Impact due to different effects of climate change

	Temperature changes	Rainfall	Floods/Debris current/high water	Sea level rise	Wind/tornados	Snow/ice	Fire/fire storms	Tropical storms
Austria		x	x					
Belgium	x	x	x					
Chile	x	x	x				x	
China (Beijing)	x	x	x	x	x	x	x	x
China (Wuhan)		x			x			
Hungary		x	x					
France	x	x	x	x	x	x	x	x
Germany	x	x	x					
Japan	x	x	x	x	x			x
Netherlands	x	x	x	x				
Niger	x	x	x					
Norway	x	x	x	x	x			
Portugal			x				x	
Slovenia			x					
USA Utah	x	x	x	x	x	x	x	x

	Temperature changes	Rainfall	Floods/Debris current/high water	Sea level rise	Wind/tornados	Snow/ice	Fire/fire storms	Tropical storms
Total	10	13	14	6	6	3	5	4

4.1.3. Impacts of climate change on bridges, Questions 5 to 11 and 13

Seven questions (Questions 5 to 11) dealt with the impacts of climate change on bridges. An extra question (Question 13) sought information about specific impacts to bridge structures. The responses with respect to Questions 5 to11 and 13 are presented in Figure 3 and Appendix B.

Temperature differences, Question 5

Five countries (33%) responded that they have had impacts on bridges due to extreme temperature differences. France, Germany, the Netherlands and Portugal have experienced problems with expansion joints due to temperature differences especially on older bridges. Germany reported that some expansion joints and bearings were exceeding their operational limit on hot summer days. Portugal encountered problems with expansion joints on some older long steel bridges. However, other countries responded that although they have temperature fluctuations, they do not have problems on bridges under current conditions. For example, Hungary responded they do not experience extreme temperatures which exceed the design assumptions for their bridges. Japan responded that the temperature is rising, but it has not had a significant impact on bridge behavior.

Rainfall/floods, Question 6

Question 6 dealt with the impacts on bridges due to rainfall/floods. Fourteen countries and states except for Austria responded “Yes” that they have experienced impacts due to rainfall/floods. Many countries reported problems due to scour, undermining, uplifting, wash out and collapse due to floods (Chile, China-Beijing, China-Wuhan, Hungary, Germany, Japan, Netherlands, Niger, Norway, Portugal and Slovenia). Other issues reported for bridges due to increased rainfall include impact due to movement of big rocks in Chile and adjustments needed to rainwater drainage systems in the Netherlands.

Sea level rise, Question 7

Only two countries (About 10%), Chile and the Netherlands, reported impacts due to Sea Level rise. Tidal waves and frequency of unpredicted waves were increased in Chile. More extreme fluctuation in water levels has resulted in a reduced clearance between the water level and bridge superstructure which may result in more allisions. Other countries responded that they had experienced sea level rise, but that current sea levels have not affected bridge condition, maintenance nor design (China-Beijing, China-Wuhan, France, Germany and Japan). Four countries and states, Austria, Belgium-Wallonia, Hungary and Niger, are not impacted by the sea.

Wind/tornados, Question 8

Six countries and states (40%), China-Beijing, China-Wuhan, Japan, the Netherlands and Niger, reported that they have impacts on bridges due to wind/tornados. China-Beijing has experienced severe windstorms during bridge construction and operation. In addition they responded that the frequency of strong winds had increased in areas that are less susceptible to strong winds. Japan reported that vessels have allided with bridges due to strong typhoons. In the Netherlands, they are trying to model wave force impact due to sea level rise in combination with heavy storms.

Snow/ice, Question 9

Three countries and states, Chile, France, and USA-Utah, responded they have impacts on bridges due to snow/ice. However, in one case the impacts were not severe (Chile). Austria responded that avalanche galleries were present and they have a management system for natural hazards. China-Beijing responded that avalanches have not affected bridge behavior. Belgium and Japan indicated a decrease in the amount and frequency of snow. However, several countries reported the effects of de-icing salt and increasing frequency of freeze/thaw cycles (Austria, China-Beijing and Hungary). It is noted that there are three countries and states including Niger and Portugal where no snow/ice is expected.

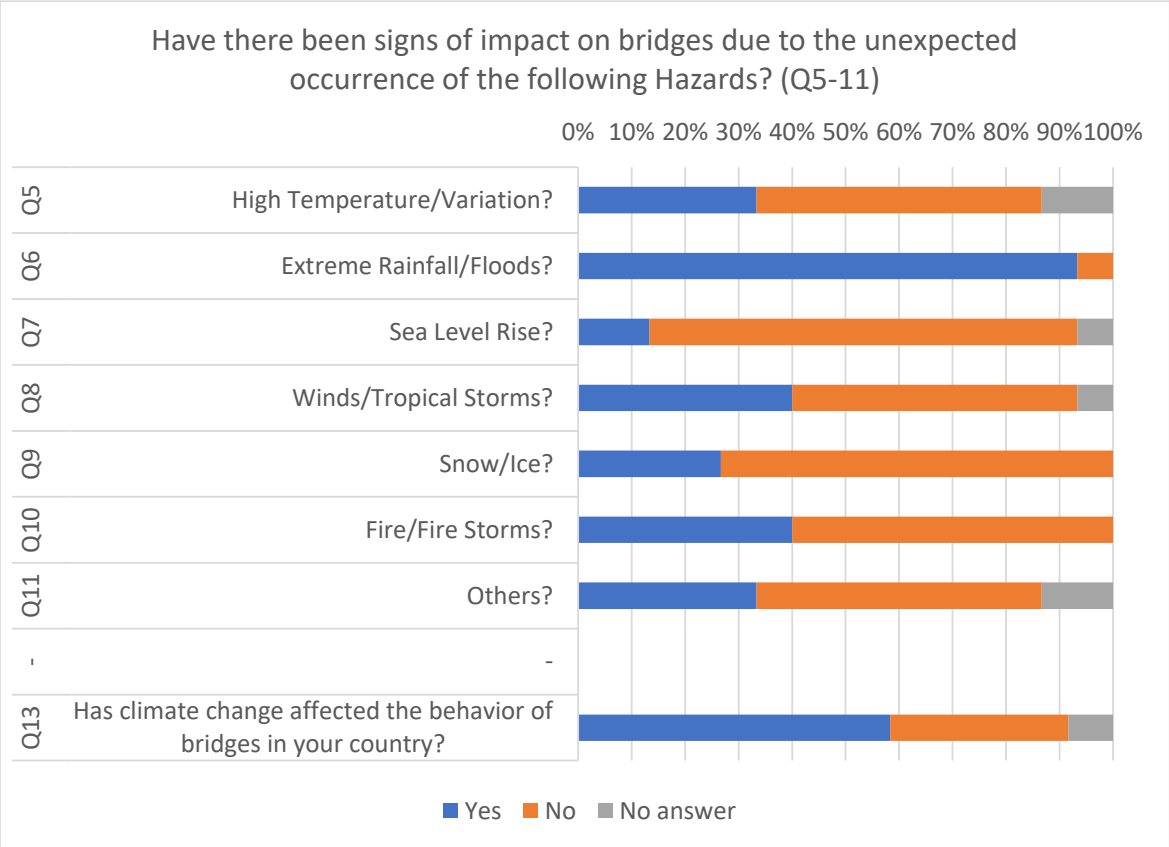


Figure 3. Country responses with respect to Questions 5 to 11 and 13

Fire/Fire storms (Question 10)

Six countries and states, Chile, China-Beijing, China-Wuhan, France, Portugal and USA-Utah, answered that they have impacts on bridges due to Fire/Fire storms. In Chile, the frequency of fire storms and significant forest fires has increased, especially in the central and southern parts of the country. In China-Beijing, the impact of fire on bridges is significant including fires due to traffic

accidents, fires of combustible deposits near bridges and fires that have occurred during construction. On the other hand, Hungary reported that they have a few fire events on/under bridges due to vehicle failures/collisions but not many impacts to bridges.

Others (Question 11)

Other impacts on bridges due to effects of climate change are reported from Belgium, China-Beijing, Germany, the Netherlands and Niger. Belgium has concerns about pavement deformation in hot summer. In China-Beijing, freeze-thaw effects in cold regions were identified for concrete structures. On the other hand, Germany is concerned that dryness will change the properties of soil from the original parameters assumed in the design. The Netherlands is also concerned that drought may cause the foundations of wooden piles to rise and float above the ground water level.

Behavior of bridge, Question 13

This question concerned special impacts on bridge structures due to climate change. Ten countries responded that the behavior of bridges has been affected by climate change. Belgium, Chile, France, Germany and Japan have experienced impacts on bridge behavior due to flooding and/or scour. In addition, rock impact and uplifting on bridge superstructures has occurred in Chile. Durability issues were encountered in China (corrosion due to the increased application deicing salt) and France (accelerating aging phenomenon). China, Japan and the Netherlands reported that their bridges have been affected by heavy storms. These effects have been combined with sea level rise in the Netherlands. High temperature introduced drought conditions and decreasing groundwater levels have put wooden piles are at risk in the Netherlands. On the other hand, Hungary responded that bearings and expansion joints have not yet been affected due to climate change. As a result, it was concluded that there are a variety of impacts on bridge behaviors in difference countries consistent with their location and prevailing weather.

4.1.4. Recycle materials, Government policy, Bridge design code and Specific research program, Questions 12, 14, 15 and 16

Recycle materials, Question 12

Question 12 asked about how countries and states use recycled materials so as to reduce the carbon footprint (total CO2) of construction. Several countries and states including Austria, China, Hungary and Slovenia, replied that pavement materials have effectively incorporated recycled materials. However, in bridge construction, it was reported that recycled materials are not used much . Responses included “Recycled concrete is not used for bridge constructions due to the high-quality requirements” (Austria), “For new bridges we use recycling concrete only for some foundations” (Germany), and “Recycled materials are not common in bridge structures” (Hungary).

In order to use recycle materials on bridges, it is important to note that “old bridges usually cannot be recycled because the concrete contains asbestos or the steel has contaminated coatings” (Germany).

Several countries and states have already established a policy and started assessment programs to promote the recycling of construction waste. Austria assesses greenhouse gas potential (Global Warming potential) in the field of asphalt production or steel production, including transport to the construction site. The Netherlands prepared a document on “Making Concrete More Sustainable” and based on this document are responsible for processing demolished concrete to ensure it can

be reused in new concrete. In Portugal, they use at least 10% recycled materials or components that incorporate recycled materials in all Public Works projects.

Government policy, Question 14

Question 14 asked what Government policy is in place in each country. Climate change has become a global issue of concern. Most countries identified impacts to bridges from climatic change, so about 80% of responses indicate they have government policies relating to climate change. Within countries which have governmental policy, some countries responded that they have their own national policy but other countries responded that they follow the regional policy such as Euro policy.

Bridge design codes, Question 15

According to the answers to question 15, no country has developed a specific design code referring to climate change. However, several countries are going to take into account climate change in the development of a new bridge design code (Hungary), an audit of increased flooding (Germany), and the adjustment of rainwater drainage requirements (Netherlands). Some countries considered the affects of climate change on inspection procedures. Japan prepared a reference manual for scour, and Portugal now includes underwater bridge inspection in their Bridge Management System.

Specific research, Question 16

As a result of the answers to question 16, it was found that about 60% of responses (Austria, Chile, China, France, Germany, Japan, Norway, and USA-Utah) indicate that they are running specific research programs on impacts to bridges resulting from climate change. It should be noted that Austria and Norway have introduced projects to reduce carbon footprint related to cement production, but this is an effort to reduce climate change factors, which is slightly different from the impact on bridges due to climate change.

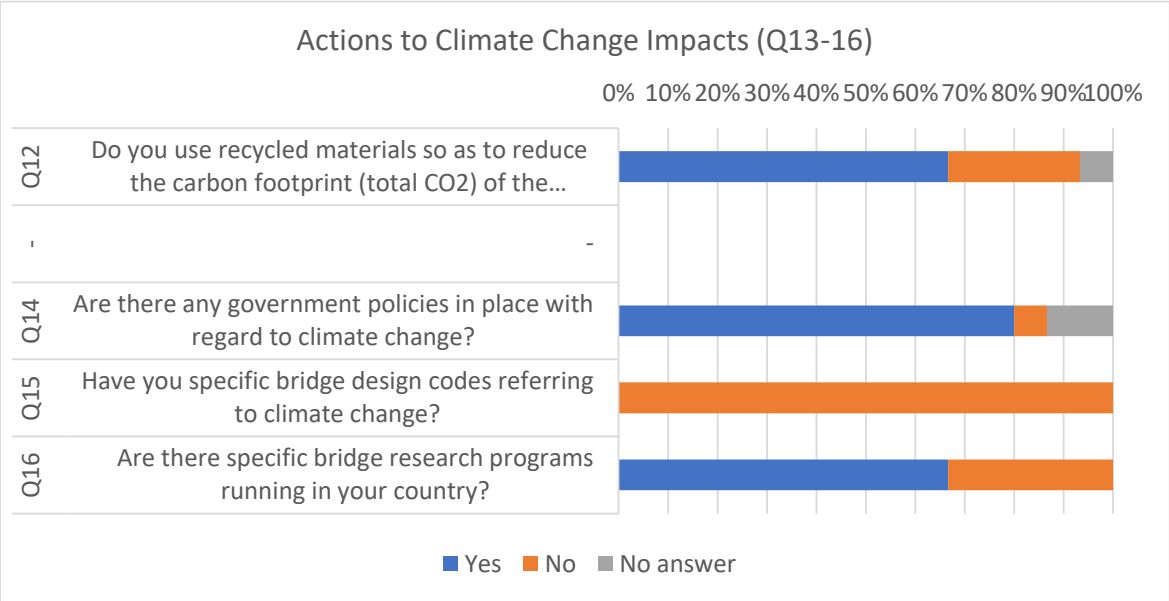


Figure 4. Country responses with respect to Questions 12 to 16

4.2. CASE STUDIES

Nineteen case studies were collected with the answers to the general questions. This chapter includes a summary and classification of the nineteen case studies, and identifies the relationships among climate, hazards and impacts on bridges by using a mind mapping analysis.

4.2.1. Summary and classification of case studies

The content of each case study was carefully reviewed and evaluated and then summarized on a cover sheet created by TC 4.2 members. Contents of the cover sheet include Photos, Description of bridge, and Impact due to Climate change. In addition, in order to classify each case study, they were evaluated by applying the following categories with respect to Climate, Hazards, and Impacts on bridges.

- Climate: Precipitation, Temperature, Wind, Sea level rise
- Hazards: Heavy precipitation, River flooding, Flash flood, Debris current, Erosion, Heat (waves), High temperature, Daily temperature range (DTR), Drought, Storms, Tropical storms, Gusts, Ocean waves
- Impacts on bridges: Scouring, Extreme load impact, Settlement, Clearance under bridge, Insufficient drainage capacity, Slope stability, Material evolution, Temperature gradients, Expansion, Dynamic load

Appendix C includes all case studies and cover sheets. Table 4 summarizes the information included on the coversheets including country, description of events, and classifications with respect to Climate, Hazards and Impact on bridges.

Table 4: Classification Case Studies with respect to Climate, Hazards and Impacts on bridges

#	Country	Description of events	Classification		
			Climate	Hazards	Impact on bridges
01	Belgium (1)	High flooding caused the bridge to move laterally by 0.5 to 1.3 m	Precipitation	River flooding, Flash flood, Debris current	Scouring, Extreme load impact
02	Belgium (2)	Flooding caused the central pile of Arch Bridge to be partly collapsed	Precipitation	River flooding, Flash flood, Debris current	Scouring, Extreme load impact
03	Chile	Superstructure of the bridge moved 500m due to alluvium	Precipitation	River flooding, Flash flood, Debris current	Scouring, Extreme load impact
04	China	Heavy rainfall caused slope instability and lateral displacement of pier	Precipitation	Heavy precipitation	Slope stability
05	France (1)	Localized corrosion of Steel Culvert due to tidal level	Precipitation, Temperature	Heavy precipitation, Drought, Heat (waves)	Material evolution
06	France (2)	Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m	Precipitation	River flooding, Flash flood,	Settlement, Scouring,

#	Country	Description of events	Classification		
			Climate	Hazards	Impact on bridges
				Erosion, Debris current	Extreme load impact
07	France (3)	Vertical and almost entire height visible cracks on high Piers	Temperature	High temperature, Heat (waves)	Temperature gradients
08	France (4)	Pier foundation protection against Sea level rise and high waves	Sea level rise	Storms, Ocean waves	Scouring, Extreme load impacts, Dynamic load
09	Germany	Floods caused pier subsidence and resulted the bridge in a skewed position	Precipitation	River flooding, Flash flood, Erosion, Debris current	Settlement, Scouring, Extreme load impact
10	Japan (1)	Extensive scouring in the concrete revetment and the pier foundation	Precipitation	River flooding, Flash flood, Erosion, Debris current	Scouring
11	Japan (2)	Tanker ship collided with the bridge due to typhoon	Wind	Tropical storms, Gusts, Ocean waves	Extreme load impact
12	Netherlands (1)	Space for the river program (Raise the elevation of the bridge)	Precipitation, Temperature	Heavy precipitation, River flooding, Flash flood, Erosion	Clearance under bridge
13	Netherlands (2):	Temperature expansion (combined with unforeseen settlement)	Temperature	Heat (waves)	Expansion
14	Niger	Silting under a bridge in the Galmi valley	Precipitation	Heavy precipitation, River flooding, Flash flood, Erosion	Clearance under bridge
15	Norway	Floods reduced and removed erosion protection	Precipitation	River flooding, Flash flood, Erosion, Debris current	Scouring,
16	Portugal (1)	High rain-wind induced vibration on stay cables	Wind	Storms, Gusts	Dynamic load
17	Portugal (2)	Impact on steel bridges due to extreme temperature differences	Temperature	Heat (waves)	Expansion

#	Country	Description of events	Classification		
			Climate	Hazards	Impact on bridges
18	Portugal (3)	Heavy rains and increase drainage capacity	Precipitation	Heavy precipitation	Insufficient drainage capacity
19	Switzerland	Pavement and waterproofing of decks were deformed and leaked.	Temperature	Heat (waves), Daily temperature range (DTR)	Material evolution

4.2.2. Climate, Hazards and impacts on bridges

The classification of Climate, Hazards and Impact on bridges are related and represented by causes and consequences. For example, hazards are due to climate, and hazards cause impacts on bridges. The information in Table 4 of the causes of climate impact on bridges is summarized on Figure 6. It can be seen that 12 case studies resulted from precipitation, and 6 case studies were due to temperature. The last 3 case studies were due to wind (2) and sea level rise (1). Based on these limited case studies, many countries and states believe that they are experiencing impacts on bridges due to increased precipitation and temperature.

As for the hazards, Figure 7 presents the climate generated hazards that caused impacts to bridges. It was reported that river flooding, flash floods, debris current, erosion and heavy rain are major hazards to bridges and are all due to increased precipitation. The next reported hazards in priority include heat (waves), storms, ocean waves, gusts, drought, high temperature, daily temperature range (DTR) and tropical storms. All of these hazards are due to Wind, Temperature and Sea level rise.

Figure 8 presents the impacts to bridges due to climate change. The major two impacts to bridges are scour and extreme load impacts which are mainly due to river flooding, flash floods and debris currents. Those impacts are followed in priority by settlement, clearance under bridge, material evolution, dynamic load and expansion. Based on the responses, it seems that many bridge engineers believe that bridges are affected by scour and extreme load impacts due to river flooding and flash floods.

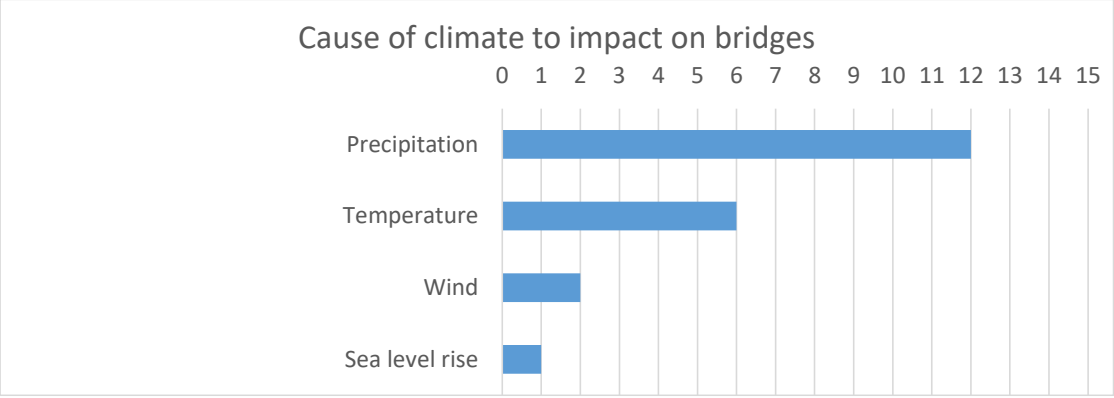


Figure 6: Climate which caused impacts on bridges based on case studies

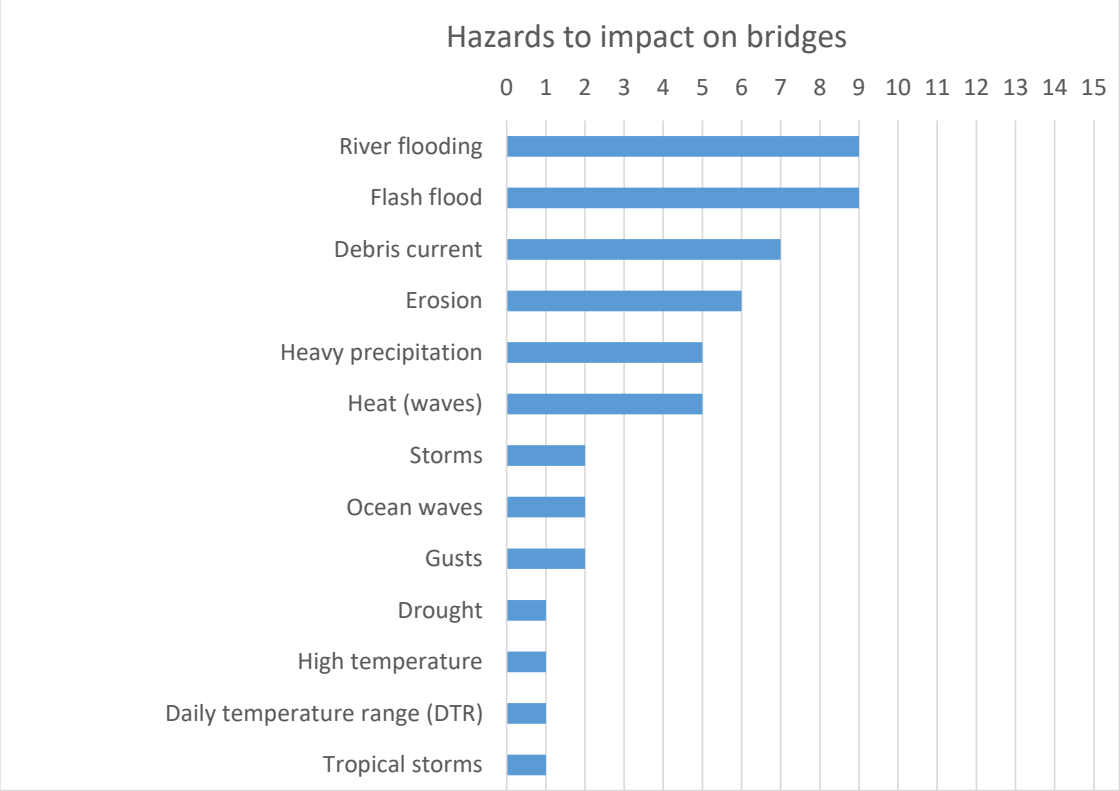


Figure 7: Hazards to introduce impacts on bridges

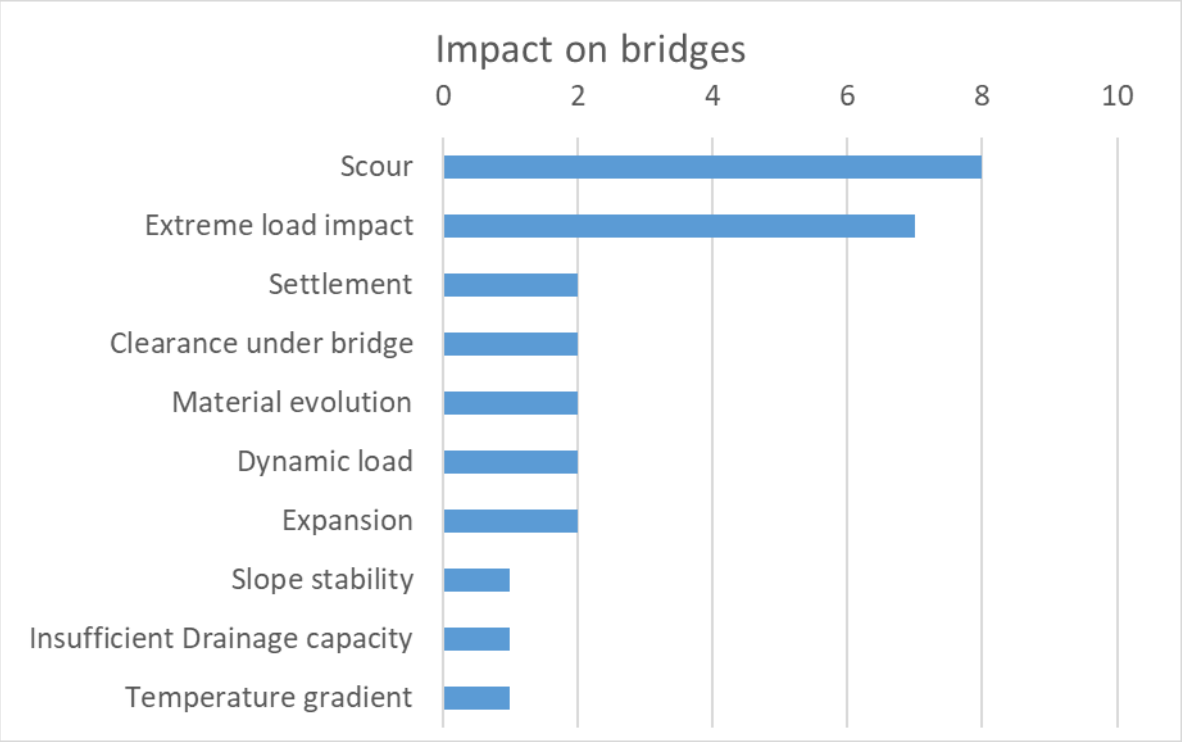


Figure 8: Impacts on bridges due to climate change

4.2.3. How climate change impacts bridges

The case studies were used to identify the relationship between Climate, Hazards and Impacts to bridges using a mind mapping analysis. The results of that mind mapping analysis are presented in Figure 9. The intent of this figure is to make it easier for bridge engineers to understand the impacts of climate change on bridges.

Bridge engineers are able to control and take measures against Scour, Settlement, Extreme load impact, Slope stability, Bridge Clearance, Bridge drainage, Bridge expansion, Material degradation as well as Extreme dynamic load. However, bridge engineers are not able to control hazards such as coastal flooding, river flooding, heavy precipitation, icing, flood debris, bare soil, drought/low soil moisture, fire, heat (waves) daily temperature range, tropical storms, oceanic waves and gust.

All of these hazards are due to either sea level rise, or increases in precipitation, temperature and/or wind. Based on this classification and mapping of causes and consequences, it becomes clear that bridge engineers must develop a better understanding of how climate change impacts bridges. At first, bridge engineers need to understand what can be controlled and what measures against climate change can be taken. Secondly, bridge engineers need to understand that impacts on bridges are due to hazards and climate. Finally, it is important to pay attention to the trend of climate change in order to make structures more resilient.

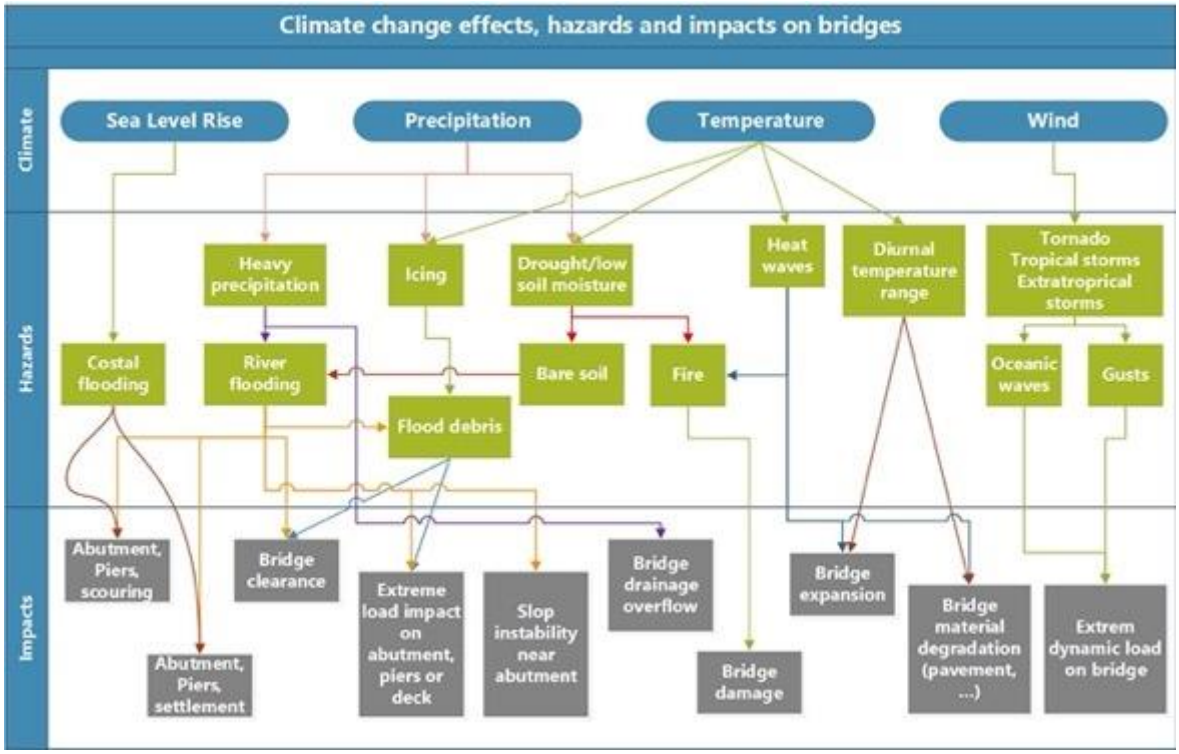


Figure 9: Relations among Climate, Hazards and Impact on bridges

5. CONCLUSIONS

5.1. GENERAL QUESTIONNAIRE

Responses to the general questions are mainly from Europe including Austria, France, Germany, Hungary, Netherlands, Norway, France Portugal and Slovenia. Responses were also recieved from Africa (Niger), Asia (China-Beijing, China-Wuhan and Japan), North America (USA-Utah), and South America (Chile).

According to the responses, all countries have experienced and been impacted due to different effects of climate change.

Many countries believe that bridges are also being affected and, in particular, countries recognize that bridges are being affected by flooding and scour. They also believe that wind/tornados, fire/fire storms and high temperatures/variation have impacted bridge behaviors.

Furthermore, the Netherlands, which is low in elevation, has raised the issue of sea level rise as an impact on bridges from climate change, while Japan and China, which are affected by tropical storms, have raised the issue of wind effects.

As measures to deal with these impacts are developed, it is necessary to prepare and revise current bridge design codes to incorporate these measures so bridges can accommodate these impacts. However, no country responded that they have revised and/or adjusted their design codes as a result of climate change although several have research projects underway.

5.2. HOW DOES CLIMATE CHANGE IMPACT BRIDGES?

The case studies were used to identify the relationships between Climate, Hazards and Impact on bridges which are summarized in Figure 9. The authors expect that Figure 9 will help bridge engineers understand climate change impacts on bridges.

Bridge engineers are able to control and take measures against scour, settlement, extreme load impact, slope stability, bridge clearance, bridge drainage, bridge expansion, materials degradation as well as extreme dynamic loads, and so on. However, bridge engineers are not able to control hazards such as coastal flooding, river flooding, heavy precipitation, icing, flood debris, bare soil, drought/low soil moisture, fire, heat (waves) daily temperature range, tropical storms, oceanic waves and gusts.

All of these hazards are due to either sea level rise or increased precipitation, temperatures and/or wind. Bridge engineers are not able to control these hazards due to climate change. Based on this classification and the mind mapping of cause and consequences, it becomes clear that bridge engineers must develop an understanding of how Climate Change impacts bridges. Engineers need to pay attention to these relationships to understand the impacts of climate change on bridges as well as to make structures more resilient.

6. RECOMMENDATION

Bridge engineers need to accumulate knowledge about the impacts of climate change on bridges including the quantification of hazards and impacts. As climate change is an evolving phenomenon, this will probably take years and even decades.

However, it is not necessary to wait to collect all of that knowledge before adapting design codes for existing and new bridges to account for the impacts of climate change even if there will be some uncertainties. The adaptations of design codes may include actions and design details that increase the resilience of bridges to impacts due to climate change.

Since these impacts are the consequence of climate change effects, it is very difficult to quantify these impacts currently. Therefore, it is important to apply a risk management framework in order to adapt impacts of climate change on bridges under the current circumstances. A prioritization by risk assessment may support bridge owners in making decisions in order to increase the resilience of bridge stocks. It is recommended that the bridge management system consider these impacts.

7. GLOSSARY

The following terms come from the World Road Association (PIARC), Technical Committee E.1 - Adaptation Strategies and Resiliency [4]. These are prepared and provided as a reference for related PIARC Technical Committees to assist in the development of products.

Term	Definition
Adaptation	Adaptation is adjustment within natural or human systems in response to actual or projected climatic stimuli or their effects, which aims to moderate harm or exploit beneficial opportunities (PIARC Framework, 2015).
Consequence	Outcome of an event affecting objectives. An event can lead to a range of consequences. A consequence can be certain or uncertain and can have positive or negative effects on objectives (ISO, 2009).
Criticality	The relevance of an infrastructure element or section to the availability of a road infrastructure system. Note: Based on All-Hazard Guide for Transport Infrastructure, 2015
Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected (Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, IPCC, 2012).
Frequency	Measure of the likelihood of an event expressed as a number of events or outcomes per defined unit of time (ISO, 2009).
Hazard	A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. (UNDRR) A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural or induced by human processes. (Sendai Framework 2015).
Likelihood	Chance of something happening (ISO, 2009). ISO uses the word "likelihood" to refer to the chance of something happening, whether defined, measured or determined objectively, subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as probability or a frequency). See “Frequency” and “Probability”
Probability	Impact probability relates to the likelihood of an impact occurring within a given timeframe (PIARC Framework, 2015). Measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty (ISO, 2009).

Term	Definition
Resilience	The ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events. Note: Definition developed by the study committee based on the extant literature and is consistent with the international disaster policy community (UNISDR, 2011), U.S. governmental agency definitions (SDR, 2005; DI-IS Risk Steering Committee, 2008; PPD-8, 2011), and NRC (2011).
Risk	Effect of uncertainty on objectives. Risk is often characterized by reference to potential events, consequences, or a combination of these and how they can affect the achievement of objectives. Risk is often expressed in terms of a combination of the consequences of an event or a change in circumstances, and the associated likelihood of occurrence (ISO, 2009).
Risk analysis	Process to comprehend the nature of risk and to determine the level of risk. Risk analysis provides the basis for risk evaluation and decisions about risk treatment (ISO, 2009).
Risk Management	Coordinated activities to direct and control an organization with regard to risk (ISO, 2009).
Sensitivity	Is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (PIARC Framework, 2015).
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (PIARC Framework, 2015).

8. REFERENCES

[1] World Road Association (PIARC), Technical Committee D.3 - Road Bridges, “Adaptation to climate change for bridges”, PIARC Reference 2011R08EN, Paris, 2011, 68pp

[2] World Road Association (PIARC), Technical Committee 4.2 - Road Bridges, “Adaptation of road bridges to climate change”, PIARC Reference 2017R03EN Paris, 2016, 14 pp.

[3] World Road Association (PIARC), Special Project, “International Climate Change Adaptation Framework for Road Infrastructure”, PIARC Reference 2015R03, Paris, 2015, 88pp.

[4] World Road Association (PIARC), Technical Committee E.1 - Adaptation Strategies and Resiliency, “Refinement of PIARC’s International Climate Change Adaptation Framework for Road Infrastructure”, PIARC Reference 2019R03EN Paris, 2019, 66pp.

APPENDIX A: QUESTIONNAIRE: TC4.2.1 MEASURES FOR INCREASING RESILIENCE TO CLIMATE CHANGE

There are already signs of extreme weather in certain parts of the world including droughts, heavy rain, windstorms and tropical cyclones. The frequencies of some of these events are also increasing.

In general, there are extreme natural events being experienced in many countries resulting in loss of lives and loss or damage to infrastructure.

Climate change has become a global issue of concern and it is for this reason that PIARC has incorporated it into the strategic themes and technical committee bridges for the terms of 2008-2011 and 2012-2015.

With regard to road bridges, concerns associated with climate change are the extreme day and night air temperatures causing expansion and contraction of bridge superstructures, frequency and intensity of rainfall (causing major flooding and landslides), windstorms, wild fires, storm surge, wave forces and so on.

Importantly, however, it is difficult to quantify these events because there is very limited information collected about them. Without information, taking these events into account in bridge design and maintenance is challenging.

To meet that challenge, it is important to, first, investigate how the various countries quantify the effects of climate change on their bridge stock, and second, to share case studies associated with repair/rehabilitation and/or monitoring/inspection that are intended to mitigate the effects of climate change and, in doing so, increase bridge resilience.

Your contributions are very useful for all road and bridge owners as well as bridge engineers.

So, please complete the following questionnaire as well as the template for each case study you want to share.

Your answer up to 20 April 2022 are very welcome to complete our work.

Please kindly submit your response to hgil@ex.co.kr and kiyohiro-imai@jb-honshi.co.jp

All data collected will be compiled and discussed by TC road bridge committee members in a case study report available for free in 2022 on the PIARC website: www.piarc.org.

Issue 4.2.1 Questionnaire – Measures for increasing resilience to climate change – General questions

Contact person	Give the name and contact information of the person who can provide additional information if necessary (e-mail, address, phone)
Answer	Name: E-mail: Address: Phone:
These personal data will not be published into public PIARC report. They will only be used by TC 4.2 Road Bridges members if additional information is required to fully understand the answer.	

QUESTION 1: What kind of climate change did your country experience during the last decade?

QUESTION 2: Does your country have concerns about the impact of climate change on your transportation system especially on the bridge stock? (Yes or No)

QUESTION 3: Does your country define climate change effects on your transportation system especially on the bridge stock? (Yes or No) If so, how do you define climate change effects on the bridge stock?

QUESTION 4: Has your country been impacted by one of the following effects (unexpected intensity and/or frequency): Temperature changes, rainfall, floods, sea level rise, wind/tornados, snow/ice, fire/fire storms, tropical cyclones, others?

QUESTION 5: Temperature: Have there been signs of impact on bridges due to extreme temperature differences i.e., day-time to night-time temperature differences exceeding the limits assumed during design?

QUESTION 6: Rainfall/floods: Have there been signs of impact on bridges due to the occurrence of unexpected rainfall? Floods? Mudslides? Scour?

QUESTION 7: Sea level rise: Have there been signs of impact on bridges due to increasing in the sea level rise? Tidal waves?

QUESTION 8: Wind/tornados: Have there been signs of impact on bridges due to the occurrence of severe wind conditions during construction or service in the last decade? Are the frequencies of severe wind events increasing in areas that were less prone to wind?

QUESTION 9: Snow/ice: Have there been signs of impact on bridges due to the unexpected occurrence of avalanches? Have there been signs of impact due to increasing de-icing products?

QUESTION 10: Fire/Fire storm: Have there been signs of impact on bridges due to the unexpected occurrence of fire? Fire storms?

QUESTION 11: Others: Have there been signs of impact on bridges due to effects of climate change other than listed above?

QUESTION 12: Do you use recycled materials so as to reduce the carbon footprint (total CO2) of the construction? How do you reduce the carbon footprint (total CO2) in your bridge construction project?

QUESTION 13: Has climate change affected the behaviour of bridges in your country? If yes, how and which elements of the bridge construction did they affect? Superstructure? Substructure? Bridge components (e.g., bearings, expansion joints)?

QUESTION 14: Are there any government policies in place with regard to climate change?

QUESTION 15: Have you specific bridge design codes referring to climate change, if yes: Please provide a copy or a link. When were these implemented? Are there similar regulations for management of the existing bridge stock?

QUESTION 16: Are there specific bridge research programs running in your country on the subject of climate change?

QUESTION 17: Are there any specific case studies associated with issues on road bridges due to climate change that you can share? If so, please fill out the attached template including the repair/rehabilitation methods and/or inspection/monitoring techniques used to mitigate the effects of climate change. (Please refer to the attached example)

Issue 4.2.1 Template – Measures for increasing resilience to climate change - Case studies

This case study template is related either to repair/rehabilitation or to monitoring/inspection of road bridges against climate change.

PS: photos and illustrations must be free of copyright.

Case: *give a name*	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	
Picture of the problem	
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion

Case: *give a name*	
Answer	
Pictures of the repair/rehabilitation materials and technologies	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	

Case: *give a name*	
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

APPENDIX B: ANSWERS TO GENERAL QUESTIONS

Answers to general questions are tableted with respect to each question and answers are classified to “Yes”, “No” and “N/A (Not applicable)” by Technical Committee 4.2.

Question 1: What kind of climate change did your country experience during the last decade?

Country	Question 1: What kind of climate change did your country experience during the last decade?
Austria	Heavy rainfall, floods (Tornado in the Czech Republic near the Austrian border on June 24th 2021)
Belgium	Flooding and high heat period during summer. Winter with less cold temperature and less snow.
Chile	Heavy rainfalls on desert zone, fire forest, debris currents, landslide, tsunami/oversize waves
China-1 (Beijing)	China is an area sensitive to global climate change and is significantly affected by it. The annual average temperature of the ground surface shows a significant upward trend, and the rate of temperature rise is significantly higher than the global average level in the same period. The annual average rainfall is in an increasing trend and the variation of rainfall is significant in different zones of the country.
China-2 (Wuhan)	Heavy rain, windstorms and typhoon happens with small probability during the last decade in China.
Hungary	Significant, unexpectedly heavy rainfalls leading to bridge defects and embankment damages caused by sudden floods.
France	In metropolitan area: Flood, scouring, Fires, heavy increase of temperatures, strong local storm, In over sea islands: Number of cyclones, temperatures, sea level rise, effort and swell level
Germany	local heavy rain, flooding, extreme winds
Japan	<u>Temperature</u> Annual mean temperatures observed at 15 sites in Japan that are less affected by urbanization increased at a rate of 1.24°C per 100 years between 1889 and 2019. The number of extremely hot days and tropical nights increased and the number of winter days decreased between 1910 and 2019. In particular, the number of extremely hot days increased significantly after the mid-1990s. <u>Precipitation</u> Significant increase in the frequency of heavy and short duration intense rain events and decrease in the number of days with rainfall. On the other hand, there is no statistically significant long-term change trend in annual or seasonal precipitation (total). <u>Snow</u> Observation data since 1962 show a decreasing trend in the annual maximum snow depth (the most snow accumulated in a winter) and a decreasing trend in the annual number of days with a daily snowfall of 20 cm or more. <u>Typhoon</u>

Country	Question 1: What kind of climate change did your country experience during the last decade?
	No long-term changes in the number of typhoons or the number of typhoons approaching or making landfall in Japan have been observed. No long-term changes are seen in the number of typhoons with intensity of "strong" or higher, or in the ratio of such intensity to the total. The latitude at which typhoons near Japan reach their lifetime maximum intensity has shifted northward. <u>Sea Level</u> Global mean sea level rose about 0.16 m between 1902 and 2010 (due to sea water expansion associated with melting of ice sheets and glaciers and rising water temperatures). The rate of rise during 2006-2015 was about 3.6 mm/year, 2.5 times the rate of rise during 1901-1990. Long-period fluctuations (likely natural variations) predominate along the Japanese coast, but a clear upward trend is seen only after 1980. There is no significant long-term trend in the number and magnitude of storm surges along the Japanese coast. Wave heights tend to increase for storm surges along the Japanese coast, and the amount of change is larger on the Pacific side.
Netherlands	local heavy rain, flooding, extreme temperature fluctuations, drought, extreme winds
Niger	Flooding and soil erosion resulting in silting of waterways
Norway	There are many typical experiences during the last decade. Below is a list of some of the most typical changes: 1. Rise of average temperature. This means that many parts of the country where we used to have snow with temperatures below zero now shift more below and over zero degrees centigrade. The result is less snow and more ice and difficult conditions for walking and cycling. 2. More heavy local rain. We experience more local rain and have lost several small bridges to flood and mudslides. There are frequent floods in areas known as dry areas with small brooks growing to rivers within hours. 3. More frequent winter storms 4. Trees are growing on higher altitude than they used to. 5. The winter season is shorter than it used to be.
Portugal	Heat waves; extreme wind, storms; shorter and more intense precipitation events.
Slovenia	Flooding. Short storms with heavy rainfall.
USA Utah	Unknown

Country	Heavy rainfall	Floods, Scouring,	Fire	Debris current	Land slide	Tsunami,	Extreme wind,	Temperature	Sea level rise	Dry. Drought
Austria	X	X								
Belgium		X						X		
Chile	X		X	X	X	X				
China-1 (Beijing)	X							X		
China-2 (Wuhan)	X						X			
Hungary	X	X								
France		X	X				X	X		
Germany	X	X					X			
Japan	X						X	X	X	
Netherlands	X	X					X	X		X
Niger		X								
Norway	X						X	X		X
Portugal	X						X	X		
Slovenia	X	X					X			
USA Utah										
Sum	11	8	2	1	1	1	8	7	1	2

Question 2: Does your country have concerns about the impact of climate change on your transportation system especially on the bridge stock? (Yes or No)

Country	Classification of answers	Question 2: Does your country have concerns about the impact of climate change on your transportation system especially on the bridge stock? (Yes or No)
Austria	No	No
Belgium	Yes	Yes
China-1 (Wuhan)	Yes	Yes

Country	Classification of answers	Question 2: Does your country have concerns about the impact of climate change on your transportation system especially on the bridge stock? (Yes or No)
China-2 (Beijing)	Yes	Yes. In recent years, bridges in Mainland China have encountered the problems of insufficient structural resistances against disasters including earthquakes, floods, mudslides, landslides and other disasters, as well as extreme terrorist attacks. Over a thousand bridges were destroyed by water flooding every year. In 2018, the flooding of "Bage Barrier Lake" caused more than 30 bridges damaged along the Jinsha River. In China, there are around 6,000 extra-large bridges and more than 500 large-scale river/sea crossing bridges. BUT only a few of them have been equipped with network based monitoring system, and early warning and safety prevention control systems have not been established for most of the major infrastructures. The major bridge structural resistances against disaster and attack by explosion have to be improved. A large number of reinforced concrete bridges generally have problems such as insufficient concrete covers, poor detailing for structure durability, and existence of concrete defects. The bridge structures deteriorated significantly, and resulted in early occurrence of structural deficiencies. Extensive repairs are required in coming 10 to 15 years for some bridges located at coastal environments and northern area with deicing salt environments.
China	Yes	Yes
Hungary	Yes	Yes
France	No	No
Germany	Yes	Yes
Japan	Yes	Yes
Netherlands	Yes	Yes
Niger	Yes	Yes
Norway	Yes	Yes, we are concerned about climate change.
Portugal	No	Not specifically for bridges.
Slovenia	No	No
USA Utah	Yes	I assume in certain areas.

Question 3: Does your country define climate change effects on your transportation system especially on the bridge stock? (Yes or No) If so, how do you define climate change effects on the bridge stock?

Country	Classification of answers	Question 3: Does your country define climate change effects on your transportation system especially on the bridge stock? (Yes or No) If so, how do you define climate change effects on the bridge stock?
Austria	No	No
Belgium	No	No
Chile	Yes	Yes, we are under a funding project with university in order to define terminology associated with Climate Change, and define protocols of review the structures and action proposal (start on 2015)
China-1 (Beijing)	Yes	Yes. Meteorological disasters include typhoons, rainstorms, blizzards, cold waves, strong winds, sandstorms, high temperatures, droughts, lightning, hail, frost, heavy fog, haze, road icing, etc., which are generally classified according to the degree of harm, emergency and development situation as consequences. According to “Meteorological Disaster Warning Signals and Defense Guidelines” issued by China Meteorological Administration, four grades are classified: grade IV (general), grade III (heavier), grade II (severe), and grade I (extremely serious), which are indicated by blue, yellow, orange and red in colors respectively.
China-2 (Wuhan)	Yes	Yes, but there is no formal definition of climate change effects in transportation system, but some Chinese scholars are studying the effects of climate change on bridges. In China, the effects of climate change mainly include temperature changes, rainfall, floods, wind/typhoon, snow/ice, fire/fire storms, tropical cyclones, and more studies are under way on bridge structures.
Hungary	No	No
France	No	No

Country	Classification of answers	Question 3: Does your country define climate change effects on your transportation system especially on the bridge stock? (Yes or No) If so, how do you define climate change effects on the bridge stock?
Germany	Yes	Yes Movable bridges: - Expansion of the span due to higher temperature. - More extremes in strong winds, showers, which affects maintenance and condition (faster degradation of joint transitions, overlays) Fixed bridges: - for long bridges, the design of the rainwater drainage system is revised, because we are not allowed to discharge directly into the surface water in Germany - A derivative is also more and more extreme fluctuation in water levels, so that clearance heights are sometimes no longer guaranteed which can result in more collisions.
Japan	No	No. JSCE (Japan Society of Civil Engineering), however, is conducting research about impact of flooding on bridges since it occurs almost every year.
Netherlands	Yes	Yes • Movable bridges: - Expansion of the span due to higher temperature. - More extremes in strong winds, showers, which affects maintenance and condition (faster degradation of joint transitions, overlays) • Fixed bridges: - For long bridges, the design of the rainwater drainage system is revised, because we are not allowed to discharge directly into the surface water in the Netherlands. - A derivative is also more and more extreme fluctuation in water levels, so that clearance heights are sometimes no longer guaranteed which can result in more collisions. • high water levels in rivers have knocked several bridges off their supports • Due to fast currents, we have not yet discovered any undermining/scouring of the foundations.
Niger	N/A	-
Norway	Yes	Yes, we do. The most common measures are increased wind loads and increased height above water.
Portugal	No	Not specifically for bridges.
Slovenia	No	No
USA Utah	N/A	Unknown

Question 4: Has your country been impacted by one of the following effects (unexpected intensity and/or frequency): Temperature changes, rainfall, floods, sea level rise, wind/tornados, snow/ice, fire/fire storms, tropical cyclones, others?

Country	Classification of answers	Question 4: Has your country been impacted by one of the following effects (unexpected intensity and/or frequency): Temperature changes, rainfall, floods, sea level rise, wind/tornados, snow/ice, fire/fire storms, tropical cyclones, others?
Austria	Yes	Yes, Rainfall, floods
Belgium	Yes	Temperature changes, rainfall, floods
Chile	Yes	Yes, frequency of debris currents, intensive rainfall, fire forest, and Temperature changes.
China-1 (Beijing)	Yes	Yes. The above effects are all happening in our country.
China-2 (Wuhan)	Yes	Yes, the effects of rainfall, wind/typhoon happen in China
Hungary	Yes	Yes, sudden floods caused by intensive rainfall.
France	Yes	Yes
Germany	Yes	Yes • Warmer summers, heavy rainfall combined with high water has led to heavy flooding in some regions in Germany in July 2021. • High water levels in rivers have knocked several bridges off their supports or the foundation was undermined which has led to away breaking supports.
Japan	Yes	Yes (See answer to Question 1)
Netherlands	Yes	Yes: • Warmer summers, heavy rainfall combined with high water has led to flooding in Limburg July 2021 • Sea level rise has an impact on the functional life of our primary flood defenses; our storm surge barriers will close more often in a storm season, which in turn will lead to higher maintenance costs.
Niger	Yes	Temperature changes, unexpected rainfall, floods
Norway	Yes	Temperature changes: Yes (but not a major concern for bridges) Rainfall: Yes. More and heavier floods. Floods: Yes Sea level rise: Not so much. Not a major concern. Norway and Scandinavia are still rising after the last ice age 10.000 years ago. Wind: Yes – Increased wind loads. No tornados. Snow/ice: Not a major concern. Fire/fire storms: Not a major concern. Tropical cyclones: No Others: More difficult driving conditions because of temperatures shifting around freezing point.

Country	Classification of answers	Question 4: Has your country been impacted by one of the following effects (unexpected intensity and/or frequency): Temperature changes, rainfall, floods, sea level rise, wind/tornados, snow/ice, fire/fire storms, tropical cyclones, others?
Portugal	Yes	Floods and fires.
Slovenia	Yes	Yes, floods.
USA Utah	Yes	Yes

Question 5: Temperature: Have there been signs of impact on bridges due to extreme temperature differences i.e., day-time to night-time temperature differences exceeding the limits assumed during design?

Country	Classification of answers	Question 5: Temperature: Have there been signs of impact on bridges due to extreme temperature differences i.e., day-time to night-time temperature differences exceeding the limits assumed during design?
Austria	No	No
Belgium	No	No
Chile	Yes	Yes, Chile has a process of desertification, coming from the north to the south, with a strong and unpredicted rainfalls.
China-1 (Beijing)	No	There are no such cases where extreme temperature differences leading to significant impact on the bridge or exceeding the limits assumed during the design in recent years.
China-2 (Wuhan)	No	No
Hungary	No	Our country is not (yet) characterized by extreme temperature fluctuations that exceed the temperatures assumed during the design.
France	Yes	Yes (on pavement and bituminous expansion joints) Yes, on sea level rise.
Germany	Yes	Yes • Some expansion joints and bearings were going over limit on hot summer days.
Japan	No	It is true that temperatures are rising, but we do not believe that they have reached a level that will have a significant impact on the behavior of the bridge.
Netherlands	Yes	Yes: • We see that several movable bridges can no longer close due to extreme expansion combined with settlement of the foundations. • An old bridge over the Zandkreek (Oosterschelde bridge) received a new deck about 10-12 years ago, which had to be modified again because it indeed could not cope with temperature fluctuations. Also, cooling of the bridge takes place in summer, sometimes even with salt water, which results in higher costs for the maintenance of the various components.
Niger	N/A	-
Norway	No	No

Country	Classification of answers	Question 5: Temperature: Have there been signs of impact on bridges due to extreme temperature differences i.e., day-time to night-time temperature differences exceeding the limits assumed during design?
Portugal	Yes	In some old and long steel bridges (end of 19th century, beginning of 20th century).
Slovenia	No	No
USA Utah	N/A	Unknown

Question 6: Rainfall/floods: Have there been signs of impact on bridges due to the occurrence of unexpected rainfall? Floods? Mudslides? Scour?

Country	Classification of answers	Question 6: Rainfall/floods: Have there been signs of impact on bridges due to the occurrence of unexpected rainfall? Floods? Mudslides? Scour?
Austria	No	No
Belgium	Yes	Yes
Chile	Yes	The floods and rainfalls, increase the scours process of our bridges. Also, the current move big-size rocks and material with and a heavy impact on the structures. Also, the uplifting is a concern during the floods.
China-1 (Beijing)	Yes	Unexpected rainfall/flood can affect bridges. Mainly, floods, debris flows and scouring have local scouring on the bridge piers/foundations, thus affecting the safety of the bridges.
China-2 (Wuhan)	Yes	Yes, the effect of current scour happens more in China which lead to bridge foundation exposure and more seriously lead to bridge failure.
Hungary	Yes	The sudden floods appearing more and more often in our area caused significant damage to several of our bridges. Typical damages are: • Undermining to flat foundations or masonry substructures; • Wash-always of embankment, wash-out from between piles; • Damage to bridge accessories.
France	Yes	In metropolitan area: Yes: In occurrence and intensity In overseas: More frequent number of cyclones
Germany	Yes	• High water levels in rivers have knocked several bridges off their supports or the foundation was undermined which has led to away breaking supports. • Smaller old bridges (esp. old brick arch bridges) were broken away in total.
Japan	Yes	In recent years, there have been cases of scours due to river load obstructions, inadequate foundation rooting, etc., and bridge losses due to insufficient clearance under the girders, etc.
Netherlands	Yes	Yes, a small bridge in Limburg/Valkenburg has been destroyed Yes, more extreme showers cause adjustment to the rainwater drainage system. Rijkswaterstaat Technical Document 1008 (RTD1008) is new. See attachment but it is in Dutch.
Niger	Yes	Yes: flood and scour

Country	Classification of answers	Question 6: Rainfall/floods: Have there been signs of impact on bridges due to the occurrence of unexpected rainfall? Floods? Mudslides? Scour?
Norway	Yes	Yes. In Norway we have a bridge stock of emergency bridges. They have been used frequently the last years because of flooding. The main problem seems to erosion. · 2022 3 · 2021 4 · 2020 4 · 2019 5 · 2018 6 · 2017 10 · 2016 3
Portugal	Yes	Yes, there are some records.
Slovenia	Yes	Yes, floods. Impact on local roads and their bridges.
USA Utah	Yes	Yes

Question 7: Sea level rise: Have there been signs of impact on bridges due to increasing in the sea level rise? Tidal waves?

Country	Classification of answers	Question 7: Sea level rise: Have there been signs of impact on bridges due to increasing in the sea level rise? Tidal waves?
Austria	No	No (Austria is landlocked)
Belgium	No	No sea in Wallonia. There are some signs in Flanders (North part of Belgium)
Chile	Yes	Yes, tidal waves are increasing and the frequency of an unpredicted wave are increasing.
China-1 (Beijing)	No	There is currently no indication that rising sea levels will have a significant impact on bridges.
China-2 (Wuhan)	No	No, there are no signs of impact on bridge due to increasing in the sea level rise.
Hungary	No	Due to the geographical location of Hungary, we have no such experience.
France	No	Not yet but forecast taken into account, project by project
Germany	No	Not yet
Japan	No	It is true that sea level is rising, but we do not believe it has reached a level that would affect bridge planning.
Netherlands	Yes	Yes • A derivative is also more and more extreme fluctuation in water levels, so that clearance heights are sometimes no longer guaranteed which can result in more collisions.
Niger	No	No

Country	Classification of answers	Question 7: Sea level rise: Have there been signs of impact on bridges due to increasing in the sea level rise? Tidal waves?
Norway	No	No
Portugal	No	No records.
Slovenia	No	No
USA Utah	-	Unknown

Question 8: Wind/tornados: Have there been signs of impact on bridges due to the occurrence of severe wind conditions during construction or service in the last decade? Are the frequencies of severe wind events increasing in areas that were less prone to wind?

Country	Classification of answers	Question 8: Wind/tornados: Have there been signs of impact on bridges due to the occurrence of severe wind conditions during construction or service in the last decade? Are the frequencies of severe wind events increasing in areas that were less prone to wind?
Austria	No	No
Belgium	No	No
Chile	No	No
China-1 (Beijing)	Yes	During construction and operation stage, severe wind conditions did occur to the bridge. There has also been a marked increase in the frequency of strong wind events in areas that are less susceptible to wind.
China-2 (Wuhan)	Yes	Yes, the severe wind conditions sometimes happen on extra-large span bridge. The frequencies do not increase in areas that were less prone to wind.
Hungary	No	No
France	Yes	In metropolitan area: no information available. In overseas: Cyclones have always existed, but their frequency seems to be more important
Germany	No	Not yet
Japan	Yes	Yes, there have been cases of vessels colliding with bridges due to the shift of the latitude of the typhoon's maximum force to the north, etc. (See Case Study 1)
Netherlands	Yes	Yes • Due to sea-level rise in combination with heavy storms we currently are modelling wave impact on the deck of the bridge Kornwerderzand in the Afsluitdijk.
Niger	Yes	Yes
Norway	No	No, but guidelines have been updated.
Portugal	No	No records.
Slovenia	No	No
USA Utah	N/A	Unknown

Question 9: Snow/ice: Have there been signs of impact on bridges due to the unexpected occurrence of avalanches? Have there been signs of impact due to increasing de-icing products?

Country	Classification of answers	Question 9: Snow/ice: Have there been signs of impact on bridges due to the unexpected occurrence of avalanches? Have there been signs of impact due to increasing de-icing products?
Austria	No	No - Avalanche galleries are present in the stock and there is a management system for natural hazards. The existing structures are affected by de-icing salt. Particularly vulnerable areas are piers and abutments in the splash water area and spray water area.
Belgium	No	No (decrease of the amount of snow)
Chile	Yes	Yes, but not severe.
China-1 (Beijing)	Yes	There is no indication yet that the exceptional avalanche will affect the bridge. However, the use of deicing salt has an impact on the durability of bridges. For example, the bridges exposed to deicing salt environments in northern our country need large-scale maintenance within 10 to 15 years.
China-2 (Wuhan)	No	No
Hungary	No	There are no conditions for the formation of avalanches in Hungary. De-icing products, NaCl and CaCl, cause severe corrosion damage, especially on structures less resistant to corrosion, built before the 1990s.
France	Yes	Metropolitan area and mountain area: increasing frequency of freeze/thaw phenomenon causing avalanches and mudslides Overseas: not relevant
Germany	No	Not yet
Japan	No	Observation data on the Sea of Japan side since 1962 shows a decreasing trend in the annual maximum depth of snow cover (the most snow accumulated in a winter) and a decreasing trend in the annual number of days with a daily snowfall of 20 cm or more. Therefore, we do not expect any unexpected snow/ice to affect the bridge.
Netherlands	No	No
Niger	No	No
Norway	No	No
Portugal	No	No records.
Slovenia	No	No
USA Utah	Yes	Yes

Question 10: Fire/Fire storm: Have there been signs of impact on bridges due to the unexpected occurrence of fire? Fire storms?

Country	Classification of answers	Question 10: Fire/Fire storm: Have there been signs of impact on bridges due to the unexpected occurrence of fire? Fire storms?
Austria	No	No
Belgium	No	No
Chile	Yes	Fire storms and significant forest fires increase the frequency, with special focus in the central and south zone of Chile.
China-1 (Beijing)	Yes	The impact of fire on bridges is significant, including fires caused by traffic accidents, fires caused by combustion of inflammable deposits near bridges, and fire occurred during construction. The main structure components would result in different degrees of damage including stay cables, main cables of suspension bridge steel superstructure or concrete structure, pavement.
China-2 (Wuhan)	Yes	Yes
Hungary	No	Fire storms and significant forest fires have not yet occurred in Hungary. There were a very few fire events on/under bridges due to a vehicle failures/collisions, but all bridges were recoverable.
France	Yes	Metropolitan area: Fire: Yes (no information about fire storm) Overseas: Yes
Germany	No	Not yet
Japan	No	No
Netherlands	No	No
Niger	No	No
Norway	No	No
Portugal	Yes	Yes, there are at least records of damage on bridge and road components (2017 Portugal wildfires).
Slovenia	No	No
USA Utah	Yes	Yes

Question 11: Others: Have there been signs of impact on bridges due to effects of climate change other than listed above?

Country	Classification of answers	Question 11: Others: Have there been signs of impact on bridges due to effects of climate change other than listed above?
Austria	No	No
Belgium	Yes	Pavement deformation due to high temperature in the summer
Chile	No	No

Country	Classification of answers	Question 11: Others: Have there been signs of impact on bridges due to effects of climate change other than listed above?
China-1 (Beijing)	Yes	Freeze-thaw effect. Concrete structures in cold regions and often in contact with water have suffered freeze-thaw hazard in Northeast China, Inner Mongolia, North China, Qinghai, and Tibet. For concrete bridges, freeze-thaw hazard (the shedding of cement mortar on the surface of components and the exposure of coarse aggregates) generally occurred at the piers, especially in the tidal zone where the water level fluctuated.
China-2 (Wuhan)	No	No
Hungary	No	No
France	N/A	-
Germany	Yes	Some regions are becoming permanently drier, so that the soil no longer corresponds to the original design parameters. In the long term, this can lead to a different settlement behavior.
Japan	No	No
Netherlands	Yes	Drought, • We are concerned that foundations consisting of wooden piles will rise above the groundwater level. (Note: drought leads to many more problems in the Netherlands. Our dikes function only if they contain some moisture. The fresh water supply in some parts of the Netherlands is at risk)
Niger	Yes	Yes: Silting
Norway	No	No
Portugal	No	No records.
Slovenia	No	No
USA Utah	N/A	

Question 12: Do you use recycled materials so as to reduce the carbon footprint (total CO2) of the construction? How do you reduce the carbon footprint (total CO2) in your bridge construction project?

Country	Classification of answers	Question 12: Do you use recycled materials so as to reduce the carbon footprint (total CO2) of the construction? How do you reduce the carbon footprint (total CO2) in your bridge construction project?
Austria	Yes	The criteria "Life Cycle Assessment of Asphalt" and "Life Cycle Assessment of Structural Steel" are in the catalogue of criteria for the acquisition of construction works. The assessment is carried out by determining the greenhouse gas potential (Global Warming Potential) by declaring the CO2 equivalent (kg CO2e) in the course of asphalt production or steel production, including transport to the construction site. Reinforcing steel is up to 100% recycled, depending on the plant. The recycling systems used in concrete plants enable almost complete, safe recovery of residual water and sludge.

Country	Classification of answers	Question 12: Do you use recycled materials so as to reduce the carbon footprint (total CO2) of the construction? How do you reduce the carbon footprint (total CO2) in your bridge construction project?
		Recycled concrete is not used for bridge constructions due to the high quality requirements. Wooden decks are occasionally used for subordinate bridges. (e.g., wildlife crossings, cycle path bridges, field bridge). We try to keep the bridges in use as long as possible in order to avoid early replacement and to reduce the carbon foot-print.
Belgium	Yes	We only start to establish a strategy to reduce carbon footprint. Still much work to do.
Chile	No	The recycled material industry is not so strong in Chile yet in Infrastructure.
China-1 (Beijing)	Yes	YES, we use recycled materials in bridge construction projects. The total mileage of highway network has reached 4.8 million kilometers in China. The excavation and milling of old asphalt pavement will produce a huge amount of mixture. If it is not handled properly, it will cause environmental pollution and great waste of resources. At present, waste asphalt pavement materials have been effectively recycled.
China-2 (Wuhan)	Yes	Yes, On the basis of not affecting the structural strength of the bridge, the industrial waste materials such as fly ash and slag are added to the engineering concrete such as the pier to improve the cohesion of concrete. In order to reduce the carbon footprint in bridge construction project in China, we encourage the use of steel structures, high strength steel, Ultra-High Performance Concrete and Improve the bridge assembly construction level.
Hungary	Yes	Asphalt pavement works have a strong focus on reducing CO2 emissions by minimizing transport distances and/or using remix procedures. Recycled materials are not common in bridge structures.
France	Yes	Local project initiatives, but without national support
Germany	Yes	• Unfortunately, old bridge structures usually cannot be recycled because the concrete contains asbestos, for example, or the steel has contaminated coatings. • For new bridges we use only for some foundations recycling concrete. We already have done some pilot projects to evaluate carbon footprint, but it is not the only parameter to be consider. Sustainability aspects and resilience aspects, as well as other boundary conditions must be considered.
Japan	Yes	Recycle rate of construction waste has improved (1990s: approx. 60% → 2018: approx. 97%.) In 2020, Ministry of Land, Infrastructure, Transport and Tourism issued “Construction Recycling Promotion Plan 2020” to encourage the use of recycled materials as well as to improve the "quality" of recycling, such as looking at ways to use recycled materials.

Country	Classification of answers	Question 12: Do you use recycled materials so as to reduce the carbon footprint (total CO2) of the construction? How do you reduce the carbon footprint (total CO2) in your bridge construction project?
		In the plan, the following three main issues are summarized as measures to be taken. (1) Further contribution to the formation of a recycling-oriented society by maintaining a high recycling rate of construction by-products, etc. (2) Consideration for the coming age of maintenance and renewal of social capital (3) Measures that contribute to productivity improvement in the construction recycling field
Netherlands	Yes	The Transition Path for Civil Engineering works, among other things, on making concrete more sustainable. The goal is to achieve climate neutrality - that is, zero CO2 emissions - and a circular economy with value retention of concrete structures at the highest level. In this context, the Rijkswaterstaat Technical Document (RTD) 1033 "Verduurzaming Beton" translated" Making Concrete More Sustainable" was developed and adopted. Very concretely, this technical document means taking into account a decrease in the "Milieu Kosten Indicator (MKI)" translated "Environmental Cost Indicator (EQI)" ceiling values, high-quality reuse of concrete released during demolition and the provision of validation space in the projects. This is because RWS is now responsible for processing the concrete to be demolished and must ensure that the concrete retains its value and can be reused in new concrete.
Niger	No	No
Norway	No	Not so much, but there are research projects working on cement with low carbon footprint.
Portugal	Yes	Yes, we use at least 10% recycled materials or that incorporate recycled materials in all Public Works projects, in compliance with the New General Regime for Waste Management.
Slovenia	No	No. However, recycling is used in pavement construction and reconstruction.
USA Utah	N/A	Use Portland limestone cement

Question 13: Has climate change affected the behavior of bridges in your country? If yes, how and which elements of the bridge construction did they affect? Superstructure? Substructure? Bridge components (e.g., bearings, expansion joints)?

Country	Classification of answers	Question 13: Has climate change affected the behavior of bridges in your country? If yes, how and which elements of the bridge construction did they affect? Superstructure? Substructure? Bridge components (e.g., bearings, expansion joints)?
Austria	No	No
Belgium	Yes	No except flooding
Chile	Yes	Yes, superstructure (beams and slab) due to rock impact and uplifting process. Substructures due to scour. The huge problem is the concomitant process of this with our seismic behavior.

Country	Classification of answers	Question 13: Has climate change affected the behavior of bridges in your country? If yes, how and which elements of the bridge construction did they affect? Superstructure? Substructure? Bridge components (e.g., bearings, expansion joints)?
China-1 (Beijing)	Yes	YES, Climate change has a certain impact on the performance of bridges in China. In winter of northern China, the corrosion of deicing salt and chloride ions in the marine environment are more prominent. They may lead to the failure of the bridge structure and affect the safety of the bridge structure. The impact on the bridge is mainly reflected in the protection measures for the thickness of the concrete cover, the provision of waterproof and drainage system, and concrete construction quality. The impact on bearings and expansion joints are also obvious, mainly reflected in the lack of durability.
China-2 (Wuhan)	Yes	Yes, climate change affects the construction of superstructure, substructure. For the substructure design we increasing the thickness of concrete cover of pier, pile cap and pile, and considering reduction of pile length due to local current scour depth. As to the superstructure design, we pay more attention to wind resistance design and conduct wind tunnel test when necessary.
Hungary	No	The behavior of the bridge loadbearing structures, bearings and expansion joints has not yet been changed by the current climate change.
France	Yes	Yes: basically, due to flood and scour Temperature and increase of relative humidity are accelerating aging phenomenon
Germany	Yes	Because of flooding the substructure is mostly affected.
Japan	Yes	The effects of climate change on bridges include rainfall, flooding, scouring, and storms. For bridge substructures, flooding has caused scouring and subsidence of pier foundations and scouring of abutment backsides, leading to the eventual collapse of the superstructure, and in some cases the superstructure itself has been washed away. There have also been cases where ships have collided with and damaged bridge superstructures due to typhoon storms, storm surges, and high waves.
Netherlands	Yes	• Due to sea-level rise in combination with heavy storms we currently are modelling wave impact on the deck of the bridge Kornwerderzand in the Afsluitdijk. The opening bridges have a problem of not closing correctly due to higher temperatures in the summer. This is the secondary cause or the tipping point to take measures. The root cause is the continuous settlement of the pillars. Measures now are taken in the design of the opening bridge by including an extra length in the movable part of the bridge that can later be removed. • Drought conditions can cause groundwater levels to fall below what was anticipated. Foundations made of wooden piles are then at risk. • In general terms, the increase in physical load leads to adjustments in management and maintenance, which in turn leads to additional costs.
Niger	Yes	Yes: piers, bearings, expansions joints
Norway	No	No
Portugal	Yes	Expansion joints, road rails.
Slovenia	No	No

Country	Classification of answers	Question 13: Has climate change affected the behavior of bridges in your country? If yes, how and which elements of the bridge construction did they affect? Superstructure? Substructure? Bridge components (e.g., bearings, expansion joints)?
USA Utah	-	Unknown

Question 14: Are there any government policies in place with regard to climate change?

Country	Classification of answers	Question 14: Are there any government policies in place with regard to climate change?
Austria	Yes	Yes. ASFINAG is 100% owned by the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology.
Belgium	Yes	Yes, but global policies
Chile	Yes	There are several projects related with climate change. During 2020 to 2030, one of the focuses is the implementation of mitigation action on bridge due to Climate Change. The Public and Academia are joint in order to define the best policies related with this topic.
China-1 (Beijing)	Yes	From 2014, China began to carry out research on the long-term performance of bridges and key technologies for life extension, to promote the development of bridges in the direction of safety and long life.
China-2 (Wuhan)	Yes	Yes, our Chinese government has introduced a policy to promote carbon neutrality.
Hungary	No	Although the issue of climate change is receiving a great attention from our leading politicians (our outgoing President is personally very committed to this issue), we are not yet aware of any governmental efforts to put it at the legislative level.
France	N/A	-
Germany	Yes	• Bundes-Klimaschutzgesetz (KSG) - Federal Climate Protection Act • Klimaschutzsofortprogramm – Immediate Climate Protection Program • Klimaschutzprogramm 2030 - Climate Protection Program 2030 • Klimaschutzplan 2050 - Climate Protection Plan 2050
Japan	Yes	Ministry of the Environment aims for a 46% reduction in greenhouse gas emissions in FY2030 (compared to FY13), and continue the challenge to achieve a 50% reduction Ministry of Land, Infrastructure, Transport and Tourism issued “Five-year accelerated measures for disaster prevention, disaster mitigation, and land resiliency”. In order to protect the lives and property of citizens from increasingly severe and frequent weather disasters caused by climate change and imminent large-scale earthquakes, as well as from aging infrastructure that may not only increase the total cost of maintenance but may also cause socioeconomic systems to malfunction, priority and intensive measures will be taken over a five-year period (2021-2025) to accelerate and deepen efforts for disaster prevention/mitigation and national land resiliency.
Netherlands	Yes	WRR (Nationale Klimaatadaptatiestrategie 2016) translated (National Climate Adaptation Strategy 2016) PBL (VAN RISICOBEOORDELING NAAR ADAPTATIESTRATEGIE) translated (FROM RISK ASSESSMENT TO ADAPTATION STRATEGY)

Country	Classification of answers	Question 14: Are there any government policies in place with regard to climate change?
		Not for bridges but relevant: Deltabeslissing Ruimtelijke adaptatie The Deltadecision for spatial adaptation that follows from the Delta Program states the Netherlands need to be *as climate-proof and water-resilient as possible by 2050; and by 2020 parties have incorporated climate-proof and water-resilient planning into policies and actions*
Niger	Yes	Yes (validation of the national adaptation plan is under process)
Norway	Yes	Yes. One of the main goals for the Norwegian public roads administration is to reduce CO2.
Portugal	Yes	Yes, coming from EU policies.
Slovenia	Yes	Yes, but only general guidelines, not specific for road infrastructures.
USA Utah	N/A	I don't believe so

Question 15: Have you specific bridge design codes referring to climate change, if yes: Please provide a copy or a link. When were these implemented? Are there similar regulations for management of the existing bridge stock?

Country	Classification of answers	Question 15: Have you specific bridge design codes referring to climate change, if yes: Please provide a copy or a link. When were these implemented? Are there similar regulations for management of the existing bridge stock?
Austria	No	No
Belgium	No	No
Chile	No	Not yet, but is something we are starting to discuss.
China-1 (Beijing)	No	There are similar requirements in industry authorities. For details, please refer to the "Opinions of the Ministry of Transport on Further Improving the Safety and Durability of Highways and Bridges", Please refer to: https://www.mot.gov.cn/2020zhengcejd/qiaoliangaqyj/202012/t20201229_3509570.html
China-2 (Wuhan)	No	No
Hungary	No	We have not included this task in the bridge design codes yet, however, the new bridge design regulations currently being developed will take into account the aspects of climate change.
France	No	No
Germany	No	Not yet, but we are creating an audit for the existing bridge stock in areas with more floods in future.
Japan	No	No. In bridge inspections, reference materials are prepared for inspections against scouring, etc., and are used by road operators. The wind load and effect of temperature in the current design codes are determined to be equivalent to a 95% non-exceedance probability based on a 100-year maximum value distribution, so even if the statistics change slightly in the future, safety is not considered to be an issue.

Country	Classification of answers	Question 15: Have you specific bridge design codes referring to climate change, if yes: Please provide a copy or a link. When were these implemented? Are there similar regulations for management of the existing bridge stock?
Netherlands	No	• Not for existing structures • Rijkswaterstaat Technical Document 1008 (RTD1008): "Hemelwaterafvoer 2017" translated "Rainwater drainage 2017"
Niger	No	No
Norway	No	The design codes do not refer to climate changes, but the guidelines are updated (10 years ago). We do not have similar guidelines for the existing bridge stock.
Portugal	No	Not yet. However, there are measures that are already implemented, in order to increase the resilience of bridges to the most extreme events, in terms of flow increase and speed, such as: - Location of the pillars outside the flood beds, in particular the smaller beds; - Geometry of the pillars, favoring the flow; - Dimensioning considering the appropriate payback periods; - Protection of pillar foundations; - Other erosion protection solutions: rockfill. Existence of a Bridge Management System, which provides for periodic inspections to them, including underwater bridges, carried out by IP's own material and human resources.
Slovenia	No	No
USA Utah	No	No

Question 16: Are there specific bridge research programs running in your country on the subject of climate change?

Country	Classification of answers	Question 16: Are there specific bridge research programs running in your country on the subject of climate change?
Austria	Yes	We have done research projects on the topic of reducing the carbon foot-print. - ERESCON … Energy and Resource Efficient Concrete for Infrastructure (https://mobilitaetderzukunft.at/de/projekte/verkehrsinfrastrukturforschung/erescon.php) - - Corrosion protection - Investigations on the corrosion protection of the steel reinforcement of admixture-optimized concretes
Belgium	No	No
Chile	Yes	Yes, the name is CORFO leading by the Pontificia Universidad Católica de Valparaíso with the Ministry of Public Works..
China-1 (Beijing)	Yes	There are similar studies. For example, "Investigation on the Construction of Highway and Bridge Safety and Durability System", "National Highway Tunnel Quality Upgrading Special Action Survey".
China-2 (Wuhan)	Yes	Yes

Country	Classification of answers	Question 16: Are there specific bridge research programs running in your country on the subject of climate change?
Hungary	No	We have no information of such a research program.
France	Yes	Yes
Germany	Yes	Yes • In the network of experts, we have addressed many climate change topics: https://www.bmdv-expertennetzwerk.bund.de/EN/Home/home_node.html;jsessionid #NAME? • « Analysis of July 2021 floods » – depending on the results there might be more research topics as « Bridge construction in flood-prone regions (concrete, steel, composite) » or « Upgrading of existing bridges in flood-prone regions »
Japan	Yes	At the Japan Society of Civil Engineers (JSCE), research is being conducted from the angle of responding to floods in conjunction with measures for bridges against tsunamis. At the Ministry of Land, Infrastructure, Transport and Tourism, in response to increasingly severe and frequent floods and torrential rains, hazard maps, action plans, and local disaster prevention plans are being developed, and comprehensive measures for roads, including software and hardware, are being studied. In addition, in order to efficiently and effectively strengthen the road network against disasters, the "Road Risk Assessment Procedure" is being developed to assess the current risk of the road network against disasters in response to heavy rainfall.
Netherlands	No	No
Niger	No	No
Norway	Yes	See question 12. (Answer to question 12: Not so much, but there are research projects working on cement with low carbon footprint.)
Portugal	Yes	ClimaBridge Homepage - ClimaBridge (ulusofona.pt) The goal of this project is to develop a systematic framework for the probabilistic assessment of the impact of climate change on the structural health of existing bridges, by coupling climate risk evaluation and health monitoring techniques. Basically, we intend to integrate existing procedures for the assessment of climate change threats into the Structural Health Monitoring (SHM) of bridges, leading to a climate-aware SHM framework.
Slovenia	No	No
USA Utah	Yes	https://nap.nationalacademies.org/catalog/12801/a-transportation-research-program-for-mitigating-and-adapting-to-climate-change-and-conserving-energy

Country	Classification of answers	Question 16: Are there specific bridge research programs running in your country on the subject of climate change?
		https://onlinepubs.trb.org/onlinepubs/circulars/ec164.pdf https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation https://www.nationalacademies.org/trb/blog/address-climate-change-and-breathe-easier-with-research-on-transportation-emissions Many more publications exist on the web.

APPENDIX C: CASE STUDIES

#	Country	Cause of Climate	Description
01	Belgium (1)	Precipitation	High flooding caused the bridge to move laterally by 0.5 to 1.3 m
02	Belgium (2)	Precipitation	Flooding caused the central pile of Arch Bridge to be partly collapsed
03	Chile	Precipitation	Superstructure of the bridge moved 500m due to alluvium
04	China	Precipitation	Heavy rainfall caused slope instability and lateral displacement of pier
05	France (1)	Precipitation, Temperature	Localized corrosion of Steel Culvert due to tidal level
06	France (2)	Precipitation	Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m
07	France (3)	Temperature	Vertical and almost entire height visible cracks on high Piers
08	France (4)	Sea level rise	Pier foundation protection against Sea level rise and high waves
09	Germany	Precipitation	Floods caused pier subsidence and resulted the bridge in a skewed position
10	Japan (1)	Precipitation	Extensive scouring in the concrete revetment and the pier foundation
11	Japan (2)	Wind	Tanker ship collided with the bridge due to typhoon
12	Netherlands (1)	Precipitation, Temperature	Space for the river program (Raise the elevation of the bridge)
13	Netherlands (2):	Temperature	Temperature expansion (combined with unforeseen settlement)
14	Niger	Precipitation	Silting under a bridge in the Galmi valley
15	Norway	Precipitation	Floods reduced and removed erosion protection
16	Portugal (1)	Wind	High rain-wind induced vibration on stay cables
17	Portugal (2)	Temperature	Impact on steel bridges due to extreme temperature differences
18	Portugal (3)	Precipitation	Heavy rains and increase drainage capacity
19	Switzerland	Temperature	Pavement and waterproofing of decks were deformed and leaked.

#01 Belgium (1): High flooding caused the bridge to move laterally by 0.5 to 1.3 m.

Description of bridge	**Bowstring steel bridge of about 30 m length.**
Impact due to Climate change	**Due to a very high flooding in July 2021, the bridge was laterally moved by 0.5 to 1.3 m**

Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Erosion, Debris current**
3. Impact on bridge	**Scouring, Extreme load impact**
4. Action	**The bridge was lifted up and moved to its original position.**

#01 Belgium (1): High flooding caused the bridge to move laterally by 0.5 to 1.3 m.

#01 Belgium (1): High flooding caused the bridge to move laterally by 0.5 to 1.3 m.	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Bowstring steel bridge of about 30 m length.
Picture of the bridge	

#01 Belgium (1): High flooding caused the bridge to move laterally by 0.5 to 1.3 m.	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection . What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection ?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	Due to a very high flooding in July 2021, the bridge was laterally move by 0.5 to 1.3 m

#01 Belgium (1): High flooding caused the bridge to move laterally by 0.5 to 1.3 m.	
Picture of the problem	
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	In 2021, after the flooding, the bridge was lift up and replace at its original place.
Pictures of the repair/rehabilitation materials and technologies	

#01 Belgium (1): High flooding caused the bridge to move laterally by 0.5 to 1.3 m.	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	No
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	No
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection ?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	No
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.

#01 Belgium (1): High flooding caused the bridge to move laterally by 0.5 to 1.3 m.	
Answer	Simple and rapid
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	No
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	Good solution
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

#02 Belgium (2): Flooding caused the central pile of Arch Bridge to be partly collapsed

Description of bridge	**Multi arch masonry bridge: 4 arches, total length: 30 m. Width: 4.8 m**
Impact due to Climate change	**Due to the flooding of July 2021, the central pile collapse with parts of the two central arches. The bridge didn't collapse due to an existing concrete slab which overlays the arches.**

Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Debris current**
3. Impact on bridge	**Scouring, Extreme load impact**
4. Action	**Collapsed piers will not be rebuilt and a new arch will be rebuilt incorporating the two collapsed central arches.**

#02 Belgium (2): Flooding caused the central pile of Arch Bridge to be partly collapsed

#02 Belgium (2): Flooding caused the central pile of Arch Bridge to be partly collapsed	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Multi arch masonry bridge: 4 arches, total length: 30 m. Width: 4.8 m
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …

#02 Belgium (2): Flooding caused the central pile of Arch Bridge to be partly collapsed	
Answer	Due to the flooding of July 2021, the central pile collapse with parts of the two central arches. The bridge didn't collapse due to an existing concrete slab which overlays the arches.
Picture of the problem	 
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	The collapsed piers will not be rebuilt and a new arch will be rebuilt incorporating the two collapsed central arches. Completion is expected in 2022

#02 Belgium (2): Flooding caused the central pile of Arch Bridge to be partly collapsed	
Pictures of the repair/rehabilitation materials and technologies	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	Increasing the free section for water
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	No
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	-

#02 Belgium (2): Flooding caused the central pile of Arch Bridge to be partly collapsed	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	Increase the free section for the river without rebuilding all the bridge.
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	There remain 2 piers in the river
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	The solution is interesting. But will we not regret keeping 2 piers in the river?
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	-

#03 Chile: Superstructure of the bridge moved 500m due to alluvium

Description of bridge	**The Nicolás Naranjo Bridge was two spans of 22m each, with a 20cm deck thickness, four post-tensioned concrete girders and 10.4m total width including two sidewalks of 1.2m each.**
Impact due to Climate change	**The superstructure of the bridge was moved due to the alluvium 500 meters from the original position. The substructure resisted staying in its place.**

Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Erosion, Debris current**
3. Impact on bridge	**Scouring, Extreme load impact**
4. Action	**Under investigation.**

#03 Chile: Superstructure of the bridge moved 500m due to alluvium

#03 Chile: Superstructure of the bridge moved 500m due to alluvium	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	The Nicolás Naranjo Bridge is located on El Tránsito River, on C-495 route of Alto del Carmen commune, in the province of Huasco, Atacama Region. The superstructure was two spans of 22m each, with a 20cm deck thickness, four post-tensioned concrete girders and 10.4m total width including two sidewalks of 1.2m each. The infrastructure was shape of two concrete reinforcement abutments with wingwalls at 90° and superficial footings.

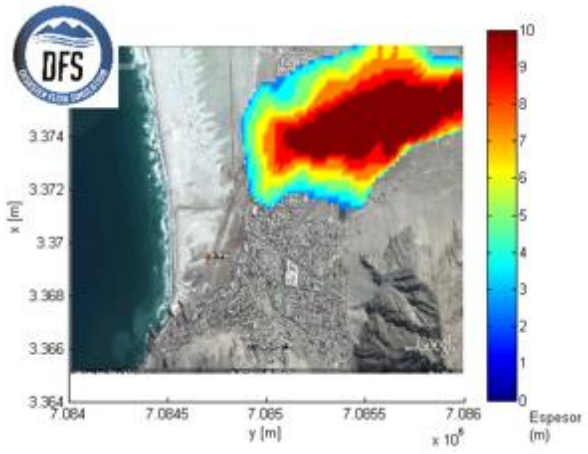
#03 Chile: Superstructure of the bridge moved 500m due to alluvium	
Picture of the bridge	 
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …

#03 Chile: Superstructure of the bridge moved 500m due to alluvium	
Answer	**The superstructure of the bridge was moved due to the alluvium 500 meters from the original position. The substructure resisted staying in its place.**
Picture of the problem	 Before alluvium  After alluvium
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	**Not yet repaired, currently this event is investigated, and try to propose improvement in the future.**

#03 Chile: Superstructure of the bridge moved 500m due to alluvium

The representation of the fluid model is based on the vertical average of equations of conservation of mass and momentum. This principle is the main base of the majority of granular fluid models like debris avalanche and dense pyroclastic fluid.

The model allows simulating the erosion and sedimentation in which was included all rheological law on the thickness and velocity: friction behaviour, viscous, turbulent, etc.



To calculate the debris thickness that is impacted on Nicolas Naranjo Bridge, the fixed and variable parameters were considered.

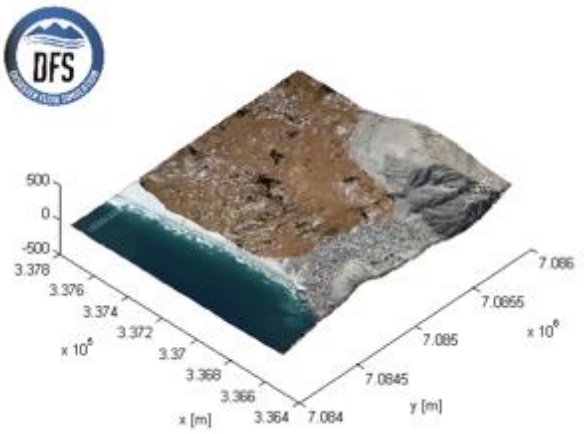
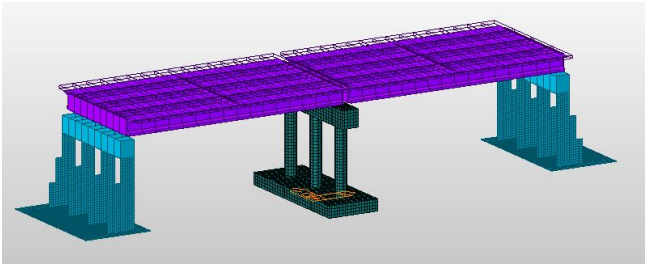
The values are considered equal to zero in those cases where average thicknesses and velocities in a time X are less than 0.1m and 0.3 m/s, respectively.

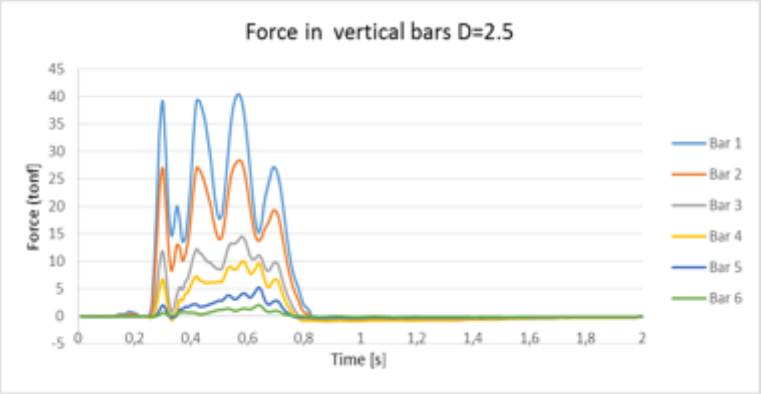
On that count, to create the experimental design, a minimum and maximum value to each variable parameter is considered.

Fixed parameters	Value [units in brackets]	Variable parameters
Hydrodynamic coefficient (Cd)	0.44	viscosity
Angle of repose	1[°]	density
Angle of friction	0[°]	cohesion
Initial height of landslide	10 [m]	Volume
Gravity force	9.8 [m/s²]	-

The result, from the solution domain analysis, is that 69% can reach or impact on Nicolás Naranjo Bridge, with thicknesses between 1.53m and 4.45m.

To analyse how this fluid collides on the bridge, a more realistic and unfavourable parameter is used as an input in the FEM Bridge model.

#03 Chile: Superstructure of the bridge moved 500m due to alluvium	
	 **The purpose is understanding and estimating how fluid forces act as a product of uplift force and buoyancy.** **Strengths produced on the deck are determined to utilize a force function from an experimental scale test.** **Forces are entered using time-history analysis in the FEM Model.** **Obtained the forces from anti-seismic devices.**  **Results** **Forces up to 40 ton in the most requested elements for 2.5 ton/m3 fluid density.** **Bars near ant seismic stopper (pivot point) are the less requested.** **Fluid over the bridge deck produces a cyclic effect in a short period in the bars.**

#03 Chile: Superstructure of the bridge moved 500m due to alluvium	
	
Pictures of the repair/rehabilitation materials and technologies	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	**A preliminary methodology is presented to evaluate the damage because of current debris.** **However, the behaviour of bridges under this kind of events must continue investigating in future works.** **We must continue investigating the equations for other fluids in order to get more accurate analysis to evaluate the performance of bridges under this kind of extreme loads.**
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	No yet

#03 Chile: Superstructure of the bridge moved 500m due to alluvium	
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	N/A
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	**The use of hold-downs during the current debris loads is needed in order to reduce the damage produced by the effect of buoyancy and uplifting.** **In Chile, the use of hold-downs is just for vertical seismic movements.** **Therefore, this paper set a secondary use for this component.** **This methodology and analysis must be part of the current plans of maintenance in Chilean Bridges.**

#03 Chile: Superstructure of the bridge moved 500m due to alluvium	
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier

Description of bridge	**Qiaoma Forest Farm No. 2 Bridge with a total length of 341.71m was opened to traffic in 2015. Superstructure of the bridge is prestressed concrete T beam and substructure consists of U shaped abutment, column pier and bored pile foundation.**
Impact due to Climate change	**The bridge had experienced a heavy rainstorm in September, 2017 and two heavy rainstorms and floods in August 2018. Due to displacement and deformation of the slope, the pile foundation of pier 2# produced lateral displacement.**

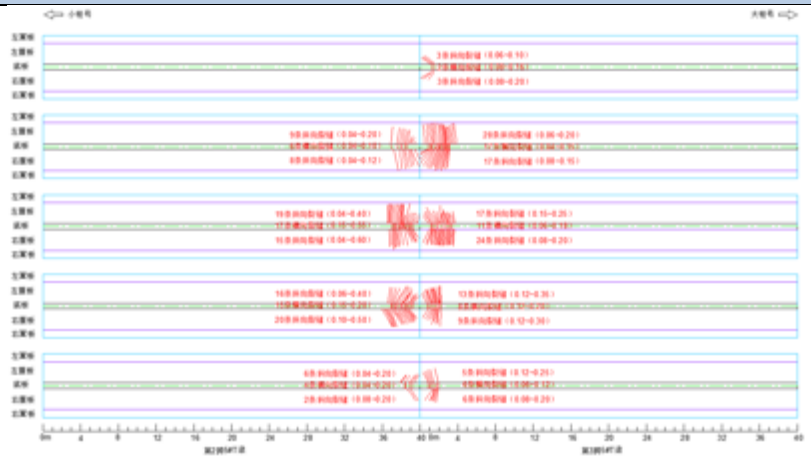
Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation,**
3. Impact on bridge	**Slope stability**
4. Action	**Anti-sliding piles, soil retaining plates, drainage ditch and new footing**

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	The bridge is located on the circular curve of R=600m, total length 341.71m, 11.25m wide, was built and opened to traffic by the end of 2015. • Consists 2 modules: 4 × 40m + 4 × 40m, • Superstructure: prestressed concrete T beam, simply supported at the beginning and then continuously, • Substructure: U shaped abutment, column pier, bored pile foundation.
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects? For example: • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	Since it was opened to traffic, the bridge and its surrounding areas have experienced a heavy rainstorm of 30 years return period from

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier	
	September 6th to 7th 2017, and two heavy rainstorms and floods in August 2018. Under the action of rainfall infiltration, the moisture content of the accumulation rock and soil increases, the weight increases, the soil tends to be saturated, the mechanical shear strength decreases, the anti-sliding force decreases, the equilibrium state of the accumulation layer of the slope body is destructed, and the overlying accumulation layer occurs creep deformation. In the case of displacement and deformation of the slope, the pile foundation of pier 2# produces lateral displacement resulting from the deformation of the slope.
Picture of the problem (1)	 
Picture of the problem (2)	

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier	
	
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	1) Comprehensive management of the slope: (a) Build anti-sliding piles + soil retaining plates along the front edge of the slope body within a length of 30m, a total of 7 anti-sliding piles, the distance between the piles is 5.0m, and the length of the pile is about 19.0m. (b) According to the principle of balance between filling and excavation, remove the loose layer with a surface area of about 200m2 and a thickness of about 4.0m on the slope body, and backfill it all behind the pile and compact it by mechanical rolling. (c) Cut-off and drainage ditch is arranged at the rear edge and inside of the slope, with a total length of about 300.0m, and is built with mortar block stone at the surface for protection. 2) New footing with dimension 14m×10.1m×3.5m added, the height of the ground beam is 2m, and the cap is connected with the ground beam and pier column by implanting reinforcements. The diameter of the additional pile is 2.0m, the length of the pile is 35m, and the clear distance between the old and new piles is 4m.

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier	
Pictures of the repair/rehabilitation materials and technologies (1)	
Pictures of the repair/rehabilitation materials and technologies	

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier	
	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	The bridge maintenance and treatment comprehensively considered the influence of traffic flow, construction cost, construction period and strengthening effect.
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	YES. The pier top displacement monitoring was carried out to monitor the top elevations of the 0# and 1~4# pier caps and girders of the bridge. According to the short-term monitoring results, after the defect was rectified, the elevations of the pier caps and beams did not change significantly.
Pictures of the monitoring / inspection / testing / NDT	

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier	
	  
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	The upper load-bearing components of the bridge are seriously damaged and the settlement of the piers has seriously affected the safety of the bridge. The bridge is evaluated according to the worst possible defective condition of the main components of the bridge, and the technical condition level is 4 according to “Standard for Technical Condition Evaluation of Highway Bridges” (JTG/T H21-2011).

#04 China: Heavy rainfall caused slope instability and lateral displacement of pier	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with "more standard method" if any.
Answer	The cost is less than 10 million Chinese Yuan, the construction period is 3 months, the cost is low, the construction period is short, the strengthening effect is good, and the social impact is relatively small.
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with "more standard method" if any.
Answer	The structure of the connection between the old and new T beams is complex, and the maintenance process will have a certain adverse impact on traffic.
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	Four additional piles added to ensure the bearing capacity of the foundation. The accumulation body was comprehensively treated to keep the stability of the slope in a good state to resist the risk of local slippage deformation under local heavy rainfall.
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	1) Zhang Hongbo. Influence of foundation settlement on bridge structure and settlement control [J]. Science and Technology Vision, 2014 (03) 2) Liu Qin; Cao Yishan; Investigation technology of uneven settlement leading to defects and hazards in highway bridges[J]; Highway Traffic Science and Technology (Applied Technology Edition);2019-03 3) Graphical Manual for Diagnosis and Rectification of Typical Defects of Highways and Bridges

#05 France (1): Localized corrosion of Steel Culvert due to tidal level

Description of bridge	**A81 Motorway PH2424: ARMCO type soil steel structure with a 4.80 m diameter and 142 m length allowing the passage of the stream "Le Quartier" under the motorway.**
Impact due to Climate change	**Localized damage to the metal sheet (at the level of the tidal zone) causing it to lose its load-bearing capacity (with the risk of shearing at the most damaged points).**

Classification

1. Climate	**Precipitation, Temperature**
2. Hazards	**Heavy precipitation, Drought, Heat (waves)**
3. Impact on bridge	**Material evolution**
4. Action	**Implementation of a GRP (Fiberglass Reinforced Polyester) casing reinforcement with a 3600 mm diameter (the largest diameter available at the time).**

#05 France (1): Localized corrosion of Steel Culvert due to tidal level

#05 France (1): Localized corrosion of Steel Culvert due to tidal level	
Case: A81 Motorway PH2424 - Reinforcement work of metal nozzle by casing (2015-2016) **Project owner: COFIROUTE, VINCI Autoroutes** **Engineer: MORSES** **Contractor: GTM Travaux spéciaux**	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	A81 Motorway PH2424: ARMCO type soil steel structure with a 4.80 m diameter and 142 m length allowing the passage of the stream "Le Quartier" under the motorway.
Picture of the bridge	

#05 France (1): Localized corrosion of Steel Culvert due to tidal level	
	
2a) Brief description of the need of rehabilitation	Describe why it is necessary to rehabilitate the bridge: degradation (which type), increasing service level (load capacity for example), …
Answer	Localized damage to the metal sheet (at the level of the tidal zone) causing it to lose its load-bearing capacity (with the risk of shearing at the most damaged points).
Picture	

#05 France (1): Localized corrosion of Steel Culvert due to tidal level	
2b) Is this need of rehabilitation related to the effect of climate change?	Is the need of rehabilitation related to climate change effects? For example: • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • … If yes, explain.
Answer	Climatic changes, influencing low (downward) and high (upward) water levels, accentuate the amplitude of the tidal range and make it necessary to carry out renovations that reduce hydraulic gauges as little as possible.
3a) Describe your new rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	Implementation of a GRP (Fiberglass Reinforced Polyester) casing reinforcement with a 3600 mm diameter (the largest diameter available at the time). <u>Main stages of the project:</u> • Cleaning of the culvert, • Creation of a paving slab, • Installation of the GRP elements, • Filling of the annular space, in about twenty phases. One of the biggest challenges of the project was to control the injection of the annular void so as not to compromise the geometry of the water flow in the nozzle, due to the thrust of the grout on the pipes. Careful phasing of the grouting is therefore essential. • Hydraulic facilities for fish fauna.

#05 France (1): Localized corrosion of Steel Culvert due to tidal level	
Pictures of the new rehabilitation materials and technologies	 Reinforcement work carried out during the 2015 low water period Additional hydraulic works carried out in 2016
3b) Which aspects were taken into account in the decision-making process while selecting the new rehabilitation materials and technologies?	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	Quick implementation of the product, due to hydraulic constraints. Possibility of rapid cleaning and reinstatement of the rehabilitation following a flood. Durability of the product.

#05 France (1): Localized corrosion of Steel Culvert due to tidal level	
3c) Have developments in materials and technology given rise to an environmental assessment?	Describe, if applicable, how the environmental assessment of the materials and technology used was carried out.
Answer	No
3d) Did the use of this innovative method helps to reduce traffic impact of the works?	Describe, if applicable, how this innovative method reduces the traffic impact of the works.
Answer	Road traffic passing over the structure is not affected by the works. The hydraulic throughput across the structure is, by this solution to implement, the least impacted for a long time (pumping).
4a) Have you implemented any monitoring/testing/NDT of the rehabilitation after works?	Did you implement a monitoring of the bridge behaviour after the rehabilitation works? If any, please describe it.
Answer	Topographical checks to validate the geometry of the watercourse.
4b) What are the main conclusions of the monitoring?	Considering the observation period, what are the main conclusions of the monitoring related to the behaviour of the bridge?
Answer	Nothing to report
5a) Main benefits of the method?	From your point of view what are the main advantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	This method is common for smaller diameter structures. In fact, many structures have been lined with GRP pipes up to 2,500 mm in diameter. The use of this method for such large diameters has never been done before. • Speed of installation compared to concrete reinforcement. In this case, the length of the structure and the intervention times authorized by the environmental authorities practically forbade the use of a classic reinforced concrete solution. • Mitigated risk (cost and cleaning time) in case of flooding of the site. • Durability of the product. • Smooth interior surface (very good Manning-Strickler coefficient): this allows a significant reduction in the diameter of the structure without modifying the hydraulic operation.

#05 France (1): Localized corrosion of Steel Culvert due to tidal level	
	• Adaptability of the product according to size and application (wide range of diameters, thicknesses and shapes).
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	Smooth inner surface which can lead to a too important increase of the water flow, endangering the fish fauna (additional facilities such as a barrier should be provided in such cases). Non-local origin of GRP (the pipes came from a factory in Poland). Handling of the components.
6) General appreciation of the method	Give a global appreciation of the method
Answer	It is an economical solution suitable for many hydraulic rehabilitation projects.
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	www.gtm-travaux-speciaux.fr www.amiblu.com/fr
8) Person to contact	Indicate the name and contact details of the person who can provide additional information if necessary (e-mail, address, telephone)
Answer	Project Owner: Nicolas BARDOU (Cofiroute) Nicolas.bardou@vinci-autoroutes.com Sidoine DE LA ROQUE SIDOINE.DELAROQUE@vinci-autoroutes.com Contractor: Benoît LE GALL (GTM Travaux Spéciaux) benoit.legall@vinci-construction.fr 06.09.39.02.26

#05 France (1): Localized corrosion of Steel Culvert due to tidal level	
10) Level of innovation maturity	What is the level of the innovation maturity? Theoretical, Experimental, Prototype, Scale 1
Answer	Well-proven and improved technology and product. Many years of implementation in different diameters and shapes.
11) Is there any public documentation available regarding this rehabilitation?	No

#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m

Description of bridge	**The Bainville-aux-Miroirs bridge consists of 3 isostatic spans of 22.5m each of 3 reinforced concrete beams and braces. It is 5.8m wide and was built in 1958.**
Impact due to Climate change	**In mid-December 2011, a strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2 m and of the left and central span.**

Classification

5. Climate	**Precipitation**
6. Hazards	**River flooding, Flash flood, Erosion, Debris current**
7. Impact on bridge	**Settlement, Scouring**
8. Action	**Raise the deck and create a new pier on a deep foundation.**

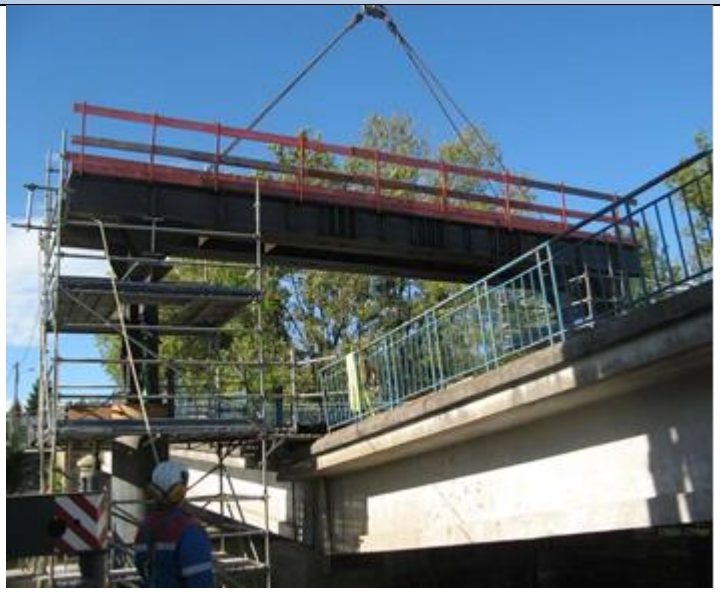
#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m

#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m	
Case: Raising the deck of the Bainville-aux-Miroirs Bridge – 54 Meurthe-et-Moselle **Owner and project manager: Municipality of Bainville-aux-Miroirs** **Main contractor: Freyssinet** **Subcontractors: Blanquin TP and Durmeyer**	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	The Bainville-aux-Miroirs bridge consists of 3 isostatic spans of 22.5m each of 3 reinforced concrete beams and braces. It is 5.8m wide and was built in 1958.
Picture of the bridge	
2a) Brief description of the need of rehabilitation	Describe why it is necessary to rehabilitate the bridge: degradation (which type), increasing service level (load capacity for example), …

#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m	
Answer	In mid-December 2011, a strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2 m and of the left and central span.
Picture	
2b) Is this need of rehabilitation related to the effect of climate change?	Is the need of rehabilitation related to climate change effects? For example: • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • … If yes, explain.
Answer	Yes: increase in duration and strength of floods.
2c) What are the positive environmental impacts of the technique or materials chosen for the rehabilitation?	Reduction in the amount of material required. The final pile is also used as a temporary one.
2d) Did the decision-making process leading to the choice of the method or material include environmental criteria?	No, economic choice: less material, less cost.

#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m	
3a) Describe your new rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	The deck of the structure is in very good condition despite 50 years of age and subsidence. It was therefore decided to raise the deck and create a new pier on a deep foundation. The technique used here avoided the need to create "temporary piers" in order to jack up the deck.
Pictures of the new rehabilitation materials and technologies	 

#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m



#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m	
3b) Which aspects were taken into account in the decision-making process while selecting the new rehabilitation materials and technologies?	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	First of all, the cost aspect. Bridge owner is a municipality of about 500 inhabitants with a very small budget. This bridge is vital for the community. The cost of a new structure would have been totally disproportionate. As the bridge deck is in good condition, a possibility of raising the deck could be studied. The advantage of this solution is that there is no need for a temporary foundation, which has a positive environmental impact.
3c) Have developments in materials and technology given rise to an environmental assessment?	Describe, if applicable, how the environmental assessment of the materials and technology used was carried out.
Answer	No
3d) Did the use of this innovative method helps to reduce traffic impact of the works?	Describe, if applicable, how this innovative method reduces the traffic impact of the works.
Answer	As the work was completed in 4 months, the interruption to traffic was greatly reduced compared to the construction of a new structure (approximately 1 year for the construction of a new bridge). Above all, this innovation made it possible to rehabilitate the structure rather than close the road permanently.
4a) Have you implemented any monitoring/testing/NDT of the rehabilitation after works?	Did you implement a monitoring of the bridge behaviour after the rehabilitation works? If any, please describe it.
Answer	No
4b) What are the main conclusions of the monitoring?	Considering the observation period, what are the main conclusions of the monitoring related to the behaviour of the bridge?
Answer	Not applicable

#06 France (2): Strong flood due to the storm JOACHIM caused the subsidence of pier P1 by 2m	
5a) Main benefits of the method?	From your point of view what are the main advantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	Reduce cost Reduce the amount of materials used.
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	Difficulty in making the pier cap.
6) General appreciation of the method	Give a global appreciation of the method
Answer	Allowed the innovative renovation of a bridge following the scouring of a pier.
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	https://www.lemoniteur.fr/article/un-pont-sauve-des-eaux.1367209
8) Person to contact	Indicate the name and contact details of the person who can provide additional information if necessary (e-mail, address, telephone)
Answer	damien.champenoy@cerema.fr - Cell phone: 06 12 54 13 03 fcuzzi@departement54.fr
10) Level of innovation maturity	What is the level of the innovation maturity? Theoretical, Experimental, Prototype, Scale 1
Answer	
11) Is there any public documentation available regarding this rehabilitation?	

#07 France (3): Vertical and almost entire height visible cracks on high Piers

Description of bridge	**Brotonne Bridge with total length of 1278.4m is a main cable-stayed structure.**
Impact due to Climate change	**Piers, particularly the highest ones (45 metres), have vertical cracks (3 to 5 per pier) with maximum openings of around 1 mm on the outside and 3 mm on the inside.**

Classification

1. Climate	**Temperature**
2. Hazards	**High temperature, Heat (waves)**
3. Impact on bridge	**Temperature gradients**
4. Action	**Addition of reinforcement rings made of carbon fibre reinforced polymer (CFRP) on the outside and inside of the hollow piers**

#07 France (3): Vertical and almost entire height visible cracks on high Piers

#07 France (3): Vertical and almost entire height visible cracks on high Piers	
Case: Brotonne Bridge, Normandy - RD490 (1974-1977) **Project Owner: The General Council of Seine-Maritime** **Architects: Auguste Arsac, Philippe Fraleu, Pierre Loyer** **Construction: Bernard Campenon**	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	The Brotonne Bridge was achieved in 1977 and has a total length of 1278.40 m. It consists of a main cable-stayed structure with a prestressed deck allowing the road RD490 to cross the Seine River. The left bank access viaduct, 464.40 m long, consists of a 38.90 m span, seven 58.50 m spans and a 16 m hinged cantilever; i.e., a total of 9 spans, including one corbelled span used to support the end of the main viaduct. The main structure, with a length of 814 m, is a prestressed concrete cable-stayed bridge comprising a 320 m central span, two lateral 143.50 m spans, two partial balancing spans and two access spans to the right bank, i.e., a total of 7 spans, one of which is linked by a cantilever support. The main structure has an air clearance of approximately 50 m above the H.W.L. It does not have any support in the Seine. The shaft of the piers consists of an eight-sided hollow tower (4 flat and 4 curved sides) with 0.25 m thick walls and corner gussets. Its height varies according to the piers.
Picture of the bridge	

2a) Brief description of the need of rehabilitation	Describe why it is necessary to rehabilitate the bridge: degradation (which type), increasing service level (load capacity for example), …
Answer	The piers, particularly the highest ones (45 metres), have vertical cracks (3 to 5 per pier) with maximum openings of around 1 mm on the outside and 3 mm on the inside. They affect the piers over almost their entire height, with maximum openings in a zone situated towards the middle of the shaft and decreasing towards their ends. Moreover, for the most affected piers, the horizontal steels are broken at the level of these cracks. These cracks are due to the excessively low horizontal reinforcement ratio in the pier shafts, which is clearly below the minimum ratio to ensure non-brittleness under bending and insufficient to take up the forces due to thermal gradients in the thickness of the walls, which were not taken into account during the design studies. The "cutting" of the pier shaft by these cracks into sub-panels greatly reduces the stability of the pier and leads to a risk of buckling of one of these sub-panels.
Picture	
2b) Is this need of rehabilitation related to the effect of climate change?	Is the need of rehabilitation related to climate change effects? For example: • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • … If yes, explain.
Answer	No, but the temperature increase will have an impact on the temperature gradients.
3a) Describe your new rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	To guarantee the stability of the piers, to restore a monolithic behaviour and to avoid the buckling of a sub-panel: The realization of strongly reinforced concrete ribs spaced from 4 to 5 m. These ribs are made inside the pier and connected to the pier walls by reinforcement seals. The concrete mix-design and the construction sequence were studied in order to reduce the impact of concrete shrinkage. In particular, the type of cement and admixture was specifically selected, and the concreting sequence allowed for a delay before clamping the ribs to the pier shaft, so that the rib could partly shrink freely.

	To take up the bending forces in the walls and to restore a non-brittleness moment capacity: Addition of reinforcement rings made of carbon fibre reinforced polymer (CFRP) material on the outside and inside of the hollow piers, with a maximum spacing of 1.00 m contributing to a horizontal reinforcement function. For the inner rings, vacuum thrust devices have been installed in the corners. They combine a careful surface preparation to soften the corner with a radius greater than that of the deflector, the installation of a resin mortar between the carbon fabric and the metal deflector to ensure the homogeneous transmission of the forces and metal deflectors to take up the forces. Treatment of the main cracks by injection and bridging by the CFRP strips. Localized repair of the concrete facings, including repointing, removal of corroded reinforcement, and patching of damaged concrete. These reinforcement works have already been carried out from 2010 to 2019, on piers P8, 11, 12, 13 and 9. Pier P10 is currently under repair.
Pictures of the new rehabilitation materials and technologies	
3b) Which aspects were taken into account in the decision-making process while selecting the new rehabilitation materials and technologies?	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	Compared to other repair methods, the chosen solution limits the aesthetic impact on the exterior of the piers, as the bridge is located in the “Boucles de la Seine Normande” Regional Park and in covisibility with a listed building (architectural heritage). In addition, this choice limits the increase in load on the supports

	and foundations already increased by the deck reinforcement work in the 1980s.
3c) Have developments in materials and technology given rise to an environmental assessment?	Describe, if applicable, how the environmental assessment of the materials and technology used was carried out.
Answer	The materials have not been subject to environmental assessment. However, the works are part of this process. The structure is located in a natural area. In addition, two of the reinforced piers are located in a SEVESO site.
3d) Did the use of this innovative method helps to reduce traffic impact of the works?	Describe, if applicable, how this innovative method reduces the traffic impact of the works.
Answer	The work concerned the structure piers and had to be carried out without impacting on traffic.
4a) Have you implemented any monitoring/testing/NDT of the rehabilitation after works?	Did you implement a monitoring of the bridge behaviour after the rehabilitation works? If any, please describe it.
Answer	The main piers (lower parts of the pylons supporting the stays) were instrumented before the works (crack closing and opening, convergence monitoring of the opposite faces). This preliminary monitoring phase showed a different behaviour of the two piers strongly influenced by the vertical cracks (the location of the cracks is different between the 2 pylons). After the works, convergence monitoring of the opposite sides of the pylons was repeated to assess the effectiveness of works. The deformations were greatly reduced, and the two piers have a similar behaviour. The repaired piers were inspected one year after the end of the work, i.e., after a summer season, to check that cracks had not reappeared and that reinforcements were holding up well.
4b) What are the main conclusions of the monitoring?	Considering the observation period, what are the main conclusions of the monitoring related to the behaviour of the bridge?
Answer	The main piers monitoring was carried out over a period of 2 years from the end of the works. The evolution is clear compared to that carried out before the works. The behaviour of the two piers is similar and consistent with the numerical models. The instrumentation could be renewed in medium term to monitor effectiveness of reinforcements over time. However, cracks have reopened outside the carbon strips on two piers.

5a) Main benefits of the method?	From your point of view what are the main advantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	The work was carried out without any impact on traffic on the structure. As the Brotonne bridge is located in the Brotonne forest nature park, particular care had to be taken to ensure that the aesthetics of the work had as little impact as possible on the appearance of the structure. The weight of the repairs had to be controlled, as the evolution of the superstructures and the work carried out in the 1980s to reinforce the deck had already significantly increased the load on foundations.
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	Disadvantages of the method: • The sizing method is not widely accepted • The execution of the works had to be done under controlled thermal and moisture conditions • The cost is mainly related to the size of the structure and the number of piers.
6) General appreciation of the method	Give a global appreciation of the method
Answer	Carbon fibre reinforced polymer materials are demanding in their installation process. The presence of convex surfaces is an additional difficulty. However, they can be adapted to any configuration.
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	Any communication about the work on piers P8, P11 and P12 is subject to the prior agreement of the company that carried out the work.
8) Person to contact	Indicate the name and contact details of the person who can provide additional information if necessary (e-mail, address, telephone)
Answer	**PERES Stephanie**: stephanie.peres-fouillet@seinemaritime.fr (ROUEN) **GOUBERT Catherine**: catherine.goubert@seinemaritime.fr

	(ROUEN)
10) Level of innovation maturity	What is the level of the innovation maturity? Theoretical, Experimental, Prototype, Scale 1
Answer	Mature level, work carried out within the framework of three successive contracts, the first having a dimension of experimentation on site for the development of operating methods and choice of materials.
11) Is there any public documentation available regarding this rehabilitation?	No

#08 France (4): Pier foundation protection against Sea level rise and high waves

Description of bridge	**The viaduct with a total length of 5400 m consists of 7 independent sections with 7 spans and located along the coast line facing to the Indian Sea.**
Impact due to Climate change	**The design of the structure took into account a rise in ocean water of 1 m in accordance with IPCC forecasts in this area of the Indian Ocean.**

Classification

1. Climate	**Sea level rise**
2. Hazards	**Storms, Ocean waves**
3. Impact on bridge	**Scouring, Extreme load impacts, Dynamic load**
4. Action	**Rock fills to protect piers against scour taking into account the effects of cyclonic waves.**

#08 France (4): Pier foundation protection against Sea level rise and high waves

#08 France (4): Pier foundation protection against Sea level rise and high waves	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	The viaduct has a total length of 5400 m. it consists of 7 independent sections with 7 spans. The main span is 120 m. The deck consists of a single box with longitudinally and transversely prestressed concrete webs. The width of the deck is 28.90 m. The height of the box varies from 3.80 m at the key to 7.30 m on the pier. Construction took 5 years
Picture of the bridge	
2) What is the effect of climate change to perform repair/rehabilitation and/or monitoring/inspection?	Is the need of rehabilitation related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • … If yes, explain.
Answer	The design of the structure took into account a rise in ocean water of 1 m in accordance with IPCC forecasts in this area of the Indian Ocean. The consequences are:

#08 France (4): Pier foundation protection against Sea level rise and high waves	
	- Modeling of the swell and the associated waves which takes into account the upwelling: wave effort, wave level, greater scouring. - A longitudinal profile of the raised road so that the waves do not reach the deck and the bearings in the event of cyclonic swell - A sizing of the piers which takes into account the forces of cyclonic swell - Sizing of rockfill to protect piers against scour taking into account the effects of cyclonic waves
	 
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position

Description of bridge	**The Ahr Bridge was completed in 1967 and consists of 2 separated bridges with three span prestressed concrete girders. The bridges have a spread foundation with a scour protection by sheeting walls.**
Impact due to Climate change	**In July 2021, a strong flood caused a subsidence of one pier of the downstream bridge and resulted in a skewed position by 40 degrees.**

Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Erosion, Debris current**
3. Impact on bridge	**Scouring, Extreme load impact, Settlement**
4. Action	**Rebuild a new bridge with new piers on a pile foundation.**

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	The Ahr Bridge along the Federal trunk road B9 consists of 2 separated bridge structures – one bridge for each direction. Both bridge structures have three different span length (31m- 39m - 31m) with two intermediate piers. The entire length is about 101 m, and the erection dates back to 1967. Both bridges structures are made of prestressed concrete. The bridges have a spread foundation with a scour protection by sheeting walls.
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), …

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position	
prompted the repair/rehabilitation and/or monitoring/inspection?	What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	In July 2021, a strong flood caused a failure by subsidence of one pier close to the abutment at the Cologne side of the bridge (from the second bridge) due heavy rain and resulted in a skewed position by 40 degrees. Two of the spans of the second substructure adjacent to the declined pier were destroyed as the floods continued and gained strength. The main reason for the lowering of the pier is due to a phenomenon known as scour. Now it is important to build a bridge which may better withstand floodings without damages.
Picture of the problem	

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position	
	 
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	Only one of the two bridges structures failed by the flood. Therefore, it was decided to replace it and build a new bridge with new piers on a pile foundation.

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position	
	In this situation it seems to be efficient to use VFT bridges (Verbund Fertigteil Träger = Prefabricated composite girder) because of a high level in prefabrication. Hence, a fast and simple rebuilding has been realized by modular and small sized prefabricated elements ensuring good transportation and leviation condition. •The construction will last around 1 year.
Pictures of the repair/rehabilitation materials and technologies	 
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position	
Answer	Taking steps to prevent flood damages: -The old bridges were mostly built and grounded using piers not deeply enough embedded into the riverbed. The new bridge benefits from being built with modern pile drilling equipment that sets piers deeper and provide a more solid foundation. -Also, the design of VFT elements enables slender structures with less height for the superstructure allowing more space for rising flood levels in future. This can also help to minimize the possibility of hitting the structure by debris and mud. Traffic impacts/ Availability: -These so-called VFT girders are laid side by side at the construction site, thereby, facilitating a rapid coverage of large areas. This results in short closure times for traffic routes. It is important because of the Federal trunk road B9 is highly frequented and one of the most important connection between the cities of Cologne and Mainz.
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	No
Pictures of the monitoring / inspection / testing / NDT	-
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	Not applicable
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.

#09 Germany: Floods caused pier subsidence and resulted the bridge in a skewed position	
Answer	-Very short construction time; bridge construction in less than one year -High quality due to serial factory production -Quick exchange of individual bridge elements -Low maintenance costs -Preventing further flood damage
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	-There are only a few companies with experience in this. -It cannot be implemented for every bridge. Aspects of cost-effectiveness and technical feasibility must be considered.
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	Measures to prevent flood damage may cost more money and labor today, but could save a lot in repair and replacement costs in the upcoming decades, as well as provide safety.
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	https://max-boegl.de/leistungsbereiche/infrastruktur/brueckenbau https://www.dwd.de/DE/presse/pressemitteilungen/DE/2021/20210730_deutschlandwetter_juli2021_news.html https://www.ssf-ing.de/fileadmin/web_data/Downloads/Broschueren/Deutsch/Bruecken_mit_VFT_Bauweise_DE.pdf

#010 Japan (1): Extensive scouring in the concrete revetment and the pier foundation

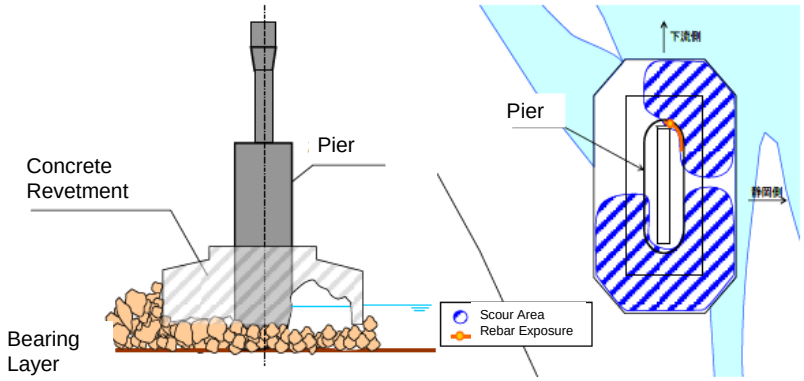
Description of bridge	**Ayusawa bridge is a 2-span simple plate girder bridge with a single pier foundation. Since the flow velocity is extremely high during floods, concrete revetments were constructed around the pier foundations.**
Impact due to Climate change	**The investigation showed extensive scouring in the concrete revetment and the base of the piers was not embedded completely.**

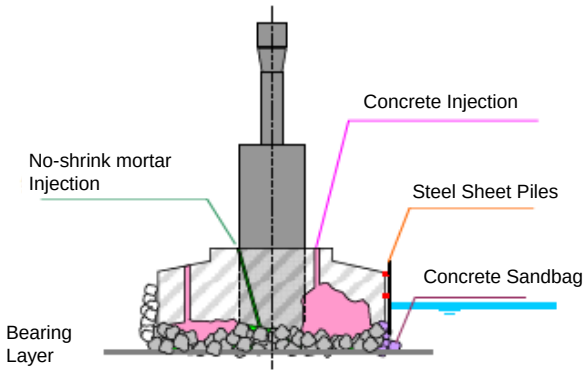
Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Erosion, Debris current**
3. Impact on bridge	**Scouring**
4. Action	**Consolidating the bottom of the piers and the inside of the revetment by concrete.**

#010 Japan (1): Extensive scouring in the concrete revetment and the pier foundation

#010 Japan (1): Extensive scouring in the concrete revetment and the pier foundation	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	<u>Ayusawa Bridge</u> The bridge is a 2-span simple plate girder bridge (bridge length 60m) with a single pier foundation in the riverbed. The river section is narrow where the flow velocity is extremely high when water flows out, so concrete revetments were constructed around the pier foundations to protect the bridge from collisions with driftwood and rocks.
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	An investigation was conducted on this bridge to confirm the shape of the foundation as well as the extent of scour. Since the

#010 Japan (1): Extensive scouring in the concrete revetment and the pier foundation	
	stability of the piers was unknown, we first confirmed the existence of scour by a diver's survey, then conducted an ultrasonic imaging sonar survey to determine the extent of scour, a core drilling into the unstructured revetment concrete to investigate the shape of the structure, and a CCD camera was used to photograph the inside of the borehole to confirm the situation of the pier base. The results of the investigation showed that extensive scouring was observed in the concrete revetment and the base of the piers was not almost embedded. In addition, it was found that rebar of the bridge piers was exposed. It was found that further scouring would likely cause usability and safety problems such as settlement and tilting due to external force action due to reduced bearing capacity. This indicated that further scouring would likely cause usability and safety problems such as settlement and tilting due to reduced bearing capacity.
Picture of the problem	 (a) Cross Section View (b) Plan View
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	The results of the investigation showed that the scouring situation was serious, and considering the safety of users as the top priority, the main bridge was closed to all traffic while using a parallel new bridge to maintain traffic, and emergency measures were implemented to complete the measures before the imminent flooding season. Since the ground on which the pier bases rested was judged to have sufficient bearing capacity, it was decided to increase the immediate stability of the piers by consolidating the bottom of the piers, and concrete was used to fill not only the underside of the piers but also the inside of the revetment concrete to make the piers one piece. To ensure reliable filling and prevent leakage to the surrounding area, steel sheet piles were placed around the revetment concrete,

#010 Japan (1): Extensive scouring in the concrete revetment and the pier foundation	
	and filling was done from the 14 core holes used in the survey. The cavity was confirmed to be closed by core drilling, and a second filling was performed from the core hole for further confirmation. In the case of irregular voids and water flow, there is a high risk that the mortar content of the concrete will flow out and cause insufficient filling. Therefore, it was necessary to ensure that water flow is intercepted during construction, and to properly plan the filling sequence and location, the amount to be applied at one time, the setting of discharge routes for air and water to be replaced, and methods for checking filling.
Pictures of the repair/rehabilitation materials and technologies	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	Since the emergency measures ensured at least the same level of safety in service as before the scour, the bridge was immediately put into provisional service. However, the scouring and structural conditions revealed by this survey indicate that the possibility cannot be denied that the scouring may progress again due to rising river water or that the bridge may become unstable due to the effects of earthquakes. Therefore, more stringent management standards than usual were established specifically for this bridge, including monitoring during abnormal conditions and restricted use in the event of an earthquake or rising river water until permanent measures are taken.

#010 Japan (1): Extensive scouring in the concrete revetment and the pier foundation	
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	When any kind of deformation is reported in bridges or other important structures, it is important to first visit the site and experience the condition, regardless of whether it is minor or major. In addition, it is also important to accurately recognize what is obvious and what is not, and to respond promptly, giving top priority to the safety of users, and to be prepared to respond quickly, including the maintenance of related technical information.
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

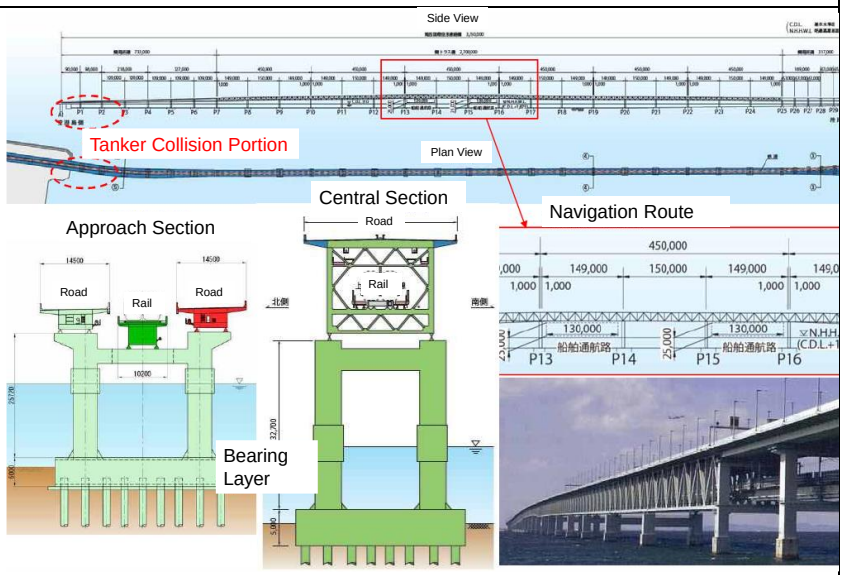
#11 JAPAN (2): Tanker ship collided with the bridge due to typhoon

Description of bridge	**Total length of the bridge is 3.75 km and access bridge to the International Airport on the man-made island.** **Bridge type is double deck steel continuous truss bridge with road and rail at upper and lower deck, respectively.**
Impact due to Climate change	**Due to the fierce winds of Typhoon No. 21 on September 4, 2018, a tanker ship moored near Kansai Airport collided with the bridge, causing severe damage to the bridge girders.**

Classification

1. Climate	**Wind**
2. Hazards	**Tropical storms, Gusts, Ocean waves**
3. Impact on bridge	**Extreme load impact (Tanker ship collision)**
4. Action	**Replace or repair girders depending on damage**

#11 JAPAN (2): Tanker ship collided with the bridge due to typhoon

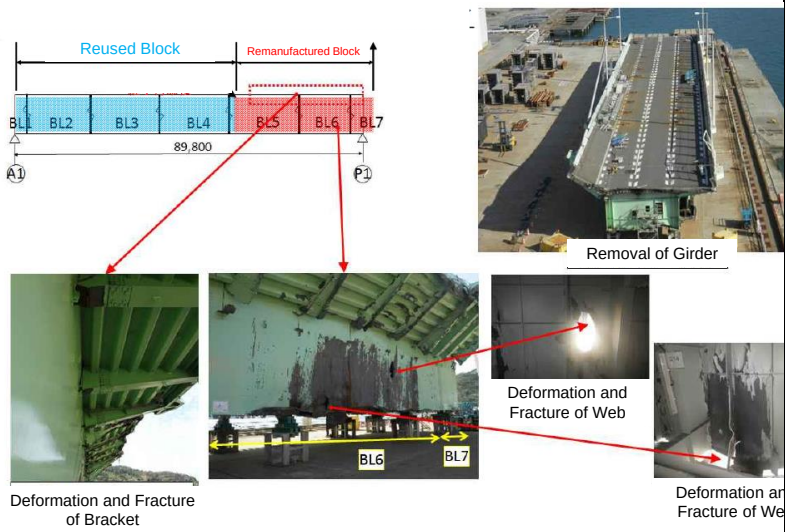
#11 JAPAN (2): Tanker ship collided with the bridge due to typhoon	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	KIX Bridge (access bridge to Kansai International Airport Island) Total length: 3.75 km Bridge type (central section): Steel continuous truss bridge (double-deck structure with road at upper deck and rail at lower deck) Bridge type (approach section): Steel continuous box girder bridge (separate road and rail structures)
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …

#11 JAPAN (2): Tanker ship collided with the bridge due to typhoon	
Answer	Due to the fierce winds of Typhoon No. 21 that hit the Kansai region on September 4, 2018, a tanker ship moored near Kansai Airport collided with the bridge at around 13:40 on the same day, causing severe damage to the bridge girders. At the time, the road was closed due to strong winds, but in order to rescue the approximately 8,000 passengers left at the airport, buses and other emergency vehicles began to use the in-bound line, which was not directly affected by the tanker collision, for one-way alternating traffic from 0:40 a.m. on September 5.
Picture of the problem	
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	As a result of the investigation, the girders at two spans of A1-P1 and P1-P2 girder were damaged so much that they were removed by using a large FC vessel and repaired or remanufactured. The decision to reuse the girders was made on a block-by-block basis, after a detailed survey was conducted at the plant. If large deformation or rupture is found in the block, partial repair is considered difficult and the block will not be reused. If no large deformation or rupture is observed, after the confirmation of no cracks or fractures at the welding and member accuracy requirements specified by the design code, the block will be used. In the girders at the span of P2 and P3, the side longitudinal girders, lower flange and web of the overhang were damaged. To repair the damage, a suspended scaffold was set up on site, and the damage was repaired by replacing the plates and parts of the girders.

#11 JAPAN (2): Tanker ship collided with the bridge due to typhoon

Pictures of the repair/rehabilitation materials and technologies

Removal of Girder by FC Vessel



Confirmation of Girder Damage (A1-P1)

Web and Lower Flange:
Steel Plate Patching
(No bolts are used in the a
where the deformation is la
and the gap between the ba
material and patched plate
filled with resin.)

Wind Stabilizer:
Partial Replacement

Repair of Web and Lower Flange (P2-P3)

#11 JAPAN (2): Tanker ship collided with the bridge due to typhoon	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	In this case, complete restoration was achieved in a very short period of time, only seven months after the disaster. This was made possible by the road administrator's crisis management system and advanced expertise in directing the companies involved and coordinating with related agencies.

#11 JAPAN (2): Tanker ship collided with the bridge due to typhoon	
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	1) Sato et al.: Restoration of Bridge Girders Damaged by Tanker Ship Collision at Kansai International Airport Bridge, Bridges and Foundations, June 2019. 2) Japan Society of Civil Engineers, Committee on Earthquake Engineering: Report of the Research Subcommittee on Tsunami and Flood Resistance Design of Bridges, November 30, 2020.

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)

Description of bridge	**Netherlands is located under delta condition. Many bridges are located in low elevations.**
Impact due to Climate change	**Since the flood problems in 1995 and 1996 we have started to design our river crossings differently.**

Classification

1. Climate	**Precipitation, Temperature**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Erosion**
3. Impact on bridge	**Clearance under bridge**
4. Action	**Raise the elevation of the bridge**

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Netherlands is located under delta condition. Many bridges are located in low elevations. The following photos are some of examples which were affected due to flooding, water level rise, and so on. Noordwaard project 
Picture of the bridge	Bridge over the side channel at the Waal at Lent in Netherlands.

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)	
	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	Since the flood problems in 1995 and 1996 we have started to design our river crossings differently.

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)	
Picture of the problem	 
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	(1) Climate change adaptive design The bridges over the side channels can also be seen as climate adaptive design. The bridge at Lente over the side channel at the Waal near Nijmegen is an example of this.

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)

Bridge over the Waal near Nijmegen.

Bridges over breached dikes in the Biesbosch (Noordwaard project)

Where there was no bridge before, there is a new bridge north of the old Waal bridge over a new side channel.

This bridge is actually only in function when the Waal floods.

Within the Noordwaard project, several bridges have been built that only function in situations where extreme water storage is needed.

So, we are making more bridges and longer bridges than before to give our rivers more space during high water conditions.

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)	
	(2) Fewer piers and slimmer river piers to prevent 'impoundment' upstream. With the program “Room for the River”, measures are also mandatory under the Water Act. In addition to the Water Act test (on maximum permissible impoundments and adverse effects in the summer and winter beds), a test is also carried out on the water level decline to be realized at the Normative High Water level. N.B. I can also argue that in specific cases we need fewer bridges. Rising sea levels are making it increasingly difficult to discharge excess (fresh) water at low (sea) levels. For the Afsluitdijk this means not building extra sluices (with a bridge over them), but that the solution must be found in additional pumping stations. A pumping station does not require a bridge. Only a dam.  Bridge over Lorentz locks no longer needed? Soon a dam with a pumping station?
	(3) Prevention of flooding under the bridge 

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)	
	 In the past, it was frequently chosen to increase the profile of free space by lowering the road below. Raising a bridge is quite a task, lowering a road is relatively easy. With today's rains, it has already become a regular occurrence that additional measures are required to keep dry feet under an overpass. Larger pump cellars, more powerful pumps and, in the design, raising the viaduct anyway, with all the drawbacks that this brings.
Pictures of the repair/rehabilitation materials and technologies	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	The government is taking measures to protect the Netherlands from the effects of climate change (=climate adaptive). In addition, further global warming can be limited by reducing greenhouse gas emissions. The "Space for the River" program could be seen as climate adaptive design, which typically belongs to delta conditions.
4a) Have you implemented any monitoring / inspection /	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.

#12 Netherlands (1): Space for the river program (Raise the elevation of the bridge)	
testing / NDT to identify the effects of climate change?	
Answer	
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	In addition to the Water Act test (on maximum permissible impoundments and adverse effects in the summer and winter beds), a test is also carried out on the water level decline to be realized at the High Water level.
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

#13 Netherlands (2): Temperature expansion (combined with unforeseen settlement)

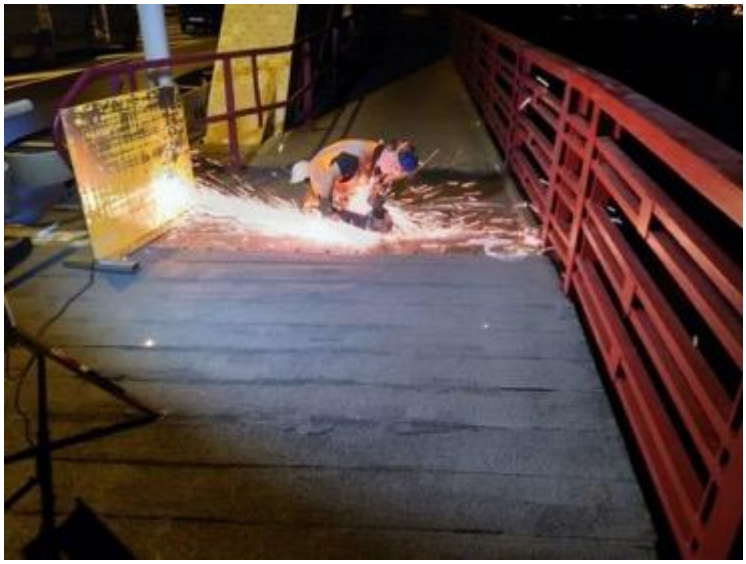
Description of bridge	**Movable bridge with a span length of maximum 32 meters and cross over a river. Bridges are old but the bascule bridges are around 1960 and up**
Impact due to Climate change	**Movable bridges are particularly affected by jamming due to temperature expansion.**

Classification

1. Climate	**Temperature**
2. Hazards	**Heat (waves)**
3. Impact on bridge	**Expansion**
4. Action	**Shortening the movable bridge as a definitive measurement.**

#13 Netherlands (2): Temperature expansion (combined with unforeseen settlement)

#13 Netherlands (2): Temperature expansion (combined with unforeseen settlement)	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Bridge is a movable bridge with a span length of maximum 32 meters and cross over a river. Due to river transport the height of the main bridge is to low and therefore we need movable bridges. Bridges are old but the bascule bridges are around 1960 and up
Picture of the bridge	Merwedebrug 
2) **Brief description of the need of the repair/rehabilitation and/or monitoring/inspection.** What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	Movable bridges are particularly affected by jamming due to temperature expansion.

Picture of the problem	  Cooling measurements are required as a temporary solution.
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	Grinding down existing bridges, making the joint at a new bridge adjustable.  Shortening the movable bridge as a definitive measurement. Techniques have been developed to quickly grind bridges to the desired joint width, and to post-adjust

Pictures of the repair/rehabilitation materials and technologies	Grinding down existing bridges, making the joint at a new bridge adjustable.
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	Temporary cooling is of limited use: a) You have to do it every time the problem occurs b) Because you can only cool part of the bridge (only the top plate), much of the expansion remains in the bridge.
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	Techniques have been developed to quickly grind bridges to the desired joint width, and to post-adjust Measurement equipment is developed to measure expansion. These are located at several movable bridges like Merwedebrug See attachment in Dutch.
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	The monitoring data are real time available on an app so the caretaker can take measurements on time.
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding

	cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

#14 Niger: Silting under a bridge in the Galmi valley

Description of bridge	**RC girder bridge; two 15 m long spans constructed in 1970 in the Galmi valley (Niger)**
Impact due to Climate change	**Accumulation of sediments in the valley due to soil erosion obstructed the waterway under the bridge. As a result, the road is submerged in case of heavy rain.**

Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Erosion, Debris current**
3. Impact on bridge	**Clearance under bridge**
4. Action	**Rebuild**

#14 Niger: Silting under a bridge in the Galmi valley

#14 Niger: Silting under a bridge in the Galmi valley	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	RC girder bridge; two 15 m long spans constructed in 1970 in the Galmi valley (Niger)
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance…
Answer	Accumulation of sediments in the valley due to soil erosion obstructed the waterway under the bridge. As a result, the road is submerged in case of heavy rain. Traffic may be completely stopped for hours or even days. The solution adopted is to raise the road level 2 m up including the deck of the existing bridge.

#14 Niger: Silting under a bridge in the Galmi valley	
Picture of the problem	 
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	Since there is a need to enlarge the deck from 8.2 m to 9 m, the solution adopted is to raise intermediate peers and abutments 2 m up and reconstruct a new deck. The raising of peers is done by drilling holes in the existing peer cap for putting reinforcement bar. Anchorage of bars is achieved by using a sealing compound. The existing abutments are made of a thin retaining wall linked to exterior peer caps. Raising of abutments is done by constructing a retaining wall abutment witch foundation is supported by existing exterior peer cap and adjacent soil.

#14 Niger: Silting under a bridge in the Galmi valley	
Pictures of the repair/rehabilitation materials and technologies	  
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …

#14 Niger: Silting under a bridge in the Galmi valley	
Answer	The major aspects taken into account are the local capacity to do the raising, the cost and the time factor.
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	No
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	With regard to our own context cost and time of traffic disruption seems to be the main benefits
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	It only raises the road level but do not address the silting aspect that created the problem.
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	

#15: Norway: Floods reduced and removed erosion protection

Description of bridge	**Middøla bridge. Typical reinforced concrete bridge. Length is 20.3 meters.**
Impact due to Climate change	**Floods reduce and remove erosion protection**

Classification

1. Climate	**Precipitation**
2. Hazards	**Heavy precipitation, River flooding, Flash flood, Erosion**
3. Impact on bridge	**Scouring, Settlement, Slope stability**
4. Action	**New and better erosion protection.**

#15: Norway: Floods reduced and removed erosion protection

#15: Norway: Floods reduced and removed erosion protection	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Middøla bridge. Typical reinforced concrete bridge. Length is 20.3 meters.
Picture of the bridge	
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	Floods reduce and remove erosion protection

#15: Norway: Floods reduced and removed erosion protection	
Picture of the problem	 
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	New and better erosion protection.
Pictures of the repair/rehabilitation materials and technologies	

#15: Norway: Floods reduced and removed erosion protection	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	• Method/Technique comparison
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	No
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	The repair protects the bridge from future floods.
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	https://vegvesen.brage.unit.no/vegvesen-xmlui/handle/11250/2687426

#16 Portugal (1): High rain-wind induced vibration on stay cables

Description of bridge	**Guadiana International Bridge completed in 1991 is a cable-stayed bridge with semi-fan system and prestressed concrete deck (width: 18 m). Total length of 666m and a central span of 324m.**
Impact due to Climate change	**Rain-wind induced vibrations in strand bundles, without sheathing could be significant as well as may result in the instable vibration of galloping.**

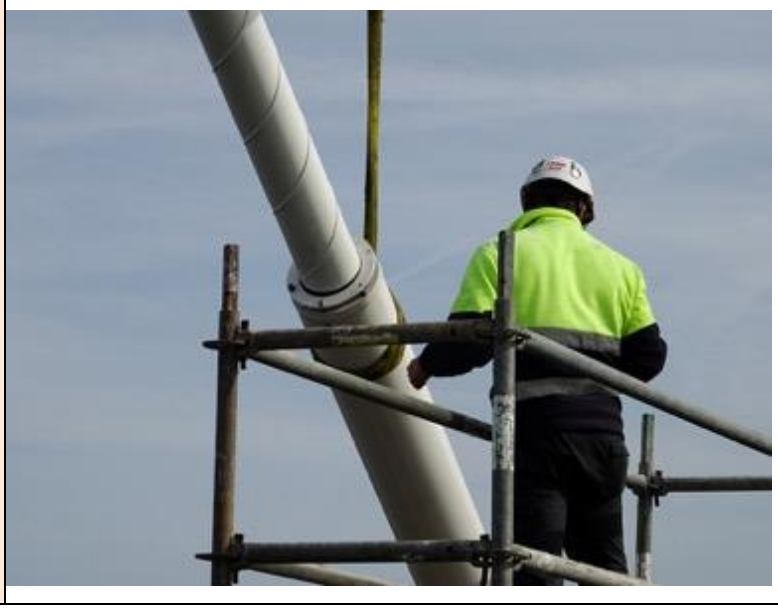
Classification

1. Climate	**Wind**
2. Hazards	**Storms, Gusts**
3. Impact on bridge	**Dynamic load**
4. Action	**Replace the cable system of the bridge.**

#16 Portugal (1): High rain-wind induced vibration on stay cables

#16 Portugal (1): High rain-wind induced vibration on stay cables	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Completed in 1991, is a cable-stayed bridge with semi-fan system and prestressed concrete deck (width: 18 m). The bridge has a total length of 666m and a central span of 324m. The 2 lateral spans and the 2 transition spans are, respectively, 135 and 36m long. The deck stands 20m above the river. The structure includes two 100m-high pylons.
Picture of the bridge	 
2a) Brief description of the need of rehabilitation	Describe why it is necessary to rehabilitate the bridge: degradation (which type), increasing service level (load capacity for example), …
Answer	The constructive technology used for the cable system of this bridge was introduced in the late 1980s and has been implemented worldwide on several bridges. This solution aimed to improve the corrosion protection and to allow the individual replacement of the strands. With the individual protection of each strand, it was possible to avoid the sheathing of the strand bundle. However, the rain-wind induced vibrations in those strand bundles, without sheathing (non-circular cross section), could be significant (when compared with sheathed strand bundles) as well as may result in the instable vibration of galloping. During bridge inspection, it was found: • Vibration in cables, with moderate wind. In some cables, strands pulsed as clamps were damaged or out of place (installed at cable length intervals); • Damages/abrasion on the coating of the individual strands, specially at deck level, near the vandalism protection pipes;

#16 Portugal (1): High rain-wind induced vibration on stay cables	
	• Failure of the sealing system in the anchoring areas, corrosion on the steel pipes and water retention in the caps; For these reasons, which may lead to the rupture of strands, it was decided to replace the cable system of this bridge.
Picture	
2b) Is this need of rehabilitation related to the effect of climate change	Is the need of rehabilitation related to climate change effects? For example: • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • … If yes, explain.
Answer	Not directly. This structural rehabilitation mitigates rain-wind induced vibrations on cables, and it may be a good solution taking into account an eventual increase in winds / storms related to the effect of climate change.
3a) Describe your new rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion

#16 Portugal (1): High rain-wind induced vibration on stay cables	
Answer	Main materials used: • Stay cable strands Ø15,7mm with a nominal cross section 150mm² (prEN 10337-Y 1860 S7); • DYNA Grip® Stay Cable System (Type DG-P31, Type DG-P37 and Type DG-P55); • TYPE 62 - DELLNER DAMPERS (on cables longer than 130m); Technologies and methods: • DYNA Grip® Stay Cable System developed by DSI – DYWIDAG-SYSTEMS INTERNATIONAL; • DYWIDAG stressing equipment – ConTen System Year of completion: 2021
Pictures of the new rehabilitation materials and technologies	 

#16 Portugal (1): High rain-wind induced vibration on stay cables	
	 
3b) Which aspects were taken into account in the decision-making process while selecting the new rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	Detours/Traffic impacts/Availability • Fast Construction accomplished with few traffic impacts (One lane was opened on each side, allowing traffic to move during the rehabilitation works) Method/Technique comparison • The correct function of strands can be checked and even adjusted during inspection; • The anchorages have been designed for threading the strands including their PE-sheathing through the anchorage; • Replaceability of the strands: strand exchange is performed directly at the anchorages; there is no need for moving the cable's outer stay pipe for accessing the strand bundle either at the deck or outside the pylon – no disruptions to traffic; Durability • this new system protects the strands and minimizes rain-wind induced vibrations on cables;

#16 Portugal (1): High rain-wind induced vibration on stay cables	
	• Bending stresses are minimized by a filter that arranges a straight-line entering into the wedge gripping area; • Compressible sealing plates ensure water and even vacuum tightness); • Fire Protection Mats for the Free Cable Length;
3c) Have developments in materials and technology given rise to an environmental assessment?	Describe, if applicable, how the environmental assessment of the materials and technology used was carried out.
Answer	Not applicable.
3d) Did the use of this innovative method helps to reduce traffic impact of the works?	Describe, if applicable, how this innovative method reduces the traffic impact of the works.
Answer	Not directly. The method used allowed only the simultaneous replacement of 2 symmetrical cables (on one tower at a time), from the shortest to the longest, as superstructure static equilibrium requirements were maintained. Lightweight equipment for strand installation and stressing operations was provided by DSI. The use of tower cranes or other lifting equipment could be limited to a minimum. Traffic impact of the works: traffic always open (one lane open on each side; other 2 lanes closed). In the future, this method allows the replaceability of the strands with no disruptions to traffic (As the PE-coating is pulled directly through the anchorage, an exchange of strands is possible at any time during the service life of the bridge without the need for renewing or replacing any other cable components).
4a) Have you implemented any monitoring/testing/NDT of the rehabilitation after works?	Did you implement a monitoring of the bridge behaviour after the rehabilitation works? If any, please describe it.
Answer	Yes. DYNA Force® Elasto-Magnetic Force Monitoring System. The force measuring technique is based on the elasto-magnetic properties of ferromagnetic materials and is carried out using DYNA Force® Sensors. The magnetic permeability of steel in a magnetic field change as a function of the mechanic normal stress condition of

#16 Portugal (1): High rain-wind induced vibration on stay cables	
	the steel. By measuring the relative change in magnetic permeability, the normal stress in the steel tendon can be determined. In this bridge: 2 sensors for each cable, placed directly on the strands, behind the passive anchorage (total of 256 sensors, 128 per tower). With this monitoring solution, it is possible to measure the force on cables at any time during the life of the bridge.
4b) What are the main conclusions of the monitoring?	Considering the observation period, what are the main conclusions of the monitoring related to the behaviour of the bridge?
Answer	No results yet.
5a) Main benefits of the method?	From your point of view what are the main advantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	This method made possible the replacement of the cable system, strand by strand (individually), allowing the use of lightweight equipment, for strand installation and stressing operations, in areas with reduced space (inside the towers). More information in 3b) and 3d)
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	At this moment, it is not possible to say any disadvantage. This method aims to improve and minimize deficiencies found in the previous cable system.
6) General appreciation of the method.	Give a global appreciation of the method
Answer	For the first time in Portugal, a cable system was fully replaced in a cable-stayed bridge. After the success of the rehabilitation works, this bridge is 30 years old with a lifespan of 100 years. More information in 3b) and 3d)
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	Materials used:

#16 Portugal (1): High rain-wind induced vibration on stay cables	
	DYNA Grip® Stay Cables (Type DG-P31, Type DG-P37 and Type DG-P55) https://www.dsicanada.ca/fileadmin/downloads/dywidag-emea/dsi-dywidag-multistrand-stay-cable-systems-en.pdf TYPE 62 - DELLNER DAMPERS (on cables longer than 130m) https://www.bdeibig.com/IBIG/adverts/IBIG21793wpb2.pdf Monitoring system after rehabilitation works https://www.dywidag-systems.com/fileadmin/downloads/dywidag-emea/dywidag-dyna-force-elasto-magnetic-force-monitoring-system-emea-en.pdf

#17 Portugal (2): Impact on steel bridges due to extreme temperature differences

Description of bridge	**Old and long steel bridges (end of 19th century, beginning of 20th century)**
Impact due to Climate change	**Due to extreme temperature differences i.e., day-time to night-time temperature differences exceeding the limits assumed during design.**

Classification

1. Climate	**Temperature**
2. Hazards	**Heat (waves)**
3. Impact on bridge	**Expansion**
4. Action	**The inspection of these bridges must be carried out at the maximum and minimum ambient temperature, to verify the behaviour of the structure in the real temperature conditions and compare with those defined in the design.**

#17 Portugal (2): Impact on steel bridges due to extreme temperature differences

#17 Portugal (2): Impact on steel bridges due to extreme temperature differences	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Old and long steel bridges (end of 19th century, beginning of 20th century)
Picture of the bridge	a) Case 1 – Truss bridge; 3 spans (50 + 60 + 50); Length 160 m  b) Case 2 – Truss viaduct; multiple span; Length 570 m 
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection. What was the effect of climate change that prompted the	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), … What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example :

#17 Portugal (2): Impact on steel bridges due to extreme temperature differences	
repair/rehabilitation and/or monitoring/inspection?	• Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	Due to extreme temperature differences i.e., day-time to night-time temperature differences exceeding the limits assumed during design. This problem occurs in some bridges, where the annual temperature varies between 0 and more than 40 degrees centigrade. It is not very common, but it could be a concern if there is a general increase in maximum temperature in the near future in Portugal. In 2 bridges it was detected crushed elements and shear stress in bolts connections (can lead to fatigue), that could be related to the increase of extreme temperature differences, or just due to an insufficient design or lack of maintenance. At the present time there are no serious damages.
Picture of the problem	a) Case 1 – crushed elements  b) Case 2 – shear stress in bolts connections + crushed elements 

#17 Portugal (2): Impact on steel bridges due to extreme temperature differences	
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	N/A
Pictures of the repair/rehabilitation materials and technologies	N/A
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	N/A
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	Steel bridges respond very quickly to temperature variations, and it's easy to observe the deck movements and to measure different GAPs in the expansion joints throughout the different periods of the day (morning, afternoon, night). During a bridge inspection it's very common to measure different GAP values in the same expansion joint observed. The inspection of these bridges must be carried out at the maximum and minimum ambient temperature, to verify the behaviour of the structure in the real temperature conditions and compare with those defined in the design.

#17 Portugal (2): Impact on steel bridges due to extreme temperature differences	
Pictures of the monitoring / inspection / testing / NDT	
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	Simple measures with a ruler, could be enough to verify the behaviour of the structure in the real temperature conditions and compare them with those defined in the design. This may seem like an archaic method, but it allows to define/design new gaps in the joints between elements.
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	Simple and with low cost.
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	In old steel bridges, usually there are only 1 fixed support (fixed bearings at 1 pillar), and the deck can move without any stress during the variation of temperature (isostatic structure). In this sense, this method is simple and effective. In hyperstatic structures, temperature stress distribution occurs, and may lead to unexpected behaviour on bridge elements (deck, piers). In this case, this method isn’t good enough and more accurate tools will have to be used.
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.

#17 Portugal (2): Impact on steel bridges due to extreme temperature differences	
Answer	In the future, new maximum and minimum temperature limits should be studied, to be incorporated into design codes, based on updated data
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	N/A

#18 Portugal (3): Heavy rains and increase drainage capacity

Description of bridge	**Cable Stayed bridge built in 2000 with main span length of 250m and total length of 570m.**
Impact due to Climate change	**It was realized that the drainage system of the bridge was insufficient, as surface water / hydroplaning occurs during heavy rains and contributes to accidents.**

Classification

1. Climate	**Precipitation**
2. Impact on bridge	**Heavy precipitation**
3. Problem on bridge	**Insufficient drainage capacity**
4. Action	**Increase drainage capacity.**

#18 Portugal (3): Heavy rains and increase drainage capacity

#18 Portugal (3): Heavy rains and increase drainage capacity	
1) Brief description of the bridge (type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Cable Stayed bridge; main span length - 250m; total length - 570m. The bridge was built in 2000. Cable-stayed bridge with semi-fan system; Post-tensioned concrete box girder. 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. Bearings (pot, elastomeric), expansion joints (Freyssinet Multiflex SX Joint), New jerseys, rails, drainage.
Picture of the bridge	   
2) Brief description of the need of the repair/rehabilitation and/or monitoring/inspection.	Describe why it is necessary to perform repair/rehabilitation and/or monitoring/inspection: degradation (which type), increasing service level (load capacity for example), …

#18 Portugal (3): Heavy rains and increase drainage capacity	
What was the effect of climate change that prompted the repair/rehabilitation and/or monitoring/inspection?	What is the cause of repair/rehabilitation and/or monitoring/inspection related to climate change effects ? For example : • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • …
Answer	It was realized that the drainage system of the bridge was insufficient, as surface water / hydroplaning occurs during heavy rains and contributes to accidents. The reason is the insufficient drainage capacity of the downspouts (insufficient number and diameter), and by the fact that the slopes were very low. For this reason, it was decided to increase drainage capacity.
Picture of the problem	
3a) Describe your repair/rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	Increase the diameter of 419 downspouts (from 100mm to 160mm) and drill 10 new ones (material: High-Density Polyethylene Pipes).

#18 Portugal (3): Heavy rains and increase drainage capacity	
	2009.
Pictures of the repair/rehabilitation materials and technologies	
3b) Which aspects were taken into account in the decision-making process while selecting the repair/rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others)

#18 Portugal (3): Heavy rains and increase drainage capacity	
	• Method/Technique comparison • …
Answer	Detours/Traffic impacts/Availability.
4a) Have you implemented any monitoring / inspection / testing / NDT to identify the effects of climate change?	Did you implement a monitoring/inspection of the bridge behaviour? If any, please describe it.
Answer	N/A
Pictures of the monitoring / inspection / testing / NDT	N/A
4b) What are the main conclusions of the monitoring/inspection?	Considering the observation period or inspection results, what are the main conclusions of the monitoring/inspection related to the behaviour of the bridge?
Answer	N/A
5a) Main benefits of the method?	From your point of view what are the main advantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	N/A
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this repair/rehabilitation or monitoring/inspection method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	N/A
6) General evaluation of the method.	Give a global evaluation of the repair/rehabilitation or monitoring/inspection method, if available.
Answer	N/A
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	N/A

#19 Switzerland: Pavement and waterproofing of decks were deformed and leaked.

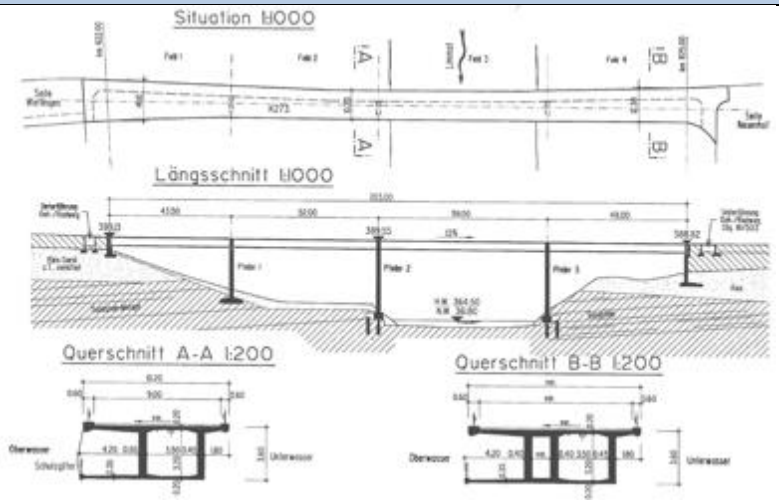
Description of bridge	**Prestressed box girder and reinforced concrete bridge, built between 1970 and 1971, in service since 1971; part of a two-lane county road leading to a highway access, actual traffic is 22,000 cars/day.**
Impact due to Climate change	**Pavement of upper deck was extremely deformed and. Pavement and waterproofing of lower deck (bicycle and pedestrian lane) was leaking.**

Classification

1. Climate	**Temperature**
2. Hazards	**Heat (waves), Daily temperature range (DTR)**
3. Impact on bridge	**Material evolution**
4. Action	**Ultra-high performance concrete (UHPC) was applied to replace the pavement and waterproofing of the lower deck.**

#19 Switzerland: Pavement and waterproofing of decks were deformed and leaked.

#19 Switzerland: Pavement and waterproofing of decks were deformed and leaked.	
1) Brief description of the bridge type, material, construction time, …	Provide a short description of the bridge including bridge type, material (steel, reinforced concrete, prestressed concrete, timber, bricks, …), construction time, span lengths, …
Answer	Object N1-504 in Neuenhof, canton Aargau, switzerland; Prestressed box girder and reinforced concrete bridge, built between 1970 and 1971, in service since 1971; part of a two-lane county road leading to a highway access, actual traffic is 22'000 cars/day. In the "good old days" of the 60ies, they planned a 2nd symmetric bridge parallel to the existing one. They prepared abutments wide enough for two similar bridges. The abutments were built them in the 70ies. The foundations of the intermediate pillars for the 2nd bridge were though not built. Right now, no 2nd bridge is in consideration.
Picture of the bridge	 Bridge superstructure, view of the side with 2nd deck.

#19 Switzerland: Pavement and waterproofing of decks were deformed and leaked.	
	 Technical sketch of the bridge: “floor plan”, elevation, cross sections on main length and on widening part (both ends).
2a) Brief description of the need of rehabilitation	Describe why it is necessary to rehabilitate the bridge: degradation (which type), increasing service level (load capacity for example), …
Answer	• Pavement of upper deck (motorway) was extremely deformed, specially in the zones in front of the semaphores • Pavement and waterproofing of lower deck (bicycle and pedestrian lane) was leaking • guide barriers did no longer cover actual standards, and under the bridge are inhabited buildings • rims had (minor) deteriorations related to corrosion of rebars (low coverage, de-icing salts) • Road wastewater may no longer be discharged into the Limmat River, but must be directed to the wastewater treatment plant - on the other side of the river.
Picture	

#19 Switzerland: Pavement and waterproofing of decks were deformed and leaked.	
	The deformations are visible in wet conditions – water shows where the wheels of the cars normally are.  In this picture, the water shows clearly the deep deformation in the pavement.
2b) Is this need of rehabilitation related to the effect of climate change	Is the need of rehabilitation related to climate change effects? For example: • Due to increasing flooding risk you may need to improve scouring protection of piers. • Due to increasing heavy rains you decide to increase drainage capacity. • Due to increasing temperature you use a new asphalt pavement with higher heat-resistance • … If yes, explain.
Answer	Due to increasing temperature a new mastic asphalt pavement with higher heat-resistance was used on the upper deck. This may be a small effect to the deformations the pavement layers show. Another cause of the deformations are the public transportation busses on the bridge, which blow air passing the liquid motor cooling device straight downwards while waiting in front of the signs- on the bridge.
3a) Describe your new rehabilitation materials and/or technologies.	Make a short explanation of the rehabilitation's materials and/or technologies that were applied. Give the year of completion
Answer	Ultra-high performance concrete (UHPC) was used on two parts of the bridge:

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	• to replace the pavement and waterproofing of the lower deck • to rehabilitate the rims of the upper and lower deck (3 rims) The UHPC used for the replacement of the waterproofing of the lower deck as well as for the repair of the three rims was a “traditional” UHPC, one of several available products available, even as bagged material, a premix kit. In this case, it was AHADur from Kibag, a Swiss company. In order to achieve a surface of UHPC that was suitable for pedestrians and cyclists, but also to test its suitability as a road surface, a new “Splitt-Matrix” of UHPC without steel fibers but with angular grains of hard stone was produced..
Pictures of the new rehabilitation materials and technologies	Application of both layers on the lower deck was carried out with a setup well known from concrete worksites, slightly adapted to the building site, a concrete vibrating beam. What is “Splitt-Matrix” in UHPC? • Roughening the concrete surface with hydrodynamic methods, 5-10 mm in-depth • Installing first layer 25 mm (1”) of UHPC with steel fibers, as needed; apply curing immediately (crucial in windy-sunny situations!) • On the next day, micro-roughen the UHPC layer with reduced hydrodynamic methods (less than 5 mm in-depth), and installing 15 mm “Splitt-Matrix” in UHPH without fibers but with broken hard grains; applying curing /retarder* immediately (crucial in windy-sunny situations). • After some hours waiting time: wash grains free until the desired roughness is achieved. *: mixture of a curing compound and a retarding solution, which can be adjusted to the desired

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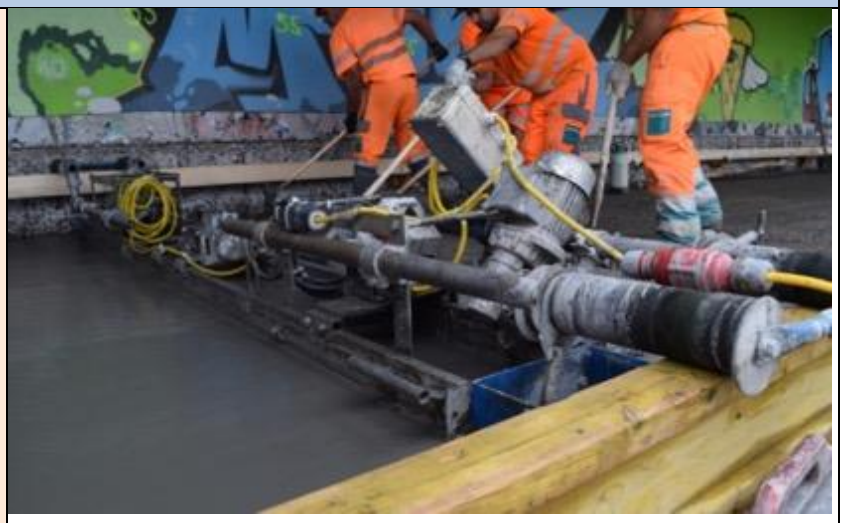

"Tremix" concrete vibrating beam in use on lower deck

Quiet a team needed around the "Tremix" beam.

Application of the first layer on the lower deck

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Finished UHPC application on lower deck (rehabilitation measure of the lower part of the web, also in UHPC, not jet executed). Rim with new anchor bolts for the bridge railing, deck pavement.

Impression of the obtained surface on the lower deck; a testing probe is visible, too.

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Close-up of the surface, units of the scale are centimeters

Other samples of the “splittmatrix” made with a different UHPC product.

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Interested engineers of other bridge offices authorities of cantonal highway administration are inspecting samples of the “splittmatrix” surface. This surface made in “Splitt-Matrix” UHPC met all the requirements for a road for motorized traffic: Flatness, skid resistance, adhesion, texture.

Close-up of the lower rim in UHPC and the pavement in “Splitt-Matrix” UHPC, units of the scale in centimeters

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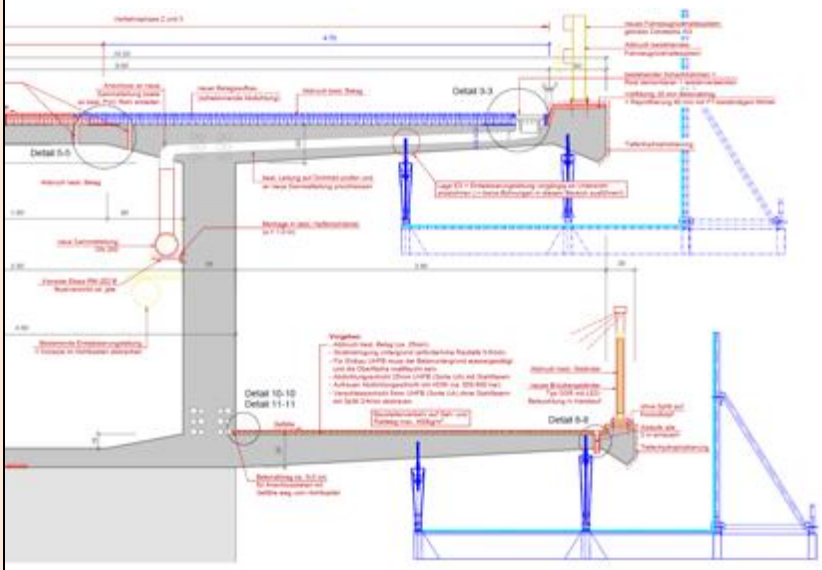
Close-up of the lower part of the outer web adjacent to the UHPC pavement, on a part with corroded duct of one prestressed tendon. The strands were without corrosion. The injection grout was in good condition. The rehabilitation measure consisted of carefully opening the area of the metal duct marked in yellow (a few more locations along the 200 m long measuring bridge at the low areas of the tendons), removing the grout material (possibly contaminated with de-icing chlorides), sealing the cladding tube with the same metal duct, injecting this part under pressure and placing a 5 cm (2") thick UHPC layer in front of the entire lower part of the bridge. This layer of UHPC was also used to fill all removed parts of concrete around the ducts.

Year of execution was 2020.



Technical plan of executed measures, one half of cross section showed. Measures on upper deck and rim were part of separate stages of construction.

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	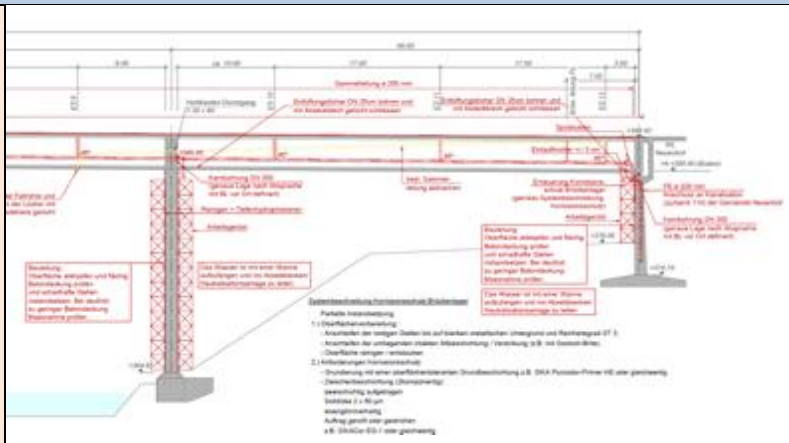 Elevation, 1/3 of the bridge shown. A detailed condition survey was carried out on the superstructure, piers and abutments after the scaffolding had been erected and with the use of under-surveillance equipment. Due to the relatively good condition despite the low concrete cover, the construction measures were limited to the application of a hydrophobic coating to the piers.
3b) Which aspects were taken into account in the decision-making process while selecting the new rehabilitation materials and technologies.	For example: • Detours/Traffic impacts/Availability • Sustainability • Environmental (material/technology/others) • Method/Technique comparison • …
Answer	The bicycle and pedestrian path on the lower level of this bridge represents a main connection for students between Neuenhof and Wettingen, the location of a cantonal high school. The upper level is one of the main accesses from the Baden-Wettingen area to the A1 freeway, the main axis of the national road network in Switzerland, connecting Geneva, Bern and Zurich. For the construction measures on the lower level, it was therefore necessary to use the 5 weeks of the summer holiday period, during which significantly fewer bicycles and pedestrians use the bridge. During this time, everything had to be carried out: Preparation, scaffolding, demolition, repair, installation of railings. This short time window led to the choice of simpler construction measures with fewer work steps. The logistics were limited to access via bicycle path, i.e., with small equipment. A sealing with pavement according to current standards would have been 7.5 cm (3") thick and would have meant 3 times the dead weight. With the chosen solution (1 layer of UHPC of 2.5 cm (1") and 1 layer of “Splitt-Matrix” in UHPC of 2 cm (3/4 ") the additional ballast could be reduced by half.
3c) Have developments in materials and technology given	Describe, if applicable, how the environmental assessment of the materials and technology used was carried out.

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rise to an environmental assessment?	
Answer	Environmental comparison was not made in this case; construction time and additional dead load were the criteria, which determined the solution.
3d) Did the use of this innovative method helps to reduce traffic impact of the works?	Describe, if applicable, how this innovative method reduces the traffic impact of the works.
Answer	• Reduction of construction time compared to “traditional” standards used in Switzerland of about 1 week • Reduction of time to reuse the bike and pedestrian way after execution to almost zero – after washing free the grains in the “Splitt-Matrix” in UHPC some hours after installing this layer, the lane was given free to the bikes and pedestrians.
4a) Have you implemented any monitoring/testing/NDT of the rehabilitation after works?	Did you implement a monitoring of the bridge behaviour after the rehabilitation works? If any, please describe it.
Answer	There was no special monitoring taken in consideration, because the impact to the structure was very little. The pavement will be inspected regularly, and the communities of Neuenhof and Wettingen, which are responsible for the regular cleaning and snow removing jobs, are instructed to keep their eyes on this special surface.
4b) What are the main conclusions of the monitoring?	Considering the observation period, what are the main conclusions of the monitoring related to the behaviour of the bridge?
Answer	-
5a) Main benefits of the method?	From your point of view what are the main advantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (capacity to accelerate the repair and/or to reduce traffic disruption), the environmental balance … Including comparison with “more standard method” if any.
Answer	The construction costs for this UHPC construction method are now at almost the same level, compared to the usual construction method for waterproofing and surfacing, so no argument for or against this solution. The consideration of the total costs over the entire service life, on the other hand, promises significantly lower costs and construction interventions. If the user costs are taken into account, the cost consideration improves considerably. This due to the justified expectation that this very high-quality building material results in "build and forget" due to its outstanding durability. Thanks to the very fast curing times and the reduced number of operations compared to standard methods of strengthening and repairing reinforced concrete structures, the time from the beginning of the construction site to the return to service can be significantly reduced.

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	With this construction material, repairs in areas to be driven on can be permanently solved in night operations. A comparison of the environmental impact for a replacement of a railway bridge in Switzerland showed a significantly (40%) improved environmental balance primarily for structures entirely in UHPC, compared to a traditional approach in reinforced concrete..
5b) Main disadvantages of the method?	From your point of view what are the main disadvantages of this method regarding cost, benefit, effectiveness, durability, traffic impact (increasing traffic disruption during works), the environmental balance … Including comparison with “more standard method” if any.
Answer	At the current time of execution in the summer of 2020, we noted the following: - The contractors are not yet used to this construction method, the application of the UHPC construction material requires some commitment in new technologies. - The technology of the "Splitt- Matrix" in UHPC was developed on-site, because the “traditional” method of UHPC slurry with grains sprinkled on it did not succeed with this UHPC product; thus, a spontaneous, not quite expected development. - the steel fibers require a very clean working method, extensive health and safety equipment and scrupulous cleanliness along the logistics and around the site - we had dozens of punctures in bike tires because the UHPC transport took place on the bicycle path... losing a small portion of UHPC sets free hundreds of needles, almost not visible for bikers. - Some cracks will occur in the surface of both layers of UHPC, depending on conditions while construction (wind, sunshine) and effectiveness of curing measures. These cracks end in the layers, decrease in width and do not pass through the whole layer. They become sintered again and do not form damage. But they can unsettle contractors, site managers and bridge owners...

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	 The “Splitt-Matrix” in UHPC shows this crack, too, on some parts the contractor mentioned he had troubles to apply the curing in time… The wooden scale is 20 cm long.
6) General appreciation of the method.	Give a global appreciation of the method
Answer	UHPC combined with a “Splitt-Matrix” in UHPC is the perfect combination of a waterproof, extremely durable repair and reinforcing material combined with a good, pleasant road surface that meets all requirements. These construction materials allow approaching the ideal "zero structural maintenance".
7) References	Give some references if available (papers, website, public domain pictures …)
Answer	Official website of this project: Wettingen/Neuenhof – Sanierung Limmatbrücke - Kanton Aargau (ag.ch) Local newspaper: Limmatwelle: Bei der Sanierung der Limmatbrücke kommt eine Weltneuheit zum Einsatz Contractor’s webpage content to his rehab projects: Projekte | Specogna Bau (specogna-bau.ch) Website of the supplier of the UHPC related to this project: AHADUR – Ultrahochleistungsfaserverbundbaustoff - KIBAG Baustoffe, Bauleistungen & Entsorgung in der ganzen Schweiz, and there on bottom of the list «Limmatbrücke Wettingen»

World Road Association (PIARC)

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