ONLINE BEST PRACTICE GUIDE

Semantic Wiki

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958171.

Document Information

Name	Remark
Document Name	Online best practice guide
Version No.	V1.0
Due date Annex I	15/07/2020
Report date	31/10/2021 (last updated in 30/10/2021, 0.9)
Number of pages	109 (including Annexes)
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Dissemination level	Public

Document history

Ver.	Date	Remark	Author	Checked by
Rev. 0.1	04/10/2021	Creation of the document	E. Bektas	S. Cuerva Navas
Rev. 0.2	18/10/2021	Preliminary draft	E. Bektas	S. Cuerva Navas
Rev. 0.3	20/10/2021	Added Annex 1	E. Bektas	S. Cuerva Navas
Rev. 0.4	22/10/2021	Document for review	E. Bektas	F. Cinquini
Rev. 0.5	26/10/2021	Added info Background Data Wiki	J. Köhler	P. Daró A. Strauss
Rev. 0.6	28/02/2021	Document for review	E. Bektas	F. Cinquini
Rev. 0.7	29/10/2021	Document revised	E. Bektas	F. Cinquini
Rev. 0.8	30/10/2021	Document revised	E. Bektas	F. Cinquini
Rev. 0.9	30/10/2021	Added Annex 2	J. Köhler	F. Cinquini
Rev. 1.0	31/10/2021	Document uploaded	E. Bektas J. Köhler	A. Bigaj-van Vliet

Document approval

Ver.	Date	Approval	Project's Role	Beneficiary
Rev. 1.0	31/10/2021	A. Bigaj-van Vliet	Coordinator	TNO

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Preface

This IM-SAFE online best practice guide report aims to provide a concise summary and overview of the process, knowledge model and information collected and developed within the Semantic Wiki. Each of the case studies listed in this document shows the information related to the best practice (e.g. geolocation, information of the infra assets, applied monitoring systems, etc.) gathered by IM-SAFE project. The online best practice guide can be accessed via the following Wiki link :

https://imsafe.wikixl.nl/index.php/Case_studies_overview.

Follow-up of this development i.e. the extension of the Semantic Wiki with knowledge related to the Survey techniques and the Maintenance Practices for transport infrastructure will be implemented at a later stage in the online Semantic Wiki, and will be delivered with the associated reports giving the background of the two other online deliverables of IM-SAFE project, namely D2.1 and D3.2.

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1 Introduction

1.1 Objectives of the deliverable

In IM-SAFE project, there are three online deliverables planned. These deliverables are as follows:

1. Deliverable 1.2: Online best practice guide for monitoring systems for transport infrastructure
2. Deliverable 2.1: Online interactive catalogue of surveying technologies for transport infrastructure
3. Deliverable 3.2: Online interactive wiki-like map of best practice in risk management and use of KPIs

This report focuses on the content of Deliverable 1.2 and forms the technical background for the online best practice guide (further referred to as IM-SAFE Semantic Wiki). The online best practice guide (IM-SAFE Semantic Wiki) can be accessed via the following Wiki link :

https://imsafe.wikixl.nl/index.php/Case_studies_overview

1.2 Reading Guide

In order to facilitate the understanding and interrelationship between the digital Semantic Wiki and the content used for the digital deliverable itself, this report has been structured in four sections:

- The Plan
  - Data collection
  - Semantic Wiki
- The Result
  - Knowledge Model
  - Visualization and The user Interface
- The Wiki
- The Follow-Up

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2 The Online Best Practice Guide: The Plan

This section presents the plan on setting up a knowledge management system that will connect and coordinate the three online deliverables of the IM-SAFE Project. This system proposes to make the content of those deliverable available, accessible, findable and expandable to the public.

The system will be based on Semantic Wiki Platform so that information and data can be added intuitively. More importantly, the knowledge produced during the project can be consolidated to a wider public. The system is implemented as Semantic Wiki that *resembles an intuitive wiki*[1] and makes *consolidation and assessment of the best practices of monitoring, maintenance and safety possible in the EU and worldwide*[2] as it is publicly accessible.

2.1 Data Collection for the Best Practices

A best practice refers here a specific infrastructure object, where a novel monitoring solutions is applied. The data collection for each best practice aimed to gather all relevant information that would describe the details of the structure and the method of implementation. This description is to be associated to a number of aspects such as structure type, assessment type, material type, degradation processes observed at structure, type of monitoring system etc.

Information will be findable (by hyperlinks) based on the aspects. These aspects are defined by the task partners and is presented below. Up until the submission date of this deliverable, there have been 96 cases collected.

2.1.1 Concept

The “online best practice guide” takes the documentation of case studies as a starting point. This Appendix describes the templates applied for data collection related to the case studies. In general, the information about cases contained in the reference documents is catalysed as modular as possible: the content is defined by a set of attributes and represented in a finite list of fixed options; additionally, free text is given for properties that cannot be associated with one of the options. The online forms have been created based on this template to facilitate data collection in case studies (https://nettskjema.no/a/181344).

2.1.1.1 Documented case studies

A research method that is involving an up-close, in-depth, and detailed examination of a particular case is in general referred to as a case study. In civil engineering all documented practical implementation of theory and methods is called case study. In the present project we use the latter meaning of case study, i.e. a case study can be a pure documentation of practical implementation without original research content.

2.1.1.2 Criteria for the selection of case studies

The **scope** of the selected case studies is directed to the assessment of the structural performance of existing bridges and tunnels. I.e. the study at least contains:

[1] Official description of the deliverable: *The ‘online best practice guide’ will resemble an intuitive wiki to be hosted on the IM-SAFE project website in a similar way with the ‘online interactive catalogue of surveying technologies for transport infrastructure’* (IM-SAFE Submitted proposal dated 2020-02-03, p.32).

[2] Official task objective of WP1 in relation with the D1.2: “*To consolidate and assess the best practices of monitoring, maintenance and safety in the EU and worldwide*” (IM-SAFE Submitted proposal dated 2020-02-03, p.31).

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- assessment of loads and resistance
- integration of information from monitoring and/or inspection, and
- validation of structural safety.

Furthermore the study is documented in a comprehensive way and *publicly available* (either as open or restricted access).

2.1.2 Data Structure

The following data structure is applied and supplemented by additional explanations that are given in *italic* font. For attributes that are obviously incomplete we indicate requested input explicitly in the text. In the following

2.1.2.1 Sections

attributes

and corresponding

- options

are introduced. In general multiple options can be given. For each main section the most important information is summarized and extended by inserted text.

Section A - Description of the object

Basic Information

- Name of the object
- ID e.g. C_SWE_B_001 (generated automatically after submission). (*Convention: "C" for case study, three letter country code, Type B or T, Number 3 digits*)
- Country
- Location (*Area, city*)
- Coordinates for the structure (*in Decimal degrees (DD), WGS84*)
- Year of construction

Structure Type

- Bridge
- Tunnel
- *Free Text*

Network Type

- Road
- Railway
- *Free Text*

Material

- Concrete
  - Reinforced
  - Prestressed
  - Light Concrete
  - Shotcrete
  - *Free Text*
- Steel
- Timber
  - Solid timber
  - Glued laminated timber
  - Pre-tensioned board decks
  - *Free Text*
- Masonry
- Composite

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    - Steel - Concrete
    - Steel - Timber
    - Timber - Concrete
    - *Free Text*
- Soil
- Rock
- *Free Text*

Text summarizing and extending Section A:

Approx. 700 characters bulk text describing the structure is given. The text contains the main information of this section A, and provide further details.

Section B - Description of the analysis

Case Type

- Research (*the main driver is to produce original research content*)
- Consulting (*the main driver is to support real, practical decisions*)
- *Free Text*

Initiation of the assessment

- Anticipated change of design working life
- Required reliability check (by owner, authorities)
- Post event and anticipated damage
- Structural deterioration
- Pure research interest
- Improvement of maintenance procedures
- *Free Text*

Predominant verification type

- Risk based
  (*due account of consequences and event probabilities, explicit representation of uncertainties*)
- Reliability based
  (due account of event probabilities and assessment of reliability criteria, explicit representation of uncertainties)
- Design value criteria
  (*structural capacity and demand expressed as design values, implicit represen- tation of uncertainties*)
- Qualitative criteria
  (*e.g. damage classes, consequence classes, ranking based on indicators, etc.*)
- Engineering judgement
- *Free Text*

Predominant verification scale
(*what is the spatial system boundary of the analysis*)

- Damage/deterioration location
- Structural component
- Structural system
- Traffic network
- *Free Text*

Structural Analysis / Type of Limit State

- Ultimate limit state
- Fatigue limit state

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- Serviceability limit state
- Proxy limit state (*e.g. corrosion initiation*)
- *Free Text*

Information updating

This attribute requires more explanation. The structural performance is described by a limit state (LSF)/design equations (DE) that contains variables representing relevant properties related to resistance, stiffness, dimensions, actions etc. The information from inspection or monitoring is somehow utilized in the LSF/DE, but how? Direct in- formation means that a relevant property contained in the LSF/DE is directly measured. If only an indicator for the relevant property is measured, it is referred to indirect information. Then a model is necessary to connect the information to the relevant property (in COST TU1406 this is called "Performance Model"). Bayesian methods combine prior information and new data from inspection/monitoring into posterior information. Non-Bayesian methods refers to classical statistical methods where only the new data is evaluated.

Suggested options:

- Direct Bayesian
- Indirect Bayesian
- Direct non-Bayesian
- Indirect non-Bayesian
- Tables
- Regression
- *Free Text*

Intervention

Here, all interventions that have been considered as possible options are mentioned.

- Physical
    - Repair
    - Strengthening / upgrading
    - Demolition
    - *Free Text*
- Operation
    - Load restriction / change of use
    - Maintenance
    - Monitoring
    - *Free Text*

Text summarizing and extending Section B:

Approx. 700 characters bulk text describing the structure is given. The text contains the main information of this section B, and provide further details.

Section C - Description of the state of the object

Deterioration Process

(*If relevant. Conditional on "Material"*)

- Concrete
    - Chloride induced corrosion
    - Carbonation
    - ASR
    - Fatigue
    - Calcium leaching
    - *Free Text*
- Steel
    - Corrosion
    - Fatigue

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- Connection loosening
- *Free Text*

- Timber
    - Mold
    - Creep
    - Fungi
    - *Free Text*
- Masonry
    - Fatigue
    - Mortar deterioration
    - *Free Text*
- Composite (*Included above*)
- *Free Text*

Damage
(*If relevant. Partly conditional on "Material"*)

- General
    - Excessive deformation
    - Local rupture / Failure
    - Settlement
    - Displacement
    - Erosion
    - *Free Text*
- Concrete
    - Cracks
    - Spalling
    - Honeycombs
    - Material loss due to reinforcement corrosion
    - Concrete weathering
    - Concrete delamination
    - Washout
    - *Free Text*
- Steel
    - Material loss
    - Cracks
    - Loose connections
    - *Free Text*
- Timber
    - Cracks
    - Material degradation (e.g. from mold, fungi)
    - *Free Text*
- Masonry
    - Cracks
    - *Free Text*
- Composite (*Included above*)
- *Free Text*

Investigation

- Prior information
    - Design standard
    - Drawings

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- Design documents
- Previous inspections
- Monitoring
- Numerical model
- BIM
- *Free Text*

• Physical parameter measured/monitored (Performance indicator)
  - Deformation
  - Displacements
  - Traffic information via WIM/BWIM
  - Dynamic response (acceleration, damping, frequencies)
  - Material mechanical properties
  - Chemical properties
  - Electrical properties
  - Load bearing capacity
  - Spatial properties (like concrete cover, duct voids, ...)
  - Other actions (like wind, temperature or earthquake)
  - Cracks (width, length, pattern)
  - Anomalies (like delamination, spalling, ...)
  - *Free Text*

• Inspection/monitoring method/technology

  (*If relevant. partly conditional on "Material". Note that this can be a never ending list of options. Thus only the most important methods should be included, the rest can be handled as free text*)
  - Satellite technologies (optical and radar)
  - Aerial and UAV technologies
  - Terrestrial dedicated inspection platforms and MMS
  - NDT active or passive testing technologies (GPR, ultrasonic pulse, guided wave techniques, etc.)
  - IoT and sensor systems (DOF, WIM/B-WIM, etc.)
  - Physical methods (laboratory material test, proof loading, rebound hammer, etc.)
  - Chemical methods (carbonation depth, half-cell electrical potential, etc.)
  - Visual inspection
  - *Free Text*

Text summarizing and extending Section C:

Approx. 700 characters bulk text describing the structure is given. The text contains the main information of this section B, and provide further details.

Section D - References and pictures

Documents

All cases studies are documented in publicly available documents. Reference to these documents are made in Harvard Referencing Style.

If the document is open access it is uploaded as a pdf file.

Pictures

Upload pictures describing the structure, the analysis and the state of the structure (deterioration process, damage, inspection/monitoring method). For each picture, confirm that we have the right to publish it, give reference when applicable and write a caption.

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2.2 Building IM-SAFE Semantic Wiki and Making the Online Best Practice Guide

In order to make Best Practice Guide as an *intuitive wiki*, collected data and information on cases need to be structured and implemented in a suitable platform. Regular wikis are often syntactic have structured text and untyped hyperlinks[3]. Semantic wikis, on the other hand, provide the ability to capture or identify information about the data within pages, and the relationships between pages, in ways that can be queried or exported like a database[4]through semantic queries[5]. A semantic wiki has an underlying knowledge model that captures domain knowledge by means of classes, relationships amongst classes, properties of classes. This model is one of the core elements that can make the system intuitive once it is corresponds well to the domain represented. In make the Online Best Practice Guide as an intuitive wiki and meet the project objectives, a Semantic wiki platform has been used. Below, there is a 5-step approach defined. Figure 2.1 represents these steps to be able to set-up and set the system online.

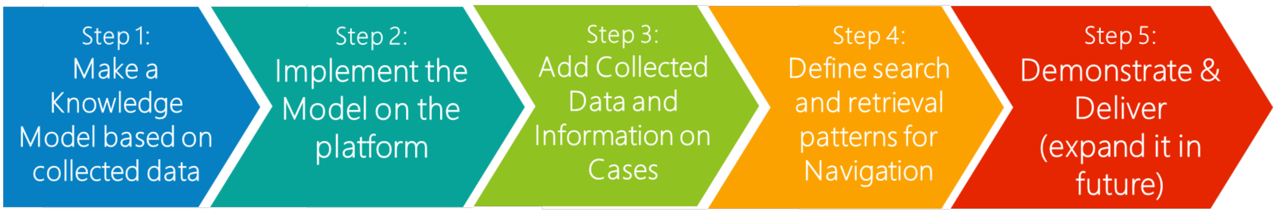

Figure 2.1 - Set-up & set-Online for the 1st deliverable

2.2.1 Making a Knowledge Model

In the first step, IM-SAFE knowledge model has to be made. Collected data and information are reviewed and used to identify classes, subclasses, data /object properties and their relationships of the knowledge model. This model needs to be validated by the domain experts. According to their feedback, alterations and adjustments are to be made.

2.2.2 Implementing the Knowledge Model

In the second step, IM-Safe knowledge model is to be implemented in the Semantic Wiki platform so that all data and information on cases can then be imported.

2.2.3 Adding Content as Case Studies

In the third step, all the data and information on cases is to brought to the IM-SAFE Semantic Wiki to prepare the Online Best Practice Guide.

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[3] Ganeshan, K., 2008, February. CKBLS: an interactive system for collaborative knowledge building and learning. In Proceedings of the 7th WSEAS International Conference on Artificial Intelligence, Knowledge Engineering and Databases (AIKED'08) (pp. 20-22).

[4] Zieche, S., 2006. Semantic wikis and disaster relief operations. In XML. Com.

[5] Boulos, M.N.K., 2009. Semantic Wikis: A comprehensible introduction with examples from the health sciences. Journal of Emerging Technologies in Web Intelligence, 1(1), pp.94-96.

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2.2.4 Defining Search Patterns

The fourth step deals with defining search and retrieval patterns that will help the end-users to navigate information embedded in the IM-SAFE Semantic Wiki. At that moment, there will be a quality control process on the cases represented in the wiki.

2.2.5 Demonstrating & Delivering The Semantic Wiki and The Online Best Practices

The fifth step is to demonstrate and deliver the Online Best Practice Guide as the first online deliverable implemented in the IM-SAFE Semantic Wiki.

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3 The Online Best Practice Guide: The Result

This section reports the implementation of the IM-SAFE Semantic Wiki and The Online Best Practice Guide within as the main result of the Task 1.2.

The IM-SAFE Semantic Wiki is operational and publicly accessible at this location: https://imsafe.wikixl.nl/index.php/About_the_IM-SAFE_project. There are three in the wiki that holds space for the three online deliverables[6]. The content of D1.2 is fully accessible under the Best Practices Tab (blue-coloured in Figure 3.1).

Figure 3.1 - The Main Page of the IM-SAFE Semantic Wiki and the Dedicated Places of the Three Online Deliverables

Below, there are key components of the IM-SAFE Semantic Wiki and features of The Online Best Practice Guide presented. These are namely the outcomes of the aforementioned 5-step approach. Firstly, the Knowledge Model is presented (corresponding to Step 1). Secondly, the Visualization of Information and the User Interface is described. This deals with the implementation of the knowledge model, features for adding and visualizing the content of case studies and search

[6] The other two online deliverables, D2.1 and D3.2 will be added in the IM-SAFE Semantic Wiki and be delivered in project Month 18.

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patterns (Corresponding to Step 2, 3 and 4). And finally, the Content is elucidated in order to clarify the way that collected data and information stored in the Best Practice Online Guide.

3.1 IM-SAFE Knowledge Model

The data structure given in 2.1.2 was represented in the knowledge model. The knowledge model captures all information collected during the first 12 Months of the project (see Appendix 2). All that data is structured according to the knowledge model and the model currently contains 14 classes. The properties of the classes include both data properties that are often described by basic data types and object properties that can be as enumerations and relation to other classes. These details can be seen in Figure 3.2.

Figure 3.2 - Knowledge Model of the Online Best Practice Guide

The classes of Civil Structure, Object State and Object Analysis are to enable dynamic and static information on the same infrastructure object. The unchanged properties are such as location, material type, year of construction, physical address etc are stored in the Civil Structure. There can be also changed properties such as the state of the structure. Having Object state class enables us to assign various observations on the same object with a time stamp. This makes the model more future-proof. The analyses on one infrastructure object can be conducted multiple times and take different state into consideration over time. Therefore Analysis class distinguishes specific assessment properties (following the Data Structure again). These four contain the most information about civil structure and case studies.

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The object properties enable connection amongst the classes and make the information semantic. For instance, Deterioration Process class and Damage Type class have a semantic relation to the Object State class. This relation is defined as “observed damage type” and “observed deterioration process”. This makes it possible to assign multiple properties to the object state and also relating other objects having the same properties. We can, for instance, see: All the Civil Structures at which same Damage Type is observed.

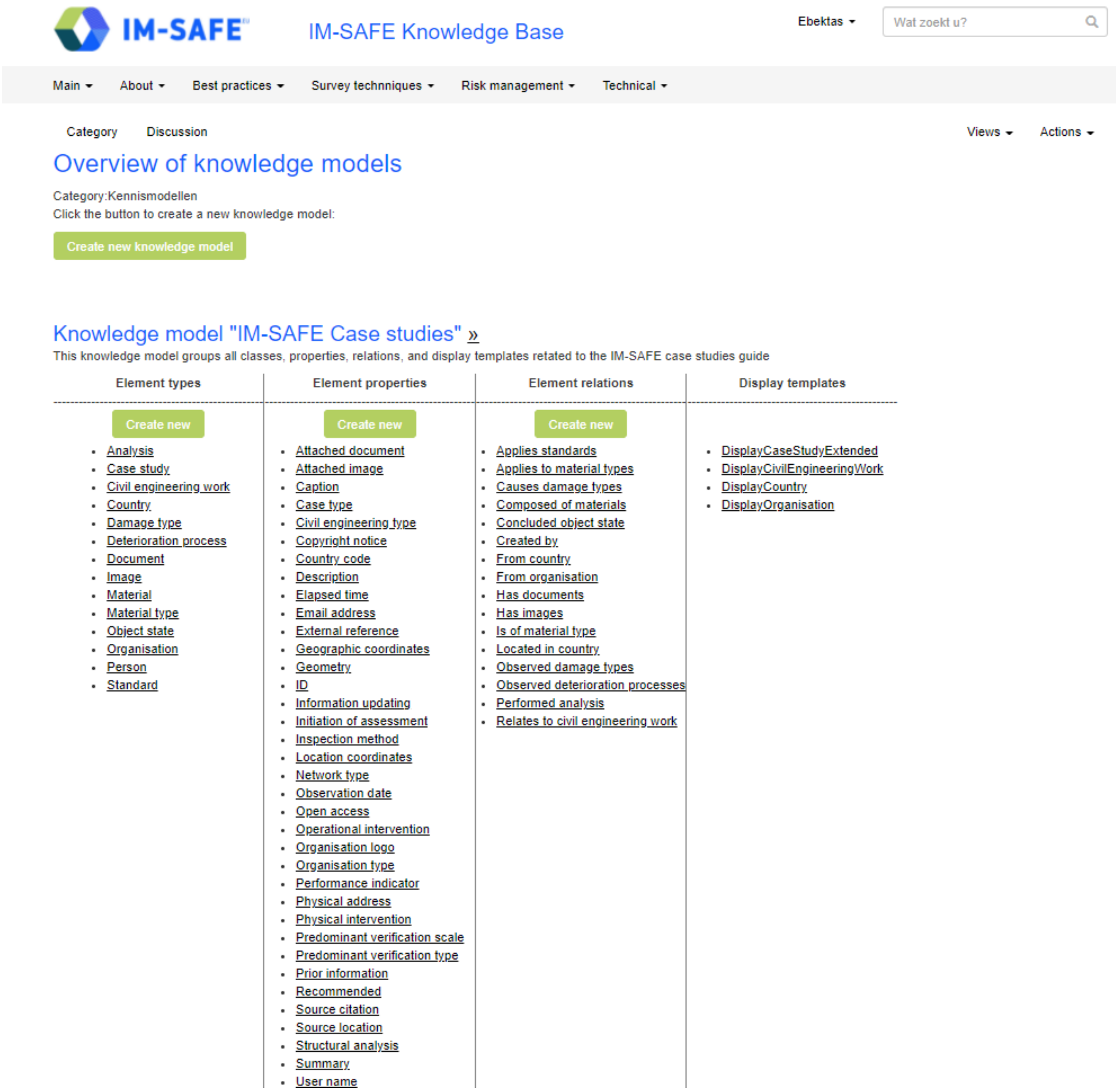

Figure 3.3 - The Page view of the Knowledge Model Implemented in The IM-SAFE Semantic Wiki

There is also a distinct classes are made for collected case study materials such as images, documents and links. Because these material can be subject to e.g. copyrights, or not being open access, or publication details, these meta information can now be also added.

This knowledge model is implemented in the IM-SAFE Semantic Wiki as seen in Figure 3.3. The User Interface has functionality to expand the knowledge model in future so that it can be

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expanded easily to capture D2.1 and D3.2 Deliverables. Each class, element, and element properties are listed. When clicked, the properties can be edited and also new items can be added. The User Interface ensures adding content effortlessly comparing to other modelling platforms. It also eases the adoption the Online Best Practice Guide by the partners, non-experts and public users.

3.2 Visualization and The User Interface

The visualization of the collected data and information is here combined with the User Interface of the IM-SAFE Semantic Wiki. By this way, the use process of the end-user can be guided by the use of key pages and functionalities of the Wiki. Under the Best Practices Tab (as Shown already in Figure 3.1), there are four key Pages:

1. Introduction
2. Map view of Best Practices
3. Overview
4. Search in Case Studies

3.2.1 Map view of Best Practice

The map view displays all 96 case studies collected so far. By clicking the green location icon, there appears a preview information for each case. Figure 3.4 represents all cases on the map and exemplifies this preview for Tadeusz Mazowiecki Bridge (case study). Appendix 1 and Appendix 2 present each case studies there. The map also displays location of project partners' and links to the Case studies contributed by the partners.

Figure 3.4 – Visualisation of All Cases on an interactive map

There is also a map view for each country to which the cases belong. By clicking e.g. Austria, there appears a list of all cases within that location. This is exemplified in Figure 3.5. Any case

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information can be unlocked by following the hyperlinks. The user can navigate itself amongst the case study of interest, geographical location, organizations. Moreover, the users can move towards specific damage types or degradation mechanisms of interest and can access to the cases with those observed properties. This will be further illustrated in the search patterns.

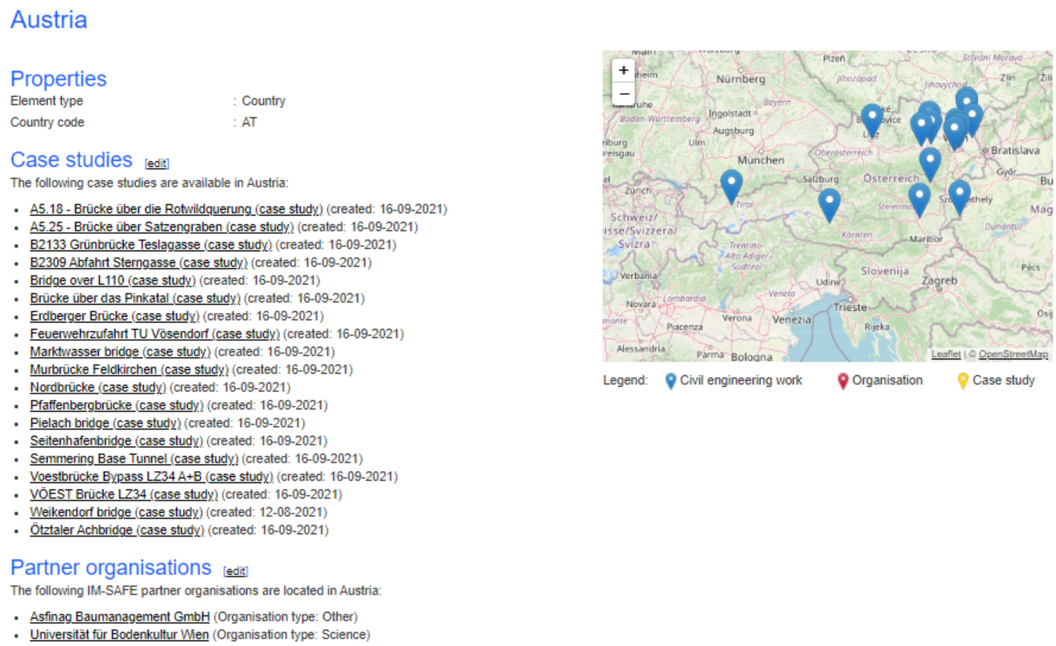

Figure 3.5 – The [View of the cases per country]

3.2.2 Overview Table for All Cases

The second visualization of the case studies is with an [overview table.] This page displays all the cases based on few properties such as the Civil Structure, Structural Analysis Type, Deterioration Processes, Summary of The Analysis and Organisations. Firstly, the full details of the case studies can be accessed by clicking simply the case name.

In

Figure 3.6, *[Arcos de Alconétar Viaduct (case study)]* is given as an example.

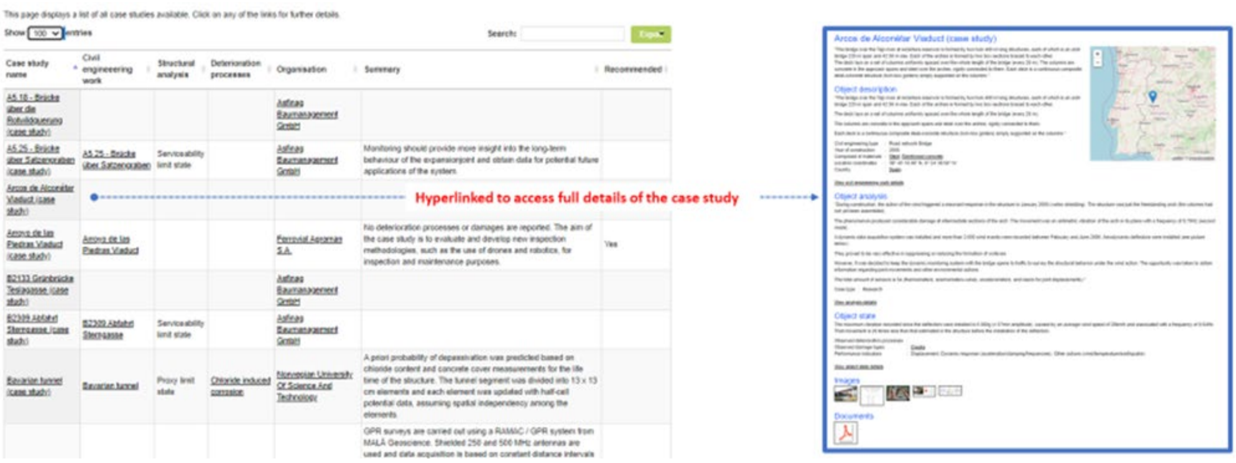

Figure 3.6 - The way that full details of case studies are accessed from the overview

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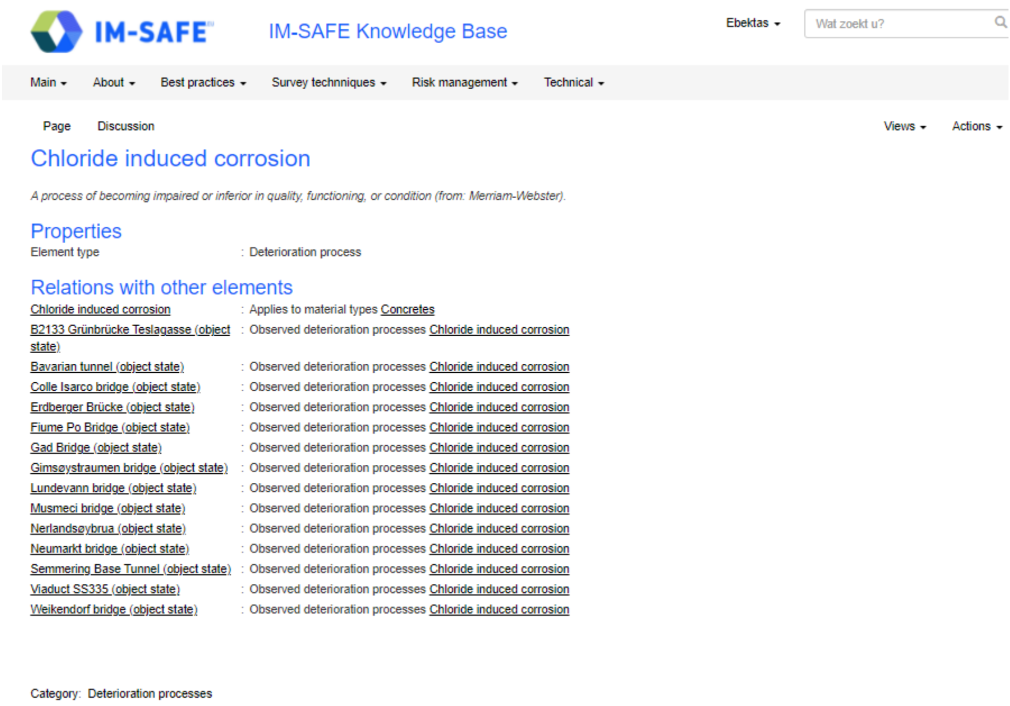

Figure 3.7 - An example view of a Deterioration Process and Linked Civil Structures based on Chloride induced corrosion

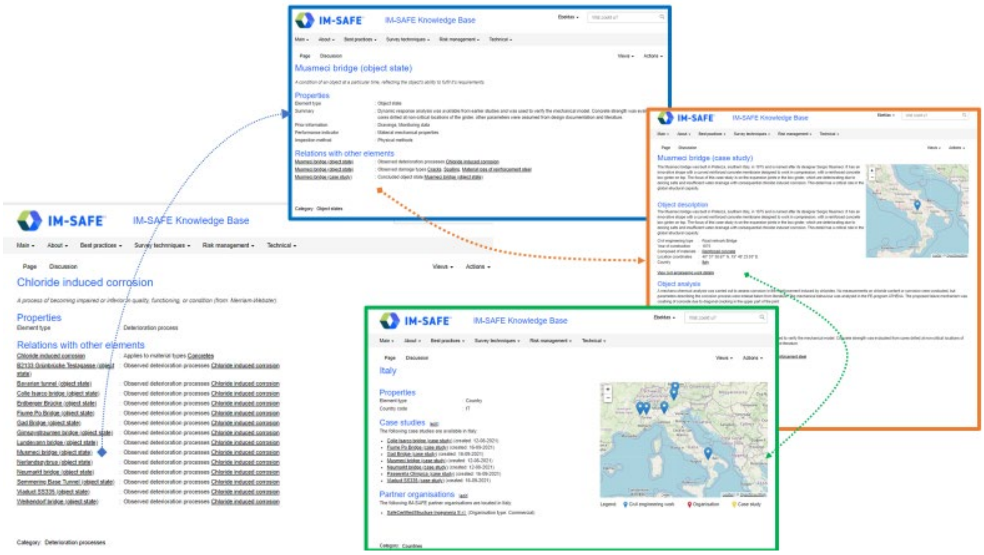

Figure 3.8 - Example of a Navigation of the end-user

Figure 3.8 illustrates an example of the navigation. There we see the list of objects where [Chloride induced corrosion]() is observed to see a specific civil structure, [Musmeci Bridge]() and the [Musmeci Case Study]() and visiting Italy as the case location, access the list of all case studies located in [Italy](). The user can continue exploring other case studies, civil structures or [organisations]() with the shared location.

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3.2.3 Search in Case Studies

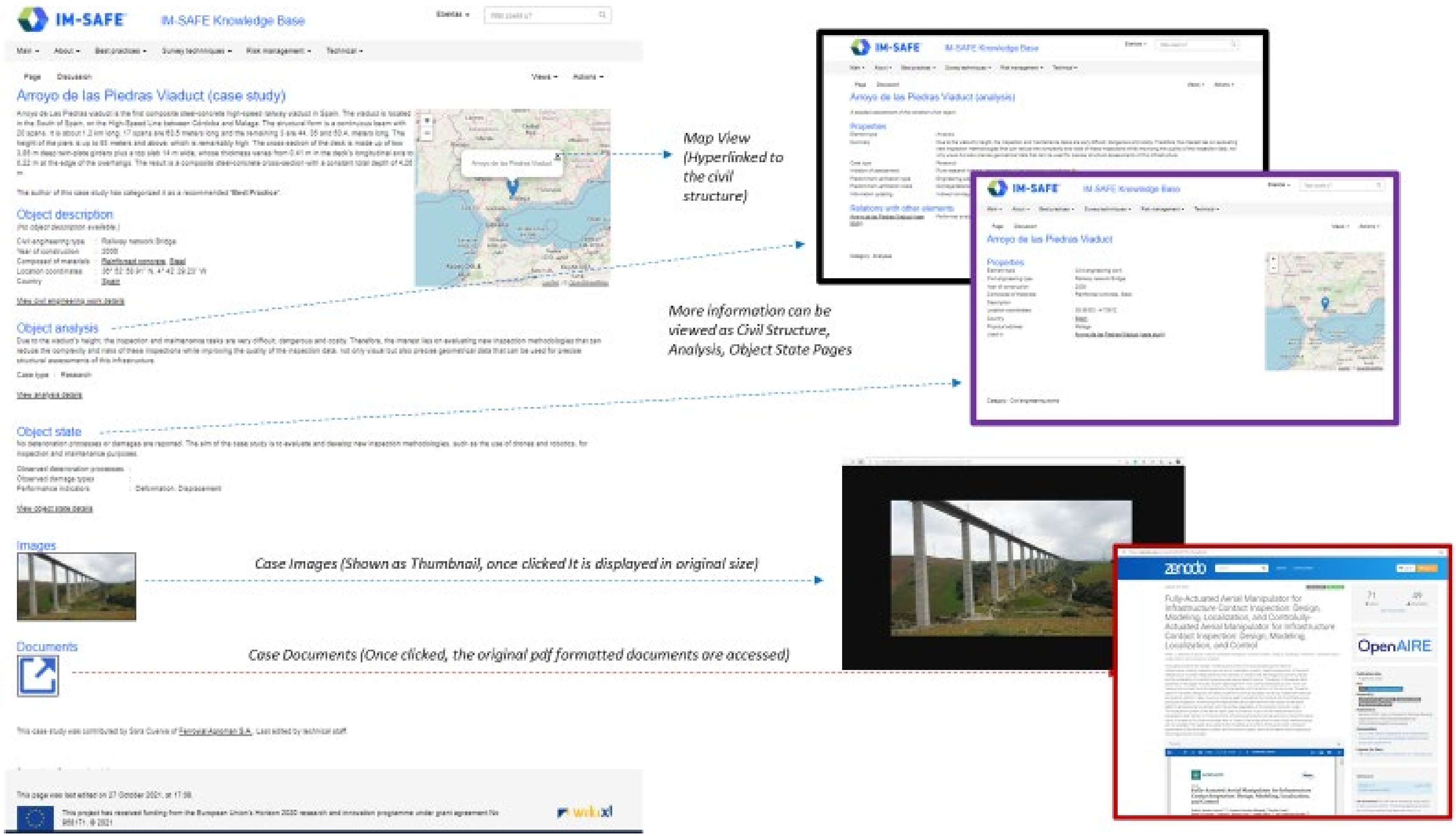

Figure 3.9 - Display of A Case Study consisting of information and data coming from various classes of the knowledge model

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Search Patterns

Search pattern consists of one or more conditions (information embedded, e.g. damage types or degradation mechanisms) that match terms of certain package of information. The Semantic Wiki can filter cases based on any information that are made semantic via the knowledge model.

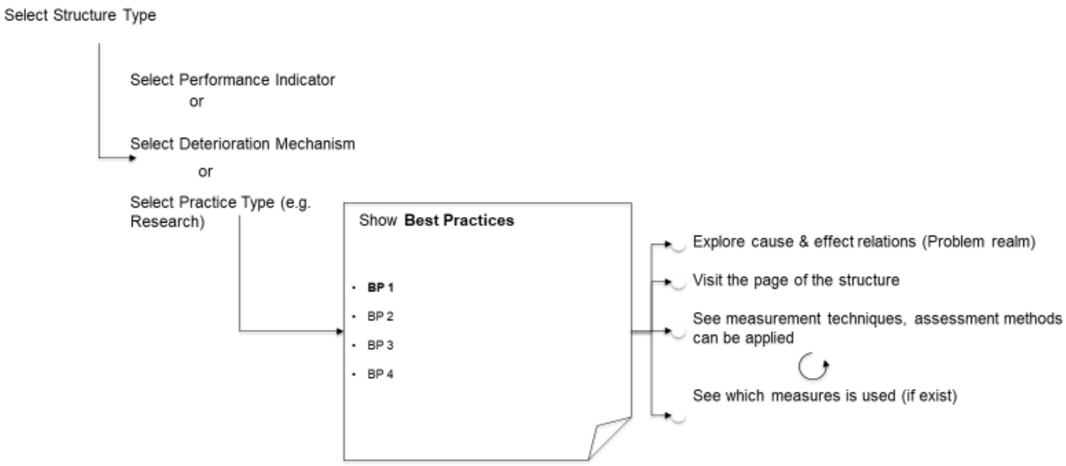

Figure 3.10 – Structure example of search pattern

Figure 3.11 is an example of how the search case studies function has been structured. It does enable the users to select the search criteria (e.g. civil engineering type, country located, material types and observed deterioration mechanism) and filter the matching cases based on a period of time (e.g. built between 1950-1976), allowing to query and provide filtered results. Figure 3.11 is an example of search and it shows all the steel bridges built between 1950-1976 in the Netherlands that observed a deterioration process for fatigue.

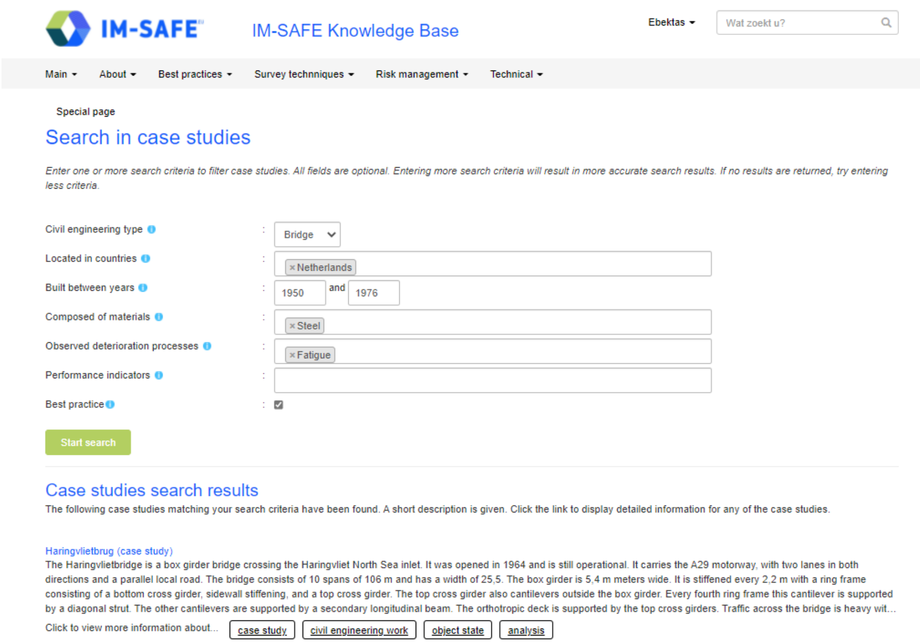

Figure 3.11 - Search Page to visualize case studies based on several filters

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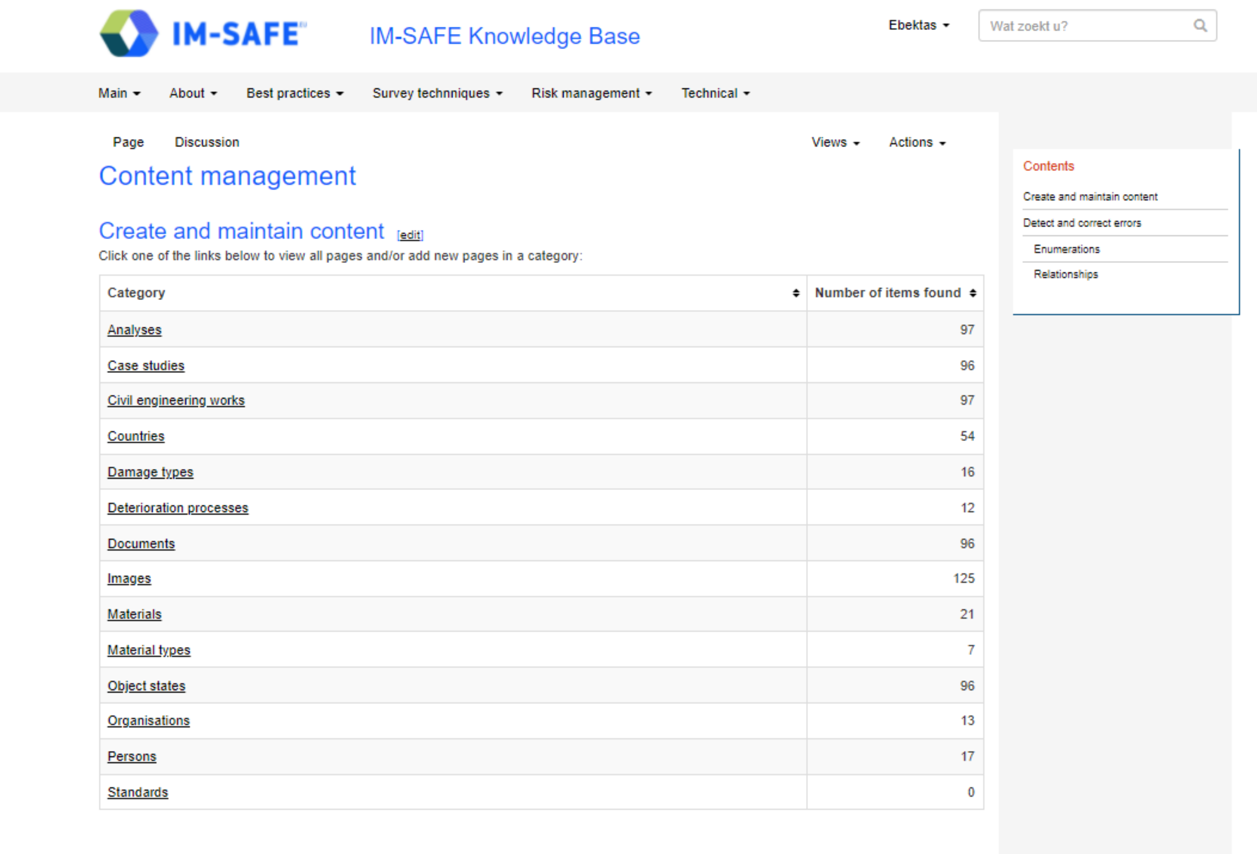
4 Content in the IM-SAFE Semantic Wiki

The content of the IM-SAFE Semantic Wiki collected so far has been grouped by categories, divided as shown in Figure 4.1.



Category	Number of items found
Analyses	97
Case studies	96
Civil engineering works	97
Countries	54
Damage types	16
Deterioration processes	12
Documents	96
Images	125
Materials	21
Material types	7
Object states	96
Organisations	13
Persons	17
Standards	0

Figure 4.1 – Categories of content management

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5 Follow-up

The follow-up will be extending the two other online deliverables, namely D2.1 and D3.2. Collected surveying technologies will be analyzed in terms of data structure. And additions or alterations will be in the knowledge model to be able to extent the Semantic Wiki to capture their content and make it available and useable for the users.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958171.

Appendix 1

This appendix presents a list of all the case studies in the IM-SAFE Semantic Wiki. Below, there are 96 cases presented in an alphabetical order.

1. A5.18 - Brücke über die Rotwildquerung (case study)
2. A5.25 - Brücke über Satzengraben (case study)
3. Arcos de Alconétar Viaduct (case study)
4. Arroyo de las Piedras Viaduct (case study)
5. B2133 Grünbrücke Teslagasse (case study)
6. B2309 Abfahrt Sterngasse (case study)
7. Bavarian tunnel (case study)
8. Bibei bridge (case study)
9. Blazowa Bridge (case study)
10. Boogbrug Beek (case study)
11. Brama Przemyska (case study)
12. Bridge in Kwidzyn (case study)
13. Bridge in Ozimek (case study)
14. Bridge in Puławy (case study)
15. Bridge of Traba (case study)
16. Bridge over L110 (case study)
17. Bridge over Nitra River (case study)
18. Brug bij Grubbevorst (case study)
19. Brug bij Zaltbommel (case study)
20. Brug bij Zaltbommel (Pro-rail) (case study)
21. Brug Muiden (case study)
22. Brug Terneuzen (case study)
23. Brücke über das Pinkatal (case study)
24. Cable-stayed bridge Obere Argen (case study)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958171.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958171.

52. Leziria bridge (case study)
53. Lundevann bridge (case study)
54. Marktwasser bridge (case study)
55. Martinus Nijhoffbrug (case study)
56. Monforte Bridge (case study)
57. Murbrücke Feldkirchen (case study)
58. Musmeci bridge (case study)
59. National Uprising Bridge (case study)
60. Nerlandsøybrua (case study)
61. Neumarkt bridge (case study)
62. Noordtunnel (case study)
63. Nordbrücke (case study)
64. Folgoso tunnel (case study)
65. Ourille River Viaduct (case study)
66. Passerella Olimpica (case study)
67. Pfaffenbergbrücke (case study)
68. Pielach bridge (case study)
69. Port Bridge (case study)
70. Ribeiriño bridge (case study)
71. Roman Bridge of Lugo (case study)
72. Rędziński Bridge (case study)
73. Scharbergbrug (case study)
74. Segura Roman Bridge (case study)
75. Seitenhafenbridge (case study)
76. Semmering Base Tunnel (case study)
77. Sesupe River Bridge (case study)
78. Soldarności Bridge (case study)

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Appendix 2

The appendix presents each case studies in the IM-SAFE Semantic Wiki and shows all general information (e.g. coordinates, material, reason for assessment, etc.) and a summary displayed per case.

Figure Appendix 2.1 displays all 96 case studies collected so far.

Figure Appendix 2.1 – Overview of all 96 case studies collected in the IM-SAFE Semantic Wiki

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958171.

A5.18 - Brücke über die Rotwildquerung

Road Bridge located in Lower Austria, Weinviertel, Austria

Coordinates: (643213,25, 519620,66)
Year of construction: 2016
Material: Concrete, Reinforced
Type of case study: Consulting
Reason for initiation of assessment: Value engineering
Predominant verification type: Engineering judgement
Predominant verification scale: Structural component

Summary of case study

Frame-like bridge, L= 94,8; 4 fields (2*19,1+2*25,9); 2 superstructures (w=2*15,45). Experimental expansion joint built.

Monitoring of the behaviour of the unique designed jointless expansion joints.

Pirmary monitoring of deformation and displacements of the expansion joints compared with temperature sensors.

Information gathered by Daniel Moore, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

A5.25 - Brücke über Satzengraben

Road Bridge located in Lower Austria, Weinviertel, Austria

Coordinates: (643424,88, 527214,12)
Year of construction: 2016
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment:
Predominant verification type: Engineering judgement
Predominant verification scale: Structural system

Summary of case study

Frame-like road bridge. 2 superstructures (w=15,45). L= 113,8. 5 fields (2*18,75+3*23). One of the longest frame-like structures in at least Austria.

Monitoring of the structure compared with detailed monitoring of displacement and deformation of the innovative jointless expansion joints.

Monitoring should provide more insight into the long-term behaviour of the expansionjoint and obtain data for potential future applications of the system.

Information gathered by Daniel Moore, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Arroyo de las Piedras Viaduct

Railway Bridge located in Malaga, Spain

Coordinates: (36,8842133537706, 4,709106273030539)
Year of construction: 2006
Material: Concrete, Steel, Reinforced
Type of case study: Research
Reason for initiation of assessment: Pure research interest, Improvement of maintenance procedures
Predominant verification type: Engineering judgement
Predominant verification scale: Damage/deterioration location

Summary of case study

Arroyo de Las Piedras viaduct is the first composite steel-concrete high-speed railway viaduct in Spain. The viaduct is located in the South of Spain, on the High-Speed Line between Córdoba and Malaga. The structural form is a continuous beam with 20 spans. It is about 1,2 km long: 17 spans are 63,5 meters long and the remaining 3 are 44, 35 and 50,4, meters long. The height of the piers is up to 93 meters and above, which is remarkably high. The cross section of the deck is made up of two 3,85 m deep twin-plate girders plus a top slab 14 m wide, whose thickness varies from 0.41 m in the deck's longitudinal axis to 0,22 m at the edge of the overhangs. The result is a composite steel-concrete cross-section with a constant total depth of 4,26 m.

Due to the viaduct's height, the inspection and maintenance tasks are very difficult, dangerous and costly. Therefore, the interest lies on evaluating new inspection methodologies that can reduce the complexity and risks of these inspections while improving the quality of the inspection data, not only visual but also precise geometrical data that can be used for precise structural assessments of this infrastructure.

No deterioration processes or damages are reported. The aim of the case study is to evaluate and develop new inspection methodologies, such as the use of drones and robotics, for inspection and maintenance purposes.

Information gathered by Sara Cuerva, Ferrovial, scuerva@ferrovial.com

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Bavarian tunnel

Road Tunnel located in Bavaria, Germany

Coordinates: (48,790195, 11,498354)
Year of construction: 1995
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Structural deterioration, Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Damage/deterioration location

Summary of case study

A 400 meter long tunnel in southern Bavaria, Germany, was analysed for corrosion. The tunnel was built in 1995 and the concerns emerged in 2014 during inspection. The exposure to de-icing salts and drying and wetting cycles is high.

A probabilistic condition assessment was carried out. The probability of corrosion was updated with data from half-cell potential measurements with a Bayesian approach. Spatial variability was addressed. The reliability of the assessment was influenced by defect size, grid size, threshold potential and moisture conditions.

A priori probability of depassivation was predicted based on chloride content and concrete cover measurements for the life time of the structure. The tunnel segment was divided into 13 x 13 cm elements and each element was updated with half-cell potential data, assuming spatial independency among the elements.

Information gathered by Frida Liljefors, Norwegian University Of Science And Technology NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Bibei bridge

Road Bridge located in Quiroga, Lugo, Spain

Coordinates: (42,333795, 7,214504)
Material: Masonry, Rock
Type of case study: Research
Reason for initiation of assessment: Pure research interest, Diagnosis revealing construction details and modifications.
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The Bibei bridge, was originally built during the Roman period, and it has three barrel arches. Stand out the different modifications bridge modifications over history, such as the restoration tasks performed during the twentieth century, when the former pathway along the entire bridge was filled. Moreover, of the hypothesis concerning a probable reconstruction of the first arch in the nineteenth century.

GPR surveys are carried out using a RAMAC / GPR system from MALÅ Geoscience. Shielded 250 and 500 MHz antennas are used and data acquisition is based on constant distance intervals following the common compensation mode. A total of two parallel longitudinal profiles is generated in opposite directions along the bridge and filtered. The study includes the use of accurate metrical documentation obtained by terrestrial laser scanner. The obtained three-dimensional surface model of the bridge supplies two-dimensional orthophotographs of the structure where the main geometrical parameters can be measured. Using these structural dimensions, it is possible to estimate, by the adaptation of diffraction hyperbolas, the radar wave velocities in different zones of the whole bridge's stonework Finally, for an exhaustive interpretation, the real GPR results were also compared to finite-difference time domain (FDTD) numerical modelling data.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Blazowa Bridge

Road Bridge located in Błażowa, Poland

Coordinates: (49,880626443384344, 22,090581626887968)
Year of construction: 2015
Material: Concrete, Composite, Light concrete
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The bridge was built in 2015. The bridge is situated in Blazowa (South-East Poland) over Ryjak River. It has a total length 22,3 m and width 10,54 m. The bridge span is single-span facility. This bridge is very innovative. It was one of the first composite bridges in Poland. The span of the bridge is made of composite girders, connected with the lightweight concrete deck slab.

The case of study of Blazowa Bridge is to research all points where it is possible to find some damages. Generally point of initiation of assessments is research interest. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria. All optical fibres sensors is situated in girders. Also very important is structural analysis. In this case it concerns ultimate limit state and acoustic emission. The physical intervention of that bridge is repair or upgrading.

The bridge over Ryjak River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation. It is very important for dynamic behaviour of the bridge. It is used three performance indicator: deformation, other loads (e.g. temperature) and acoustic emission. The signal of sensors could monitoring dynamic response or visual inspection. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Brama Przemyska

Road Bridge located in Przemyśl, Poland

Coordinates: (49,79783728586549, 22,784632811540153)
Year of construction: 2012
Material: Concrete, Steel, Gravel / mixed concrete
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The bridge was built in 2012. The bridge is situated in Przemysl (South-East Poland) over San River. It has a total length 229,5 m. The bridge had two-span facility (114 m). This bridge is very important for the city (Przemysl). The bypass allows to eliminate transit traffic from the city centre. It facilitates access to the border crossing with Ukraine in Medyka.

The case of study of bridge in Przemysl is to research all points where it is possible to find some damages. Generally point of initiation of assessments is pure research interest. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria and design value criteria. All sensors measure object displacements. The monitoring system is installed in a few elements of bridge. GNSS antennas and weather stations were installed. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair, strengthening or upgrading.

The bridge over San River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation. It is used four performance indicator: angular displacements, displacements of the span and construction deformation. The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Bridge in Kwidzyn

Road Bridge located in Kwidzyn, Poland

Coordinates: (53,759360, 18,847515)
Year of construction: 2013
Material: Concrete, Steel, Prestressed
Type of case study: Research
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The bridge was built in 2013. The bridge is situated in Kwidzyn over Wisla River. It has a total length 808,4 m and width 15,9 m. The bridge in a six-span arrangement. The lengths of the spans are: 2 x 70 m, 2 x 130 m and 2 x 204 m. To increase efficiency was used a new carrying system – extradosed prestressed bridge. This kind of bridge connected the idea of a suspended and prestressed beam bridge.

The case of study of bridge in Kwidzyn is to research all points where it is possible to find some damages. Generally point of initiation of assessments is structural deterioration. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria and design value criteria. All sensors measure different value: forces, deformation, or vibrations. The monitoring system collected information in tables or graphs. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair, strengthening or upgrading.

The bridge over Wisla River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation and geodetic conditions. It is very important for dynamic behaviour of the bridge. It is used six performance indicator: deformation of steel and concrete, angular displacements, forces in pylons, vibration acceleration, wind speed and direction and other loads (e.g. temperature). The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Bridge in Ozimek

Pedestrian traffic, bicycle footbridge Footbridge located in Ozimek, Poland

Coordinates: (50,67657535168655, 18,212348071101204)
Year of construction: 2010
Material: Steel, Iron
Type of case study: Research
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The bridge was renovate in 2010. The bridge is suspension over Mala Panew River in Ozimek. It has a total length 31,5 m and width 6,6 m. The bridge span is single-span facility. Generally this bridge was built in 1827. In 2009 it was decided to renovate it. This bridge is made from iron. The bridge was used as a road bridge until 1938. Then it continued to be used for pedestrian traffic only.

The case of study of bridge in Ozimek is to research all points where it is possible to find some damages. Generally point of initiation of assessments is structural deterioration. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria. 16 string sensors were used to measure rod deformation and rope elongation. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair or strengthening.

The bridge over Mala Panew River was constructed generally for pedestrian traffic use. The most important damage for this bridge is excessive deformation. It is used two performance indicator: deformation and elongation measurements and chemical properties. The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Bridge in Puławy

Road Bridge located in Puławy, Poland

Coordinates: (51,43740278109997, 21,943488566742133)
Year of construction: 2008
Material: Concrete, Steel
Type of case study: Research
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The bridge was built in 2008. The bridge is situated in Pulawy over Wisla River. It has a total length 1038,2 m. The bridge in a fourteen-span arrangement. The lengths of the spans are: 44 m, 3 x 56 m, 6 x 64 m, 80 m, 212 m, 80 m and 44 m. The main span is suspended from steel arches load-bearing with bar hangers.

The case of study of bridge in Pulawy is to research all points where it is possible to find some damages. Generally point of initiation of assessments is structural deterioration. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria and design value criteria. All measurements sensors is mounted along bridge. The monitoring system of bridge consist of subsystem: construction, metrology and visual monitoring. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair or strengthening.

The bridge over Wisla River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation and displacements. It is very important for dynamic behaviour of the bridge. It is used three performance indicator: deformation, deflection, angular displacements and other loads (e.g. temperature). The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Bridge of Traba

Road Bridge located in Noia, A Coruña, Spain

Coordinates: (42,785379, 8,883594)
Material: Masonry
Type of case study: Research
Reason for initiation of assessment: Pure research interest, Diagnosis revealing construction details, modifications and problems which have arisen.
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The Traba Bridge is a 14th century bridge with four arches that extend from 4.8 to 7.0 m. Two of these arches are barrel arches, while the other two are Gothic arches. These differences in geometric shape are probably due to two different times for masonry construction; the Gothic arches of the original bridge structure and the barrel arches of a later restoration. This bridge represents an integral part of the traditional Galician architectural heritage and requires constant diagnosis because this bridge is still in use within the transport infrastructure, so it has been modified for new functions supporting now increases in traffic loads and intense vibrations.

GPR surveys are carried out using a RAMAC / GPR system from MALÅ Geoscience. Shielded 250 and 500 MHz antennas are used and data acquisition is based on constant distance intervals following the common compensation mode. A total of two parallel longitudinal profiles is generated in opposite directions along the bridge and filtered. A three-dimensional model of the bridge is also constructed using a terrestrial laser scanner, and the surface texture of the object is captured using a semi-metric digital camera. Two types of scans are ejected at each scan position: first, a low resolution is acquired to have the overall geometry of the bridge and its surroundings, and then detailed scans are captured with a maximum spatial resolution of the entire bridge. Finally, the precise external geometric measurements of the bridge, as well as the orthophotography provided by laser scanning, are used as inputs to create synthetic radargrams.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Bridge over L110

Railway Bridge located in Lower Austria, Austria

Coordinates: (48,240176, 15,764071)
Year of construction: 2012
Material: Concrete, Steel, Prestressed
Type of case study: Research and consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The bridge object over the state road L110 is located on the new Vienna - St. Pölten line, built in 2012, and crosses two tracks. The prestressed concrete bridge construction consits of a three-span continuous girder system with span ratios of 19.0 m - 22.0 m - 19.0 m. The support structure consists of two abutments and two compact pillars, deeply founded. The structure is supported with abutments and pillars as point support by means of deformation bearings.

The test object was instrumented to characterize the expansion/displacement behavior of the rails and the displacements of the supporting structure. The southern track in the direction to St. Pölten was defined as a measuring track and equipped with a complete test set-up. The recording of the measurement data for the measurement track took place both for the period before the production of the rail joint and afterwards.

The designed measuring program comprised the recording of the rail longitudinal expansion and the rail longitudinal displacements in the rail fastening in defined measuring cross-sections. In addition, the relative displacements between the ends of the structure and abutments were measured and documented. The air, rail and structure temperatures were recorded and documented during the entire measurement period. By applying an accelerometer to the structure, any influence on the measurement data by construction site operations was detected and recorded. After the opening for traffic and commissioning in December 2012, additional sensors and measuring instruments were used to record the effects of vehicle-related loads such as vertical structural deformation and emergency braking attempts.

Information gathered by Lisa Ptacek, University of Natural Resources and Life Sciences, Vienna, lisa.ptacek@boku.ac.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Bridge over Nitra River

Road Bridge located in West-Selenec, Slovakia

Year of construction: 2011
Material: Concrete, Steel
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The bridge was built in 2011 in West-Selenec in Slovakia. It is situated over Nitra River. The bridge is formed od one cell box section. The bridge is 357,5 m long. The main bridge has 5 spans of length from 50,0 to 85,0 metres. The structural system of the bridge consists of steel and concrete.

The bridge in the R1 expressway is very important for railway transport In Slovakia. Monitoring of that bridge allows to eliminate all potential damages. All sensors is mounted along bridge. It is related with a heavy height transport moving (e.g. trucks). The case of study is to research all points where it is possible to find some damages of bridge.

The bridge over Nitra River was constructed generally for expressway road. The most important damage for this bridge is excessive deformation and displacement. It is very important for dynamic behaviour of the bridge. It is used three performance indicator: excessive deformation, displacements and other loads (e.g. temperature). Temperature and overload monitoring allows to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Brücke über das Pinkatal

Road Bridge located in Pinggau, Styria, Austria

Coordinates: (47.053915, 16.461049)
Year of construction: 1985
Material: Concrete, Prestressed
Type of case study: Consulting
Reason for initiation of assessment: planed Strengthening
Predominant verification type: Engineering judgement
Predominant verification scale: Structural system

Summary of case study

Prestressed RC Bridge (additional external Tension system) Boxgirder L= 273,6m W=25m

Information gathered by Fritz Binder, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

Cable-stayed bridge Obere Argen

Road Bridge located in Esseratsweiler, Germany

Coordinates: (47,640518, 9,744882)
Year of construction: 1990
Material: Concrete, Steel, Reinforced, Prestressed
Type of case study: Consulting
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Engineering judgement
Predominant verification scale: Structural component

Summary of case study

The Obere Argen viaduct is a 730 m long bridge structure on the Federal Motorway 96. The motorway overpass consists of a single-hip cable-stayed bridge in combination with a sub-tension. The bridge spans the Obere Argen and two farm roads with nine fields at a maximum height of 40 m. Because of a sliding slope, the southern end span has a span of 258 m. In the northern section, the two-part structure consists of a 381 m long prestressed concrete box girder bridge, which is separated from the southern part with a 349 m long steel bridge by double piers with an expansion joint in between. The prestressed concrete bridge has two separate superstructures, in the longitudinal direction with a continuous beam. In the transverse direction, the superstructures are designed as single-cell hollow boxes. The steel bridge has a common superstructure for both directional carriageways with a continuous beam in the longitudinal direction. In the transverse direction, the superstructure is designed as a single-cell hollow box with a 29 m wide orthotropic carriageway slab.

A test matrix describes all tests to be carried out according to the time interval to be observed, needs tests or according to an object-related damage analysis. The inspection of the cable-stayed bridge includes an optical inspection of the ropes, an inspection of the rope entry and end anchoring, magnetic inductive measurements, an ultrasonic inspection of the end anchoring, rope force determination with frequency measurement, optical inspection of the superstructure inside and outside, a measurement of the reflectors on the superstructure and pylon, optical inspection of the Pylon and pylon head, measurement of the pillars, an inclinometer and deformation measurement of the site as well as a review of the seepage and drainage system.

The optical inspection of the ropes revealed damage to the coating, bulges, bubbles, rust spots and broken wires in the outer layer. No breaks could be found in the rope anchoring. Any bumps that are discovered are recorded and documented in a bump log. It is assumed that the occurrence of bulges was caused by larger deformations with cutting force redistribution in the center of the field, which were measured from 1990 onwards. From 2003 to 2007 no further changes could be measured. The seepage pipes at the abutment and the retaining foundation were driven over with a camera in 2005. This inspection showed that the pipes were sintered up to 70

Information gathered by Florian Fliegel, AEC3, ff@aec3.de

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Ceboliño viaduct

Road Bridge located in Ceboliño, Ourense, Spain

Coordinates: (42.34367481, 7.8254951)
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Structural deterioration, Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

In OU - 536 road in Ceboliño (Ourense) is selected a viaduct abutment. The concrete of the abutments in this bridge is visibly affected by the surface run-off of the deck in the rainy season, so it is exposed to a high moisture level. This region is characterized by a high precipitation rate.

The methodology consists analysing different classification images through several unsupervised classifications based on a K-means algorithm. For this purpose, a multiband matrix comprising orthoimages collected with several 3D and 2D remote sensors is created. The K-means classifier is tested to perform several unsupervised image classifications with different numbers of classes (three, four and five classes). The goal of this approach is to determine which number of classes present a more robust classification, and to provide information on which sensor is the most suitable.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Cernadela Bridge

Pedestrian bridge Bridge located in Mondariz, Pontevedra, Spain

Coordinates: (42,239507, 8,448232)
Material: Masonry
Type of case study: Research
Reason for initiation of assessment: Post event and anticipated damage, Structural deterioration, Pure research interest
Predominant verification type: Risk-based
Predominant verification scale: Structural component

Summary of case study

The Cernadela bridge is considered of Roman origin, which underwent modifications over the centuries. It is composed of five preserved arches that are Gothic Style, except for the central one, which preserves the semicircular arch.

Terrestrial photogrammetry is used for geometry reconstruction of a real masonry arch, which contributes to the accurate geometric representation of a structure. While the metric model is used for implementation structural assessment tasks. Continuums as well as discontinuous (discrete) models are used and finite element analysis with commercial packages or limit analysis schemes are adopted. The resulting combination of techniques allows to evaluate the structural health of an existing complex masonry structure by taking into account geometric data of high precision, mechanical models of adequate complexity and elements of inverse analysis. Further information, like material data from the interior of the structure, is taken into account.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Colle Isarco bridge

Road Bridge located in Colle Isarco, South Tyrol, Italy

Coordinates: (46,933064, 11,447967)
Year of construction: 1969
Material: Concrete, Reinforced, Prestressed
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Reliability-based
Predominant verification scale: Structural system

Summary of case study

This prestressed concrete box girder bridge consists of 13 spans making up a total length of 1029 meter. It was cast in situ and post-tensioned. The girder depth varies from 10.8 meter at mid-support to 2.85 meter at midspan. There is in total 494 prestress cables in the superstructure that create tension in all three directions. Being a complex engineering structure along the highway A22 with high intensive traffic, there is an interest in assessing the reliability and performance of the Colle Isarco bridge. The superstructure is statically determinate.

The analysis is a robustness-based performance assessment of a bridge with ongoing deterioration. A probabilistic non-linear FE analysis was carried out, including the effects of corrosion of the tendons. Possible damage scenarios were modelled in 4 discrete stages ranging from 0

It is stated in the study that inspection data and data from monitoring during proof loading was included in the model, but the type of data and data collection techniques are not central for this study and therefore not specified. The idea of the method presented is to assess possible damage states independent of the cause of damage.

Information gathered by Frida Liljefors, Norwegian University Of Science And Technology NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Composite Bridge in Nowa Wieś

Road Bridge located in Nowa Wieś, Poland

Coordinates: (50,097636538420026, 22,041081069287294)
Year of construction: 2016
Material: Composite, Steel - concrete
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The bridge was built in 2016. The bridge is situated in Nowa Wieś (near to Rzeszów) over Czarna stream. It has a total length 10,7 m (single-span facility). The bridge span is made of four composite girders. This bridge is very innovative. The bridge span and beam is made from fibre reinforced polymers. The deck plate is sandwich composite. The core of this composite sandwich is PUR foam.

The bridge in Nowa Wieś is in the road between Rzeszów and Jasionka. The case of study is to research all points where it is possible to find some damages of bridge. Generally point of initiation of assessments is research interest. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria. All optical fibres sensors is situated in girders. Also very important is structural analysis. In this case it concerns ultimate limit state. The physical intervention of that bridge is repair.

The bridge over Czarna stream was constructed generally for roadway use. The most important damage for this bridge is local rupture or failure. It is very important for dynamic behaviour of the bridge. It is used three performance indicator: deformation, other loads (e.g. temperature) and acoustic emission. The signal of sensors could monitoring dynamic response or visual inspection. This leads to reduction risks of the deformation.

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Concrete Trough Bridges on the Iron Ore Railway Line

Railway Bridge located in Gällivare, Sweden

Coordinates: (66,570417, 21,021009)
Year of construction: 1967
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

An increase of the axle load from 250 kN to 300 kN was planned on the iron ore railway Luleå – Kiruna – Narvik. The fatigue capacity of the exisiting concrete trough bridges was too low according to current codes. A research program was started where the fatigue capacity was investigated, Elfgren et al. (1996). Thun et al. (2000).

In a research program, loads and deflections were monitored on four bridges along the line. One bridge, that had been taken out of service, was transported to Luleå University of Technology. It was there tested in fatigue with the planned axle load.

In tests, it was found that the bridge could withstand 6 million load cycles at 360 kN without any signs of distress. Only hairline concrete cracks could be seen. It could be concluded that the codes were quite conservative regarding fatigue.

Information gathered by Frida Liljefors, NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Dolmsund bridge

Road Bridge located in Hitra, Norway

Coordinates: (63,641101, 8,823905)
Year of construction: 2015
Material: Concrete, Prestressed
Type of case study: Master thesis work
Reason for initiation of assessment: Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The Dolmsund bridge is of the free cantilever type. It connects two islands (Hitra and Dolmøya). The bridge is made of post-tensioned concrete and has 5 spans with a total length of 483 m.

The goal of the thesis has been to gain knowledge about the time dependent effects that can cause deformation problems in cantilever bridges, namely creep, shrinkage and temperature effects. The bridge is instrumented with strain measurement sensors in two columns and the bridge deck. The bridge is modelled by using the finite element program NovaFrame, and controlled for the ultimate- and service limit state. The study compares three different models for creep and shrinkage effects.

The strain measurements from the bridge are compared to calculations from the design program NovaDesign. The comparison shows good compliance during the construction phases. Deviations occur after the two cantilevers are connected. Especially the bending strains in the main columns, where NovaDesign overestimates the difference between the strains in each side of the column. The normal strains from the programe shows good compliance compared to the measurements. The deviations may come frome differences in the rigidity between the column and the bridge deck as well as the effects from rebars in the columns. The length differences during the construction phases come from the functions of creep, shrinkage and temperature. Measurements from the bearings have been used to analyse how the mean temperature affects the length of the bridge. A review of the measurments of the bearings adjusted for temperature shows the rate of contraction in the bridge due to creep and shrinkage. It is shown that the rate of contraction in the bridge is higher while the concrete is newly cast.

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This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Eisenbahnbrücke Eglisau

Railway Bridge located in Eglisau, Switzerland

Coordinates: (47,57738, 8,509941)
Year of construction: 1897
Material: Steel, Masonry
Type of case study: Research
Reason for initiation of assessment:
Predominant verification type: Design value criteria
Predominant verification scale: Structural component

Summary of case study

This majestic railway bridge over the river Rhine in Switzerland was built in the years 1895-1897. A number of arches with piers reaching up to 50 meter above ground made of masonry makes up the side-spans. The midspan is a riveted steel truss with span 50 meter and height 9 meter, which is the structure of concern in this case study. The bridge has a significant heritage value.

A fatigue assessment was carried out by using monitoring data of strain at critical details, along with historic traffic records and future expected change in traffic loading. The fatigue analysis was done in two steps, first a fatigue limit verification and if exceeded, a Palmgren-Miner damage accumulation verification. Instead of applying partial safety factors, the safety criterion was set to damage value 0.5, where damage value 1 corresponds to failure. It was concluded that the fatigue reliability is sufficient for the next 50 years. The most critical detail was identified to be the first diagonals closest to the supports, and by rehabilitating these elements the fatigue life can be further elongated. The analysis was carried out according to the Swiss standards for assessment of existing structures from 2011.

The concern for the riveted steel truss was fatigue related as the structure was well above 100 years old, although no visible damage was detected. Monitoring with strain gauges at fatigue prone locations was carried out for one year. The measurement system was verified and the structural model was calibrated through load testing with known axle loads.

Information gathered by Frida Liljefors, Norwegian University Of Science And Technology NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Elgeseter bridge

Road Bridge located in Trondheim, Norway

Coordinates: (63,423978, 10,394055)
Year of construction: 1951
Material: Concrete, Reinforced
Type of case study: Master thesis work
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

Elgeseter bridge was opened to traffic in 1951. It consists of a reinforced concrete slab-beam bridge with 9 spans with a total length of 200m. The main load bearing system is made of 4 continuous beams supported by columns that are rigidly connected to the beams.

A capacity control (ULS) has been carried out in both the bridge superstructure and the columns for both for the original design loads and for additional loads from Alkali-Silica Reactions. The original loads and load factors are according to Handbook R412 "Bridge Classification". The load actions from Alkali-Silica Reactions are based on "Alkali Silica Reactions - Guidelines for Constructive Analysis", issued by the Directorate of Public Roads. The capacity control are performed according to the Norwegian Standard, NS 3473: "Design of concrete structures". Two computing programs have been used in this thesis, Abaqus CAE and Robot. Robot is a frame program that is used to find the design loads from the ordinary loads on the bridge, as well as the external loads actions from Alkali-Silica Reactions. Abaqus is a finite element program that is used to calculate the effect of the expansion from the Alkali Silica Reactions in several directions.

The concrete in the bridge has shown to contain Alkali-Silica Reactive deposits and several damages associated with Alkali-Silica Reactions have been observed. Among other things, an elongation of the superstructure has been measured. This has also led to an inclination of the columns. Due to this, the bridge may be exposed to significant additional forces.

Alkali reactions are a decomposition mechanism due to chemical reactions between alkali-reactive aggregates and alkalis in the cement paste. The reaction product is an alkali gel that swells during water absorption. This leads to expansion of the concrete and gradual internal and external cracking.

Information gathered by Daniel Cantero, NTNU, daniel.cantero@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Erdberger Brücke

Road Bridge located in Vienna, Austria

Coordinates: (629152,70, 481621,89)
Year of construction: 1968
Material: Concrete, Reinforced
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The Erdberger Bridge over the Danube Canal was built between 1968 to 1971. The bridge forms the heart of the traffic system with around 39,000 vehicles on the on the A4 and around 172,000 vehicles per day on the A23 (DTV Mo-Su; March 2009) and thus represents an extremely sensitive and important interface for the operator. The total width of the supporting structure of 42.30 m allows, in addition to the six lanes in addition to the six continuous directional lanes. The bridge has a total length of 147 m. The load-bearing is ensured by a shell which is formed by a cylindrical barrel with a parabolic opening. On top of the two cylindrical shells of variable thickness rests a carriageway plate with a considerable cantilever and a free inner field of over 12 m in width. Between the bond of the carriageway slab and the shells, cylindrical hollow bodies were inserted. The supporting structure was not prestressed, with the central opening having a span of 73 m.

Monitoring of behaviour of the shell in total and some other sensible components are recorded until demolition (2016)

Severe ongoing deterioration was recorded by the inspections. Settlement Abutments, Deflection of the Cantilever structure.

Information gathered by Fritz Binder, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Feuerwehrzufahrt TU Vösendorf

Road Bridge located in Vienna, Lower Austria, Austria

Coordinates: (622875,58, 473495,00)
Year of construction: 2006
Material: Concrete, Reinforced
Type of case study: Consulting
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Engineering judgement
Predominant verification scale: Structural system

Summary of case study

Simple overpas, frame bridge.
Crack monitoring incl. Temp. 1value/h

Information gathered by Fritz Binder, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Fiume Po Bridge

Road Bridge located in Piacenza-Cremona, Italy

Coordinates: (45,09913621, 10,02038985)
Year of construction: 1970
Material: Concrete, Prestressed
Type of case study: Consulting
Reason for initiation of assessment: Monitoring for reliability check and maintenance optimization.
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The Fiume Po Bridge is a prestressed reinforced continuous bridge, with alternated Gerger-hinges simply supported spans, located over the Po River, along the A21 Italian highway between Piacenza and Cremona cities. The total lenght of the bridge is 1673,50m. The portion of the structure under monitoring is the one crossing over the Po River and consists of 11 spans supported by 12 piers placed at a distance of 61.5m; specifically, there are 6 continuous spans and 5 simply supported Gerber spans. The length of the monitored section described above is approximately 676.5 meters. The precast deck, 24m wide, has 6 longitudinal beams and transverse beams.

The structural assessment of the Fiume Po Bridge has been undertaken due to reliability checks required by the road operator, and reviewed by two independent international Engineering firms (as per Autovia Padana internal assessment procedure). As a result of the seismic assessment, the prestressed gerber deck will be replaced by a steel deck solution. The Fiume Po bridge has been subject to continuous monitoring since February 2020 as part of a consulting project (Sacertis Ingegneria srl), to control the structural behaviour over time and optimize the maintenance procedures until the deck replacement. A non-linear FE model has been calibrated using optimization algorithms based on the static load test and dynamic characterization of the structural response through long-term data analytics. The definition of the thresholds, for each sensor of the monitoring system, has been based on the simulation of significant damage scenarios causing a targeted reduction of the reliability levels.

The Fiume Po Bridge experienced undermining of footings and exposed foundation piles in the piers located in the riverbed. In some of the beams, few strands of the prestressing cables were found corroded during the inspections. Concrete spalling and reinforcement steel corrosion were observed. A Sacertis continuous monitoring system is active on the structure since February 2020, with the aim to control the structural behaviour over time and optimize the maintenance procedures. It consists of 220 biaxial MEMS clinometers and 100 triaxial MEMS accelerometers, installed on the deck and the piers of the 11 monitored spans. In each sensor box are present a temperature and humidity detectors. Prior information available were: drawings, design documents, results of the proof load test. A calibrated non-linear FE model based on the static load test and dynamic characterization of the structural response through long-term data analytics has been used to determine the warning and alarm thresholds levels.

Information gathered by Paola Darò, SACERTIS Ingegneria Srl, paola.daro@sacertis.com

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Footbridge in Nowy Sącz

Pedestrian, bike road Footbridge located in Nowy Sącz, Poland

Coordinates: (49,63176972694055, 20,688855886457475)
Year of construction: 2019
Material: Concrete, Steel, Composite, Reinforced
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The footbridge was built in 2019 over Kamienica River. It was built as part of the European network (EuroVelo cycle routes). It has a span length 78 m, usable width 2,5 m and maximum height of structure 10 m. The deck (panels) of the bridge is made from hybrid concrete-composite. The material which was used to panel performance is FRP polymers.

The footbridge in Nowy Sącz is convenience for residents. The case of study is to research all points where it is possible to find some damages of bridge. Generally point of initiation of assessments is research interest. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria. The integrated structural monitoring system was built primarily on the composite EspilonRebar strains sensors. They are made in the form of GFRP reinforcing bars and connected within composite deck panels. Also very important is structural analysis. In this case it concerns ultimate limit state. The physical intervention of that bridge is repair.

The footbridge over Kamienica River was constructed generally for pedestrians or bikers use. The most important damage for this footbridge is excessive deformation. It is very important for dynamic behaviour of the bridge. It is used three performance indicator: deformation and other loads (e.g. temperature). The signal of DFOS sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Gad Bridge

Road Bridge located in Gad Oulx, Italy

Coordinates: (45,044746, 6,845676)
Year of construction: 1983
Material: Concrete, Prestressed
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Structural deterioration
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The GAD bridge is located along the A32 Turin-Bardonecchia motorway, above the Turin-Modane railway and on the SS24 state road. The bridge, built in 1983, has a slab deck with alternated continuous and Gerber simply supported spans. In particular, the structure is a prestressed reinforced concrete plate bridge with variable length spans along the development of the asset; the two-way deck is 10.35 m wide.

The Gad bridge has been subject to continuous monitoring since March 2019 as part of a consulting project of Sacertis Ingegneria srl, to specifically control the structural behaviour over time of the Gerger saddles of the simply supported spans over the Turin-Modan railway, until the deck replacement (planned within the next 5 years time). A non-linear FE model has been calibrated using optimization algorithms based on the static load test results and the analysis of the structural response through long-term data analytics. A local 3D shell FE model has been developed to further validate the results and perform sensitivity tests. The definition of the thresholds, for each sensor of the monitoring system, has been based on the simulation of significant damage scenarios causing a targeted reduction of the reliability levels.

The Gerber saddles were subject to attention in the past due to the presence of strenghtening works to restore the shear resistance, not sufficient for a lack of shear reinforcement. Strengthening works were necessary, the solution chosen was the adoption of prestressing transversal dywidag bars. The saddles show local cracks and presence of corrosion signs. The Sacertis SHM system installed in March 2019 was developed for both the short and long-term monitoring. Each Gerber saddle is equipped with a chain made by five biaxial MEMS clinometers and four IoT crackmeters. The system is completed by two gateways, one per carriageway and a power line communication to connect all the devices to the network. In each sensor box are present a temperature and humidity detectors, to perform the signal compensation. Prior information available were drawings, design documents, results of periodical visual inspections. The real-time monitoring system controls the response of both clinometers and crackmeters, and an automatic alerting system activates a direct communication to the road operator in case of thresholds levels exceedance.

Information gathered by Paola Darò, SACERTIS Ingegneria Srl, paola.daro@sacertis.com

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Galecopperbrug

Road Bridge located in Utrecht, The Netherlands

Coordinates: (52,060727, 5,096287)
Year of construction: 1971
Material: Steel
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Damage/deterioration location

Summary of case study

The Galecopperbrug (located in Utrecht, The Netherlands) is an important bridge in the Dutch road network (A12). It is a steel cable-stayed bridge with a span of 240 meters in total, of which 180 meters over the Amsterdam-Rijnkanaal. Altough one speaks about the Galecopperbrug, it are basically two separate. The first one, holding the traffic from west to east, was constructed in 1971. The second bridge was constructed in 1976. Both bridges hold six lanes of traffic (devided over a main road and a parallel road).

An important aspect of this bridge are the staycables. Each bridge consists of 2 pylons, both supporting 2 stay-cables. These stay-cables start at the anchorage just below deck at the abutment, pass the top of the pylon and are anchored again at a second anchorage below deck (above water). Each stay-cable consists of 6 locked-coil cables (76 mm diameter). These locked-coil cables on their turn are constructed out of 200+ wires of 4-8 mm in diameter.

The case study described here is related to the detection and monitoring of possible wire breaks. The capacity of the bridge is largely determined by the capacity of the stay-cables. The capacity of the stay-cables on their turn depends on the number of wires of the strands that are still intact. Regular inspection showed that, due to corrosion caused by rain, wires of the stay-cable can break and that wires have broken in the past. When multiple wires break, this affects the capacity of the strand.

To ensure a sufficient capacity of the strands, frequent inspection of the strands takes place. This inspection is done visually, and is only done by examining the outer layer of the strands in the last three meters of the strand. On top of this, after detection of the first corrosion a climate chamber is built around the ends of the strands, thereby making it almost impossible for water to intrude. By keeping the water out, in combination with sustaining correct humidity and temperature, it is tried to prevent additional corrosion and thus additional wire breaks.

In addition to the visual inspection also acoustic monitoring takes place. This monitoring system is installed in order to detect a wire break, based on the assumption that a wire break will lead to a high amount of (acoustic) energy in the strand.

Apart from the acoustic monitoring system some additional measurements and monitoring has taken place in the past: -bypass are placed at a few strands. These bypasses consist of two clamping parts that are clamped onto the strand using bolts. Two steel bars are attached to this clamp and to the anchorage, thereby taking over a part of the force in the strand. The forces in these bolts, as well as the forces in the two steel bars, are continuously monitored. -force measurements are performed in the past, to determine the force in the stay-cables. To this end the taut-string method is applied. For those measurements the stay-cable is brought into vibration, and the vibration of the cable is measured using accelerometers -multiple strain gauge measurement campaigns have taken place in the past.

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research and innovation programme under grant agreement No 958171.

Visual inspection of the strands still takes place frequently. On top of this an acoustic monitoring system is installed to detect acoustic activity in the strands. Each strand is equipped with one sensor at its end. These sensors are monitored continuously, and if activity above a certain threshold level (traffic noise) is detected, the signal is stored for later evaluation. By comparing the measured signals with prior knowledge on acoustic energy due to wire breaks (literature, lab testing), the acoustic signals that indicate a wire break can be isolated. If the acoustic signals give reason to, an additional visual inspection can take place.

As described in the previous section, apart from the acoustic monitoring and visual inspection regarding wire breaks, additional measurements have taken place in the past. Cable forces are measured using the taut string theory and the forces in the bypasses are continuously monitored using ring force meters.

Information gathered by Stefan Verdenius, TNO, stefan.verdenius@tno.nl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

German bridge examined by e.g. Hansen

Material: Concrete, Reinforced, Prestressed
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

A four-span post-tensioned concrete bridge was investigated for fatigue. One box-shaped girder serves each direction of travel. The closed box cross section prevents the equipment from vandalism.

An assessment of structure specific fatigue was carried out. Traffic axle loads and the resulting strains in the tendons were measured. The fatigue assessment was based on S-N-curves and the PM-rule for accumulation of damage.

Global deflection was measured at two locations of the bridge. Strain gauges and temperature sensors were installed at a number of locations, and axle loads were measured after calibration to known axle loads. A fatigue assessment was carried out for concrete, reinforcement and tendons.

Information gathered by Frida Liljefors, Norwegian University of Science And Technology NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Gimsøystraumen bridge

Road Bridge located in Vågan, Nordland, Norway

Coordinates: (68,262412, 14,251972)
Year of construction: 1981
Material: Concrete, Prestressed
Type of case study: Research
Reason for initiation of assessment: Structural deterioration, Pure research interest
Predominant verification type: Reliability-based
Predominant verification scale: Structural system

Summary of case study

The continuous multi span concrete bridge Gimsøystraumen bridge in northern Norway was built in 1981. It has a total length of 840 meters and the longest span is 148 meters. Located in a coastal climate the bridge is subjected to exposure of wind and sea water. The main components are abutments, pillars, a box beam and bridge deck, all made of reinforced concrete C35-C40. Generally, the concrete cover for this type of bridge constructed at this time is not sufficient.

A probabilistic assessment of the chloride concentration at the reinforcement was performed using enhanced Monte Carlo simulation. The basic random variables estimated from test data were chloride concentration at the surface, diffusion coefficient and concrete cover. Supplementary basic random variables were initial concentration, critical chloride concentration and model uncertainty. Component and system reliability was considered and reliability updating was demonstrated. The analysis makes use of the existing measured data, i.e. the measurements are not initiated in this investigation.

Concrete pillars and the box girder are subject to chloride induced corrosion and measures have been implemented to prevent further development in form of a cathodic protection system and local repair of concrete. Extensive measurements of concrete cover and chloride content have been carried out.

Information gathered by Frida Camilla Ingela Liljefors, Norwegian University Of Science And Technology, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Grünbrücke as a timber construction

Road crossing for wildlife Bridge located in Wiesenhagen (Brandenburg), Germany

Coordinates: (52,154487, 13,240179)
Year of construction: 2012
Material: Timber, Glued laminated timber
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: **Predominant verification scale:** Structural component

Summary of case study

The Grünbrücke near Wiesenhagen crosses the federal highway 101 and serves as a safe crossing point for many wild animals. With a width of 39 m, a span of 32 m and a clear height of maximum 7.5 m, it is founded on a solid reinforced concrete foundation. The superstructure is constructed in wood with glued laminated timber girders and cross-laminated timber panels made of larch wood. The static system forms a three-hinged arch with steel joints on the abutments and in the ridge. The superstructure is covered with earth and overgrown. To protect against moisture, the cross-laminated timber panels are followed by a special multi-layer sealing structure made of bitumen welding membranes, supplemented with protection against root penetration, drainage on the fighting lines to prevent backwater and an ingenious construction for moisture control. The construction represents one of the largest green bridges in Europe made of wood.

A test matrix describes all tests to be carried out according to the time interval to be observed, needs tests or according to an object-related damage analysis. The inspection of the green bridge includes a visual inspection of the load-bearing structure and connecting elements, wood moisture measurements, crack depth measurements, penetration resistance tests to check the strength of the wood structure, detection of cavities, endoscopy, resistography for the detection of cavities, there are also various notes and instructions for carrying out the test procedures as well as interpretation the Results. The documentation is written in the form of a test manual.

The documentation of the green bridge near Wiesenhagen includes a maintenance manual in which the measures intended for maintenance are described in the form of a maintenance matrix. The instructions include, among other things, the regular removal of vegetation in the area of the structure, regular cleaning of the structure, regular renewal of paint, ongoing repairs to individual component elements as well as the repair of the structural wood protection and existing repair concept for replacing individual arches and arch parts. The appendix contains further important information and instructions on how to interpret the wood moisture measurement.

Information gathered by Florian Fliegel, AEC3, ff@aec3.de

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Haringvlietbrug

Road Bridge located in Numansdorp, The Netherlands

Coordinates: (51,72533823156019, 4,401255015162126)
Year of construction: 1964
Material: Steel
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Structural deterioration
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The Haringvlietbridge is a box girder bridge crossing the Haringvliet North Sea inlet. It was opened in 1964 and is still operational. It carries the A29 motorway, with two lanes in both directions and a parallel local road. The bridge consists of 10 spans of 106 m and has a width of 25,5.

The box girder is 5,4 m meters wide. It is stiffened every 2,2 m with a ring frame consisting of a bottom cross girder, side wall stiffening and a top cross girder. The top cross girder also cantilevers outside the box girder. Every fourth ring frame this cantilever is supported by a diagonal strut. The other cantilevers are supported by a secondary longitudinal beam. The orthotropic deck is supported by the top cross girders.

Traffic across the bridge is heavy with approximately 1,5 million trucks passing in each direction per year. The bridge is constructed (starting from the north side) out of a 80 m side span, a 40 m long bascule movable bridge and an 1059.2 m long main bridge. The monitoring focuses only on the non-movable main bridge and side span.

The main bridge consists of a continuous steel box girder beam over 11 supports, with 10 spans of approximately 106 m. The side span consists of a single span box girder bridge. The box girder bridges consist of a 11,5 m wide, 5,4 m high steel box girder on which a 25,5 m wide deck is placed, carried by transverse steel girders. The deck is stiffened with open stiffeners (bulbs). The movable bridge consists of two plate girders, on which a similar deck is placed as on the box girders.

The motorway lanes in southernly direction are placed on the west cantilever of the deck. The motorway lanes in northerly directly are placed approximately central on the deck. The parallel local road is placed on the east cantilever of the deck.

The box is stiffened every 2,2 mm with a ring frame partly consisting a bottom cross girder, stiffening of the side wall and a top cross girder cantilevering on two sides carrying the deck. The bottom, sides and top (deck) of the box are stiffened. In case of the 10 mm thick deck plate, these stiffeners are placed 300 mm center to center. Every fourth ring cross girder, diagonal struts are placed outside the box, supporting the cantilevering part of the deck. At these locations, further internal cross bracing is provided as well. Running underneath the cantilevers between the external diagonal struts, an approximately 600 mm high secondary beam is placed. The box is constructed out of separate pieces of approximately 12 m length. which are riveted together. The bridge is constructed out of S355 steel.

Traffic across the bridge is heavy with approximately 1,5 million truck passing in each direction, per year (2020). A remarkable increase in traffic was seen since the year 2014 due to the construction of the A4 motorway between Delft and Rotterdam, making the A29 motorway a more logical route for many trucks. The number of trucks per direction is expected to grow to approximately 2 million in 2050.

The bridge owner (Rijkswaterstaat, the ministry of transport) has concluded, on the basis of an exploratory assessment, that a full recalculation of the bridge is required (ULS and FLS). The

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

scope of the anslysis includes the main arch structure and excludes any side structures such as the approach spans.

The recalculation is to be performed according to the relevant Eurocodes, their Dutch National Annexes, a supplementary Dutch code for existing structures and supplementary requirements by Rijkswaterstaat.

The models used in the analysis are to be validated with measurements on the bridge. Measurements will be taken of 3 months of normal traffic. Moreover, a load test will be performed on an otherwise empty bridge.

General state of the object is good. Minor corrosion at various location. A few loose rivets have been observed. Fatigue cracks are present in the orthotropic deck and main load bearing structure.

Measurement program described in summary B.

Information gathered by Sjors van Es, TNO, sjors.vanes@tno.nl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

IJssel bridge

Road Bridge located in Arnhem, Netherlands

Year of construction: 1961
Material: Concrete, Steel
Type of case study: Research
Reason for initiation of assessment: Post event and anticipated damage, Structural deterioration
Predominant verification type: Reliability-based
Predominant verification scale: Structural system

Summary of case study

IJssel bridge consists of a concrete bridge and two steel bridges. The concrete bridge carries traffic in the direction of Arnhem, the two steel bridges carry traffic in the direction of Westervoort. One steel bridge carries the main carriageway, while the second steel bridge carries the parallel carriageway. Practically, the two steel bridges are identical. Each consists of an approach bridge and the main bridge. concerning the construction years : - 1941 Start construction of embankments / abutments - 1943 Construction halted due to the second World War - 1961 Opening of the eastern IJssel bridge - 1964 Opening of the western IJssel bridge - 1975 Widen both bridges with inspection paths on extended consoles - 1977 Conservation of the eastern IJssel bridge - 1985 Restoration of concrete pillars - 1989 Conservation of the western IJssel bridge - 1990 Repair concrete deck / scraping edges of both bridges and installation of ZOAB - 1990 Driving direction

Within this case study, a probabilistic analysis using Bayesian approach were used for reliability analysis of the structures. some of the prior parameters are physical parameters and some of them are model and measurement uncertainties.

within this case study, the main measurement tests are: - strain measurements with strain gauges on the main supporting structure and fatigue details, - ballast test, - noise measurements / noise source location, these measurement were used to update the partial safety factor.

Information gathered by Asma Manai, TNO, asma.manai@tno.nl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Kalix river bridge

Railway Bridge located in Långforsen, Kalix river, Sweden

Coordinates: (65,906440, 22,924804)
Year of construction: 1960
Material: Concrete, Reinforced
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The concrete arch bridge over Kalix River at Långforsen was built in 1960 and has a mid-span of 89,5 m and a height of 13,7 m. The bridge owner, Trafikverket, wanted to increase its allowable axle load from 225 to 300 kN. Monitoring and calculations were carried out at Luleå University of Technology, Sabourova et al (2019) and Wang et al (2019).

Field tests were carried out under service condition and with ambient vibrations. The test results were used to update and validate Finite Element Models. At last, the refined models were used to check the possibility to increase the axle load.

The critical sections are in the beams carrying the rail on top of the arch in the section where the beams are united with the arch. Here the stresses in the longitudinal bottom reinforcement were slightly too high. These sections have been studied in a FEM model for different loads and results show maximum strains of about 50·10-6 corresponding to stresses of only about 10 MPa in the reinforcement in the critical sections. Live load vertical deflections of the crown of the arch are of the order of only ± 6 mm. Dynamic studies have also been made showing that fatigue is no issue. Altogether the studies show that the bridge can carry an increased axle load of 300 kN without problems.

Information gathered by Frida Liljefors, NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Kiruna bridge

Road Bridge located in Kiruna, Sweden

Coordinates: (67,851333, 20,218306)
Year of construction: 1959
Material: Concrete, Reinforced, Prestressed
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural component

Summary of case study

This 122 meter long bridge with five continuous spans was built in 1959 along highway E10 near Kiruna in northern Sweden. The superstructure consist of three prestessed concrete girders with a reinforced concrete slab on top. The prestressing system is post-tensioned system with four to six tendons parabolically aligned in each girder. One tendon is composed of 32 strands with diameter 6 mm.

This study presents a framework for successively improved structural analysis and verification. For structural analysis the initial level comprises beam, frame, handbook or simple FE models combined with local resistance models. The most enhanced level is a full non-linear FE-analysis reflecting all possible failure modes. The verification format is divided into partial safety factor format, global resistance safety factor format and full probabilistic analysis. To include bridge specific information is also treated. For the case study bride, the difference in permitted axel load was ten times higher for the most enhanced analysis compared with the initial one.

Measurements of the in situ concrete strength and modulus of elasticity as well as tensile strength, yield strength and strain at peak stress for reinforcement and strands were carried out. 25 concrete cores and 40 steel samples were collected and the data was used to update the models in a non-bayesian way.

Information gathered by Frida Liljefors, Norwegian University of Science And Technology NTNU, frida.liljefors@ntnu.no

Leziria bridge

Road Bridge located in Carregado/Benavente, Portugal

Coordinates: (39,012789, 8,934379)
Year of construction: 2007
Material: Concrete, Reinforced, Prestressed
Type of case study: Research
Reason for initiation of assessment: Pure research interest, Important, unique structure
Predominant verification type: **Predominant verification scale:** Structural system

Summary of case study

With a total length of 12 km including its approach viaducts, the Leziria bridge in one of the longest bridges in the world. It is a part of highway A10 outside of Lisbon and is made of prestressed concrete. The bridge has been though-roughly monitored since it was constructed. This case study outlines a set of good practices for advanced FE-modelling in assessment of large existing structures.

No safety verification of the bridge is done but the focus is rather on advanced FE-modelling that can be used for assessment in future. Good correlation between FE-models and monitoring data is observed.

A number of critical aspects were identified: Detailed modelling of the geometry from drawings, in situ measurements of structural mechanical properties including soil, information on actual loading conditions from construction phase and load test and the sequence of construction.

Information gathered by Frida Liljefors, Norwegian University Of Science And Technology NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Lundevann bridge

Road Bridge located in Tvedestrand, Norway

Coordinates: (58,658042, 8,956821)
Year of construction: 1970
Material: Concrete, Prestressed
Type of case study: Master thesis work
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

Road bridge in the southern Norway. The bridge consist of 11 spans with a total length of 135 m. Each span is made of prefabricated prestressed beams, supported by transversal beams resting on piles.

Loads and load combinations are calculated by the Norwegian Road Safety Authority's Handbook R412 for bridge classification, and the capacity checks are performed according to NS-EN 1992-1-1 (Eurocode 2). The bridge is modeled in Autodesk Robot Structural Analysis Professional 2017. Capacity control of the structural parts of the bridge is performed for its undamaged condition according to current regulations.

Damage assessment calculations have been made in order to estimate the consequences the damage will have for the load bearing capacity of Lundevann bridge. This has been done by examining the consequences of loss of concrete cover in the compressive zone, and by reducing the reinforcement area.

A visual inspection and a special inspection have been carried out with extraction of new concrete samples, which together with previous inspections forms the basis for an assessment of the current damage level on the bridge. RCT (rapdi chloridge test) and ISE (Ion selective electrode) methods have been carried out in order to analyze the concrete samples, and perform chloride measurements. New samples that correspond to previous withdrawal points are compared to evaluate the development of chloride content in the concrete elements.

Information gathered by Daniel Cantero, NTNU, daniel.cantero@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Marktwasser bridge

Road Bridge located in Lower Austria, Austria

Coordinates: (48,378017, 15,714011)
Year of construction: 2010
Material: Concrete, Steel, Reinforced
Type of case study: Research and Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Pure research interest
Predominant verification type: Reliability-based
Predominant verification scale: Structural system

Summary of case study

The Marktwasser bridge S33.24 is an integral reinforced concrete foreland bridge with a three-span plate structure with a peripheral span and a central span of 19.50 m and 28.05 m of the cantilever bridge leading over the Danube near Krems. The bridge was completed in 2010. The abutment end faces of the structure are inclined at an angle of 74 ° with respect to the longitudinal axis of the structure. The monolithic, rigid connection between the eight pillars and the 1.0 m thick structural slab is ensured by a 1.6 m high haunch formation over a length of 2.50 m. The width of the ceiling slab is between 19.40 m and 22.70 m, disregarding the two cantilevers, each 2.50 m long. The entire structure is based on four rows of bored piles with a length of 12.00 m in the abutment axes and a length of 19.50 m in the pillar axes.

In the course of this case study, a concept for an effective integration of monitoring information into a numerical model based on the concept of model correction factors was dealt with. In particular, this study arose from the questions posed in the course of the research project "Monitoring-based Analysis Integral Bridges (MAIB) ". The MAIB research project pursues issues relating to the structure, the interaction between the structure and the soil, the stability of the soil behind the abutment and the transition area between the structure and the ground in the roadway area.

In the course of the research project, the method of model correction factors in combination with sensor-related influence lines could be developed through a targeted test load program, which allows a comprehensive model adjustment and continuous evaluation using performance indicators based on the monitoring information.

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This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Martinus Nijhoffbrug

Road Bridge located in Zaltbommel, Gelderland, The Netherlands

Coordinates: (51,818611, 5,26)
Year of construction: 1996
Material: Concrete, Prestressed
Type of case study: Early warning system regarding failure of the modular expansion joint
Reason for initiation of assessment: Post event and anticipated damage
Predominant verification type: at first engineering judgement, updated on the basis of measuring results
Predominant verification scale: Structural component

Summary of case study

The Martinus Nijhoff brigde is a cable-stayed bridge spanning the river De Waal in the Netherlands. The bridge is situated in the highway A2, one of the main north-south highways in the Netherlands. The bridge has in total 3 spans bridge, a total length of 990 m and a main span of 256 m. The bridge had a modular expansion joint. See also https://nl.wikipedia.org/wiki/Martinus$_{N}ijhoffbrug$

Based on the measured strains and a comparison of the maximum strains with the strains at previous days, it was decided whether the increase with the previous day was larger than expected. If so, inspections were carried out to determine whether the joint was damaged.

The state of the structure (focusing on the joint) was that the joint was supposed to be replaced. The monitoring system was installed to postpone replacement of the joint by one year and to reduce the risks related to failure (sliding) of the supports of the separation beams in the expansion joint. The result of failure of the joint during service is related to traffic safety (not to structural safety)

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Monforte Bridge

Road Bridge located in Monforte de Lemos, Lugo, Spain

Coordinates: (42,522973, -7.514796)
Material: Masonry
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

Monforte Bridge is a sixteenth century masonry arch bridge in the southeast of Galicia. The bridge has four semicircular or segmental arches between a 7.0- and 11.0-m span, triangular buttresses, and an upward arching profile, as shown. This bridge is very important because it is an ancient structure that provides contemporary strategic road access to the city. Therefore, the structure is supporting traffic loads much heavier than in former times, and diagnosis is required to ensure its stability and durability.

The purpose is to analyze the potential of GPR in obtaining previously unknown, inner details that can be valuable information for developing future conservation and strengthening techniques. This case includes the use of FDTD modeling for an exhaustive interpretation of the field GPR data. Also, the input to the computation of FDTD modeling was a raster image containing a geometric description of the structural elements to simulate.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Murbrücke Feldkirchen

Road Bridge located in Graz, Styria, Austria

Coordinates: (47.014716, 15.459291)
Year of construction: 1969
Material: Steel
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

Steelbridge Crosssection: Boxgirder, Orthothropic structure. L=88m W=15m
Electronic "water level gauge" electronic inclination sensors DMS Temperature, ...
The aim is to monitor extreme deflection. Alarm when defined limit value is exceeded.

Information gathered by Fritz Binder, Asfinag Baumanagement GmbH, frizzi@gmx.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Musmeci bridge

Road Bridge located in Potenza, Italy

Coordinates: (40,627409, 15,806398)
Year of construction: 1975
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Structural deterioration, Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural component

Summary of case study

The Musmeci bridge was built in Potenza, southern Italy, in 1975 and is named after its designer Sergio Musmeci. It has an innovative shape with a curved reinforced concrete membrane designed to work in compression, with a reinforced concrete box girder on top. The focus of this case study is on the expansion joints in the box girder, which are deteriorating due to deicing salts and insufficient water drainage with consequential chloride induced corrosion. This detail has a critical role in the global structural capacity.

A mechano-chemical analysis was carried out to assess corrosion in the reinforcement induced by chlorides. No measurements on chloride content or corrosion were conducted, but parameters describing the corrosion process were instead taken from literature. The mechanical behaviour was analysed in the FE-program ATHENA. The proposed failure mechanism was crushing of concrete due to diagonal cracking in the upper part of the joint.

Dynamic response analysis was available from earlier studies and was used to verify the mechanical model. Concrete strength was evaluated from cores drilled at non-critical locations of the girder, other parameters were assumed from design documentation and literature.

Information gathered by Frida Liljefors, Norwegian University Of Science And Technology NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

National Uprising Bridge

Road Bridge located in 1972, Slovakia

Coordinates: (48,13848581095178, 17,10449699147257)
Year of construction: 1972
Material: Steel
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The bridge was built in 1972 in the capital of Slovakia - Bratislava. The road-rail bridge is situated over Danube River. It is located near the Castle Hill. It is an asymmetric cable-stayed bridge steel bridge. It has a total length 431,8 m. The lengths of the spans are: 74,8 m, 303 m and 54 m. The height of the beam is 4,6 m, the width is 21 m. The bridge was constructed in the ANSYS environment using beam and shell elements. The pylon top, stiffeners and curvature of the deck in vertical direction.

The Uprising Bridge is also very important for roadway transport in the capital of Slovakia. The case of study is to research all points where it is possible to find some damages of bridge. Generally point of initiation of assessments is research interest. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria. All sensors is mounted along bridge. The physical intervention of that bridge is repair or upgrading.

The bridge over Danube River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation and displacement. It is very important for dynamic behaviour of the bridge. It is used dynamic response as performance indicator. The signal of sensors could monitoring all possible defects (construction temperature). This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Nerlandsøybrua

Road Bridge located in Herøy, Norway

Coordinates: (62,340089, 5,606019)
Year of construction: 1966
Material: Concrete, Reinforced, Prestressed
Type of case study: Master thesis work
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

Nerlandsøybrua is a coastal bridge in Herøy, Møre og Romsdal. It is rather slender construction built in 1967. The 404 m long beam-plate bridge consists of 20 spans, a T-shaped cross section, and rectangular shaped columns with varying height. The 40 m long main span and the two adjacent spans are prestressed, while the remaining spans are ordinary reinforced. As result of a less strict set of rules of design, concerning environmental threats at the time of construction, the Nerlandsøya Bridge is not armed for the rough climate at the coast of Sunnmøre. In the 1990s, the bridge was installed with a cathodic protection system.

Capacity Control of the bridge's superstructure and the most critical column is performed at ultimate limit state. The framework program NovaFrame is used for the modeling of the bridge to determine the design forces. Håndbok 238 is the basis for control of loads and NS3473 Concrete structures - Design and detailing rules is used in capacity calculations.

During this inspection there were studies conducted on the materials where the concrete cover, carbonation and chloride content was measured. The chloride content proved to be of critical value in several places on the bridge. This indicates that chloride corrosion is likely. The largest values for chloride were registered on the north side of the bridge, sheltered from the design direction. The areas closest to the land had the highest chloride content, which is expected because of the low altitude. Visual inspection of the damages coincided well with the chloride studies. In areas with high chloride content there was also detected spalling and delamination of the concrete cover. In areas where the reinforcement is visible there is obvious corrosion.

Information gathered by Daniel Cantero, NTNU, daniel.cantero@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Neumarkt bridge

Road Bridge located in Neumarkt, South Tyrol, Italy

Coordinates: (46,335284, 11,277089)
Year of construction: 1961
Material: Concrete, Reinforced, Prestressed
Type of case study: Research
Reason for initiation of assessment: Structural deterioration, Pure research interest
Predominant verification type: Reliability-based
Predominant verification scale: Structural component

Summary of case study

The Neumarkt bridge in South Tyrol, Italy, was built in 1961 and demolished in 2008 because of doubt of structural reliability due to extensive chloride corrosion, especially in the columns. It served as an overpass over the highway in three spans, the longest being 27 meter. The superstructure consisted of four precast prestressed V-girders with a reinforced concrete deck on top. Along with the demolition, the bridge was investigated by a research team.

A multi-level assessment of the current condition and remaining lifetime due to corrosion of the prestressing system is presented. Time-variant chloride concentration distribution at various locations was predicted with the cellular automata technique and pitting corrosion was evaluated. Non-linear deterministic and probabilistic analyses were carried out for the original state and the degraded state of the structure.

Pitting corrosion due to chloride ingress was indicated in previous inspections, for instance by massive concrete spalling. Chloride concentration and pH was therefore determined from drilling powder and drilling core concrete samples from the V-girders. In total around 50 measurements were done, most intensively at the girder that was most effected by chloride induced corrosion.

Information gathered by Frida Liljefors, Norwegian University Of Science And Technology NTNU, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Nordbrücke

Road Bridge located in Vienna, Austria

Coordinates: (48,2541485, 16,3779791)
Year of construction: 1964
Material: Composite, Steel - concrete
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: Engineering judgement
Predominant verification scale: Structural system

Summary of case study

Crossection: Plate beam Longitudinal section: Continuous beam 5 spans 80m each. total length:333m width:20m

Information gathered by Fritz Binder, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

O Folgoso tunnel

Road Tunnel located in A Caniza, Pontevedra, Spain

Coordinates: (42,174822, -8.367881)
Year of construction: 1998
Material: Concrete, Shotcrete
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Functional road safety components (inventory)

Summary of case study

The Folgoso tunnel is the largest engineering project and one of the cornerstones of the current highway A-52, that connects the principal cities in southern Galicia, Spain. The O Folgoso tunnel's course runs in the municipality of A Cañiza, with a total length of 2500 m. The tunnel is monitored by a control center that checks the ventilation, light, signaling, communications and fire detection systems among others.

Automatic method for the detection of tunnel luminaries as well as to obtain their 3D spatial location, using colored 3D point clouds. Detection performance is verified by experiments carried on real data acquired with the Lynx Mobile Mapper system. In short, it seeks the detection of luminaries automatically and improve the productivity of tunnel inspections.

The first step simply consists of the point cloud pre-segmentation based on height values of the luminaire. Where all the points from the point cloud above the reference level are considered for the next stage. The stage 2, thresholds for classification are extracted from the color histogram analysis taken of 8-bit color images. Finally, is refined the existing segmentation of the luminaires using known values of vehicle speed (v) and camera shutter speed (t), and in this way calculate their centroids.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Ourille River Viaduct

Road Bridge located in Ourense, Galicia, Spain

Material: Concrete, Prestressed
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural component

Summary of case study

The Ourille River Viaduct is a structure located in the province of Ourense, Spain, which serves as a support for the group of roads that communicates the region of Galicia, Spain, with the Portuguese border. The bridge consists of two separate decks of four simply supported spans. The transverse section is composed of four beams 1.90 m in height and separated at an interval of 3.55 m with a prestressed H-shaped cross-section beam. Above the same, a 0.25-m-thick slab is located so that the total height of deck is equal to 2.15 m. The span studied corresponds to span two on the right-hand side of the bridge, whose deck has a total length of 33.05 m and a width of 12.14 m.

The aim principal is to provide an easy and practical methodology that allows the conversion of point clouds into finite-element method (FEM) models of bridges so that they can take the benefit of the precise geometrical description obtained from point cloud data. Thus, these models can be used later to carry out a structural assessment of an existing bridge.

Previously, a Lidar data collection is carried out, to which a series of corrections are applied to both the noise and the point clouds themselves to generate files that allow further optimization of the mathematical models. Subsequently, two models are created. The first is a three-dimensional solid element model that makes use of the geometric model directly obtained after the point cloud processing steps. The second structural model is a more simplified approach in which a concrete slab is modeled as a shell structural element and the beam elements are considered for the discretization of the concrete beams. The mechanical properties of the concrete beams are readily obtainable from the geometric pattern model.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Passerella Olimpica

Pedestrian Bridge located in Turin, Italy

Coordinates: (45,031773590647255, 7,660912713295258)
Year of construction: 2006
Material: Steel
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Monitoring for maintenance optimization.
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The Turin Olimpic Arc footbridge (Passerella Olimpica) is located in southern Turin and consists of a pedestrian walkway that connects the former Olympic village with the multi-purpose complex of Lingotto, overpassing the railway. It is one of the urban architectural symbols left in memory of the XX Winter Olympic Games which took place in 2006 in Turin. The pedestrian steel walkway is 368 meters long, has a maximum height of 11.8 meters, includes a single span of 156 meters supported by 32 stays over a large red metal arch with a parabolic shape, 69 meters high and 55 meters long. Lateral access spans 212 meters long are supported on V-shaped columns.

The Olimpic footbridge has been subject to continuous monitoring since august 2020 as part of a consulting project (Sacertis Ingegneria srl). The assessment has been undertaken due to reliability checks required by the municipality and a monitoring system has been installed to control the structural behaviour over time and optimize the maintenance procedures. A non-linear FE model has been calibrated based on the dynamic characterization (mode shapes and natural frequencies of the stays and the overal structure) and data analytics. The definition of the thresholds, for each sensor of the monitoring system, has been based on the simulation of significant damage scenarios that can cause a significant reduction of the safety and reliability target levels.

The Olimpic footbridge, built in 2006, has no sign of deterioration or occurring damage processes. The aim of the monitoring system is to control the structural behaviour over time and optimize the maintenance procedures. The Sacertis monitoring system, installed in August 2020, consists of 34 triaxial MEMS accelerometers installed on the deck and on a selection of stays. Prior information available were: drawings and design documents, results of the proof load test, n.2 previous dynamic measuring campaigns. A non-linear FE model has been calibrated based on the dynamic characterization (mode shapes and natural frequencies of the stays and the overall structure) and used to determine the warning and alarm thresholds levels. A near-real time alert system is active on the structure.

Information gathered by Paola Darò, Sacertis Ingegneria Srl, paola.daro@sacertis.com

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Pfaffenbergbrücke

Railway Bridge located in Kärnten, Austria

Coordinates: (46,916975, 13,253609)
Year of construction: 1971
Material: Concrete, Steel, Reinforced
Type of case study: Research and Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The Pfaffenberg Bridge from 1971 is a reinforced concrete arch bridge and is located on the southern ramp of the Tauern Railway on the Schwarzach / St. Veit - Spittal / Drau route. The bridge object transfers two tracks with a ballasted superstructure. Both in the area of the bridge and on the free stretch, the ballast bed height is 45.0 cm. The bridge construction has a total length of 377.0 m.

Through the targeted arrangement of sensors and measuring instruments, air, rail and structure temperatures, relative longitudinal displacements of the structure and relevant deformation parameters of the rails (expansion and compression) were measured and documented as part of a continuous measurement program.

The Pfaffenberg Bridge was equipped with measuring technology in 1993 to record the interaction effect. In the case of the measuring device, the focus was correspondingly on the measurement of the air, rail and structure temperature, on the recording of the expansion behavior of the rail and on the recording of the structure and rail longitudinal displacements. Track 1 (track on the mountain side) was chosen as the measuring track and equipped with strain gauges and temperature sensors. The strain gauges were applied approximately in the neutral axis of the rail.

Information gathered by Lisa Ptacek, University of Natural Resources and Life Sciences, Vienna, lisa.ptacek@boku.ac.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Pielach bridge

Railway Bridge located in Lower Austria, Austria

Coordinates: (48,200129, 15,511953)
Material: Steel
Type of case study: Research and Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The "Pielachbrücke" railway bridge is located on the double-track western line in the St. Pölten - Attnang / Puchheim section in Lower Austria. Two separate steel structures each transfer a track structure with a conventional ballast superstructure. The three-field steel structures have a total length of 91.50 m, with all three fields having a length of 30.50 m each. The support structure consists of two abutments and two compact pillars with a pillar height of around 3.45 m.

Through the targeted arrangement of sensors and measuring instruments, air, rail and structure temperatures, relative longitudinal displacements of the structure and relevant deformation parameters of the rails (expansion and compression) were measured and documented as part of a continuous measurement program.

The measuring equipment of the test object took place at two different times. On December 20, 2011, temperature sensors and displacement transducers were placed at the steel structure / track 3 on the abutment in order to record the deformation behavior of the steel structure. The measuring program was expanded from September 20, 2012 to include the strain gauges (DMS) applied to the rail web as well as further temperature sensors on the rail and on the supporting structure. Thus, the stretching behavior of the rails could be continuously observed and recorded during the measurement period [55]. From September 20, 2012, two additional displacement transducers were placed on the abutment on the supporting structure / track 4.

Information gathered by Lisa Ptacek, University of Natural Resources and Life Sciences, Vienna, lisa.ptacek@boku.ac.at

Port Bridge

Road Bridge located in Bratislava, Slovakia

Coordinates: (48,199274782062986, 17,114706585684907)
Year of construction: 1985
Material: Concrete, Steel
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

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The bridge in the capital is very important for roadway transport. The case of study is to research all points where it is possible to find some damages of bridge. Generally point of initiation of assessments is research interest. Monitoring of that bridge allows to eliminate all potential damages. All sensors is mounted along bridge. The physical intervention of that bridge is repair or strengthening.

The bridge over Danube River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation and displacement. It is very important for dynamic behaviour of the bridge. It is used dynamic response as performance indicator. The signal of sensors could monitoring all possible defects (construction temperature). This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Posedarje bridge

Road Bridge located in Posedarje, Croatia

Coordinates: (44,2221, 15,4803)
Year of construction: 1961
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Risk-based
Predominant verification scale: Structural system

Summary of case study

The bridge located near Posedarje, Croatia, was built in 1961. It is a three span continuous reinforced concrete slab bridge with reinforced concrete piers and abutments, with longest span being 15 meter. The foundation consists of reinforced concrete foundations and timber piles.

The reassessment was carried out in order to quantify the value of additional traffic load information, i.e. the case study was driven by research interests. Three different options for load modelling were analysed. As reference case, the Eurocode LM1, intended for design of new structures, was used. This was compared to LM1 adjusted with a reduction factor from earlier studies, and a site specific load model determined from WIM data. For all three options, a simulation-based reliability analysis was carried out. Two critical failure modes were identified from prior information and corresponding limit states were formulated. Assumptions for the random variables were object specific when possible and from recommendations otherwise. A value of information analysis was performed with input from the reliability analyses and consequences in terms of both bridge owner and user costs. The study demonstrates the benefits of using WIM data when making maintenance decisions.

Data from WIM was provided by the bridge owner. The monitoring was done for other purposes, such as controlling truck weight restrictions. The data was post-processed with the convolution method for extrapolation, and LDF was determined from the numerical model.

Information gathered by Frida Camilla Ingela Liljefors, Norwegian University Of Science And Technology, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Ribeiriño bridge

Road Bridge located in Ourense, Galicia, Spain

Coordinates: (42,345756, -7.875609)
Year of construction: 1971
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Structural deterioration, Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The construction of the Ribeiriño bridge, part of the road N-525 linking the cities of Santiago de Compostela and Benavente, was completed in 1971. Although this road was split by the motorways A-52 and AG-53 about one decade ago, it is still vitally important to the region. The Ribeiriño bridge is 147 m long, and all of its main elements (abutments, pillars and deck) are made of reinforced concrete. Metal formwork was used in the construction of the bridge's reinforced concrete elements. The weather conditions, pollution, traffic loads and the passage of time have caused damage to the structure. One of the significant problems is biological crusts present in most of the pillars and abutments, this problem is related to water infiltrating from the deck of the bridge.

The methodology includes survey planning and data acquisition, data filtering, generation of ortho-images and image classification using K-means and Fuzzy C-means algorithms. Both algorithms are evaluated using two classes (biological crusts and concrete) and three classes (biological crusts, water and concrete). The selection of these algorithms is motivated by their simplicity and efficiency.

The primary goal is to evaluate the possibility of using intensity information from laser scanning data to detect areas with water presence and vegetation in bridge abutments and pillars. Additional goals are to increase the degree of automation of bridge inspection work and contribute providing quantitative and qualitative information for the bridge management systems.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Roman Bridge of Lugo

Road Bridge located in Lugo, Galicia, Spain

Coordinates: (43,001943, -7.563597)
Material: Steel, Masonry
Type of case study: Research
Reason for initiation of assessment: Pure research interest, Identification of historical change in design and structural state
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The Lugo Bridge has eight gothic or canyon arches that range from 5.6 to 10.4 m. Although this bridge has a horizontal profile today, the Lugo Bridge had a double-sided medieval profile until the end of the 19th century. Various restoration and reconstruction tasks have been carried out over time. Consequently, different building materials such as granite and slate are observed on the surface of the masonry. This bridge was selected because of its importance in providing contemporary strategic road access to the city. Therefore, a structural evaluation is required because it withstands much heavier traffic loads than the useful life design of old.

Two longitudinal parallel profiles in opposite directions along the bridge, each 122 m in length, were collected using a RAMAC/GPR system from MALÅ Geoscience with 250 and 500 MHz shielded antennas. Data acquisition was based on constant distance intervals following the common offset mode, and the survey parameters previously selected. Later GPR processing filters were employed in order to reduce clutter or any unwanted noise in the raw-data. The geometry, condition and size of this reflector allow to conclude the original double slope profile as well as the response of the transversal reinforcements and the existence of masonry and filling materials within the bridge structure. Finally, a comparison of real data is performed with synthetic models, allowing the extraction of subtle interpretive information to produce a comprehensive data interpretation.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Roman Bridge of Lugo

Road Bridge located in Lugo, Galicia, Spain

Coordinates: (43,001943, -7.563597)
Material: Steel, Masonry
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

The Lugo Bridge has eight gothic or canyon arches that range from 5.6 to 10.4 m. This bridge's current appearance is the result of several reconstruction and restoration tasks from many eras (Roman –it was part of the Via XIX of the Antonino Itinerary in the III century–Medieval, XVII, XIX, and XX century). Consequently, different building materials such as granite and schist are observed in the stonework surface. Also, although this bridge has a horizontal profile today, the Lugo Bridge had a double-sided medieval profile until the end of the 19th century.

This process involves combining data from different sources. An integration of both mobile and static LiDAR methods is considered to process their scan data into asbuilt bridge documentation, and a GPR system is used to characterize its internal stonework. Moreover, fully integrated digital cameras in the LiDAR systems provide useful radiometric information for pathology detection or texture identification in different constructive materials.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo, gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Rędziński Bridge

Road Bridge located in Wrocław, Poland

Coordinates: (51,156786034691926, 16,95941449810424)
Year of construction: 2011
Material: Concrete, Steel, Reinforced
Type of case study: Research
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural component

Summary of case study

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The case of study of Redzinski bridge is to research all points where it is possible to find some damages. Generally point of initiation of assessments is structural deterioration. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria and design value criteria. All measurements sensors is mounted along bridge. The monitoring system of bridge consist of subsystem: construction and metrology monitoring. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair, strengthening or upgrading.

The bridge over Odra River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation and displacements. It is very important for dynamic behaviour of the bridge. It is used three performance indicator: deformation, deflection, angular displacements and other loads (e.g. temperature). The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Segura Roman Bridge

Road Bridge located in Alcántara, Cáceres, Spain

Coordinates: (39,817294, 6,981677)
Material: Masonry
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural component

Summary of case study

Segura Bridge is one of the best Roman Bridges conserved in the Iberian Peninsula. It is made of five arches and four pillars with triangular cutwater on the upstream side. It crosses the frontier river Eljas and over this bridge a national road communicates the councils Piedras Albas (Spain) and Segura (Portugal). According previous study the central arches of the bridge have been rebuilt in the second middle of the XVI century, after a collapse caused by growth of the river flow in 1565. In the reconstruction works the drainage area was increased, making central arches higher. Consequently, the original horizontal grad line was converted in a great sloped platform. But it is also documented a posterior reformation in the bridge , when the spandrel walls were elevated and the grad line was horizontal again.

A 3D model of the bridge is built by means of a terrestrial laser scanning, and then its geometry was analyzed by two methods. Firstly, by means of a direct way, a graphical analysis in CAD systems is performed and the main geometrical parameters were obtained and evaluated; secondly, using statistical nonparametric methods, developed for this kind of structures, it is possible to identify pathologies on the structure thanks to the measurement of deformations in vaults by means of a symmetrical study.

Terrestrial laser scanning represents a fundamental tool in the inspection of bridges based on geometric analysis, if this is also combined with a correct algorithm, it allows to obtain hidden structure information. Thus, the algorithm correct used for the geometric analysis in vaults, together with the graphical representation of overlapping semi-cross sections allows visual inspection and quantification of asymmetries and distortions, facilitating diagnosis based on the arch geometry, what's allowed the detection of pathologies. Furthermore, if it's work with (X, Y, Z) coordinates, it allows locating and measure the damage to the structure.

Information gathered by Gabriel Suárez, GeoTech - University of Vigo., gsuarez@alumnos.uvigo.es

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Seitenhafenbridge

Road Bridge located in Vienna, Austria

Coordinates: (48,176956, 16,463955)
Year of construction: 2011
Material: Concrete, Steel, Reinforced
Type of case study: Research and consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Structural deterioration
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

Seitenhafenbridge is a semi-integrale structure with length of 130 m located in Vienna, Austria. It is a roadbridge that was finished in 2011. The structure consits of a reinforced concrete slab resp. T-beam on steel columns and nodes. The structure is post tensioned for all spans. A concept of flexible abutment was applied (the first in Austria and currently the longest one in Europe). The foundation is pile foundation with flexible casing.

The monitoring system was included in the tender for the bridge. The tender design was prepared including specifications of sensors. Detail design was already considering the monitoring equipment. The goald was the verification of static calculation or input parameter for further investigations: Comparison of design assumptions with real structure. Calibration of finite element models to real structural behavior. Documentation of construction period or specific loading conditions.

The monitoring equipment consits of: earth pressure sensors, laser sensors, passive reflecting units, inclinations sensors, hydraulic levelling system, temperatur sensors.

The measurement task was to investigate the following: structural temperature, investigation of earth pressure (flexible abutment), alternation of length, vertical deflection of selected locations, observation of changes in inclination of selected locations, data storage transmission, regular reporting with regard to design assumptions.

The monitoring system is working since start for operation in 2011. Reporting and maintenance is carried out in regular intervals by the client. The system has shown that the structure behaves as assumed. Monitoring improves understanding and may influence future design.

Information gathered by Lisa Ptacek, University of Natural Resources and Life Sciences, Vienna, lisa.ptacek@boku.ac.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Semmering Base Tunnel

Railway Tunnel located in Styria, Lower Austria, Austria

Coordinates: (47,603833, 15,732119)
Year of construction: 2012
Material: Concrete, Steel, Rock, Reinforced, Shotcrete
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: Engineering judgement
Predominant verification scale: Structural system

Summary of case study

The Semmering Base Tunnel is a railway tunnel with two tubes, each 27,3 km long. It is built with reinforced tunnel lining segments and shotcrete.

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Sesupe River Bridge

Railway Bridge located in South-West Lithuania, Lithuania

Year of construction: 2012
Material: Concrete, Steel, Reinforced
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

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The bridge in the railway line Kaunas-Kybartai is very important for railway transport In Lithuania. Monitoring of that bridge allows to eliminate damage. It is related with a very heavy height transport moving (e.g. trains, locomotive). The case of study is to support real and practical decisions.

The bridge over Sesupe River was constructed generally for railway line. The most important demage for this bridge is excessive deformation. Field tests of the bridge were conducted using excitations induced by dropping a weight and by ambitne traffic excitation loadings. It is very important for dynamic behaviour of the bridge. It is used two tests: Impact excitation tests and Ambient traffic vibration tests. Generally combination of both experimental tests give relatively small number of vibration sensors. Vibration monitoring allows to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Soldarności Bridge

Road Bridge located in Płock, Poland

Coordinates: (52,52120246832903, 19,72725176932512)
Year of construction: 2007
Material: Concrete, Steel, Shotcrete
Type of case study: Research
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

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The case of study of bridge in Plock is to research all points where it is possible to find some damages. Generally point of initiation of assessments is structural deterioration. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria. The monitoring system has got two subsystem: observational and premonitory system. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair or upgrading.

The bridge over Wisla River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation and displacements. It is very important for dynamic behaviour of the bridge. It is used four performance indicator: angular displacements, deformation, deflection and other loads (e.g. temperature). The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Steel bridge over El Barranc d'Aigües

Railway Bridge located in Alicante, Spain

Coordinates: (38,460116173074844, -0.344654648194917)
Year of construction: 2018
Material: Concrete, Steel, Masonry, Reinforced
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Machine learning damage classification
Predominant verification scale: Structural system

Summary of case study

The structure under study is a steel bridge with a Pratt truss scheme, which serves as a passage over the gulch known as Barranco de Aguas for Line 1 of the FGV TRAM Network in Alicante (Spain). The bridge has a total length of approximately 106 meters, consisting of two sections: one hyperstatic with two spans of 42.00 meters each and another isostatic span of 21.12 meters length, being this last one the chosen to be monitored. This span was chosen because of a fatigue study performed to the previous old bridge, which was then replaced for the current bridge in 2018 with same overall structural scheme.

The section chosen to be monitored was the isostatic span of 21.12 meters length. This span was chosen because of a fatigue study performed to the previous old bridge, which was then replaced for the current bridge in 2018 with same overall structural scheme. This case study presents a simple and fully automatable vibration-based Structural Health Monitoring (SHM) alert system. The proposed method consists in applying an Automated Frequency Domain Decomposition (AFDD) algorithm to obtain the eigenfrequencies and mode shapes in real time from acceleration measurements, allowing to provide a diagnosis based on a Support Vector Machine algorithm trained with a database of the modal properties in undamaged and damaged scenarios accounting for temperature variability. The result is an alert system for controlling the correct performance of the structure in real time with a simple but efficient approach. Once the alert is triggered, the undamaged mode shapes (which could be previously stored in a database of modal parameters classified by temperature) and the current (damaged) mode shapes, can provide guidance for further application of Finite Element Model Updating (FEMU) techniques.

The previous existing bridge (built in 1914) presented fatigue. Nevertheless, the new bridge (built in 2018) does not present any deterioration processes nor damages to be reported at the moment of the short-term monitoring test. The aim of the case study is to address the implementation of a damage detection tool based on a machine learning algorithm known as Support Vector Machine, using the modal response of a truss bridge to calibrate a finite element model to simulate damage scenarios under changing temperature conditions to feed the machine learning algorithm.

Information gathered by Sara Cuerva, Ferrovial, scuerva@ferrovial.com

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Tadeusz Mazowiecki Bridge

Road Bridge located in Rzeszów, Poland

Coordinates: (50,06025613019246, 22,01596471155075)
Year of construction: 2015
Material: Concrete, Steel, Mixed concrete
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

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The case of study of bridge in Rzeszow is to research all points where it is possible to find some damages and check some conditions in that bridge. Generally point of initiation of assessments is pure research interest. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria and design value criteria. All sensors is mounted along the bridge. Designers used 600 m of optical fibres. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair, strengthening or upgrading.

The bridge over Wislok River was constructed generally for roadway use. The most important damage for this bridge is excessive deformation. It is very important for dynamic behaviour of the bridge. It is used two performance indicator: other loads (e.g. temperature) and span deformation. In this bridge a weather station is also installed. The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

Information gathered by Krzysztof Dul, Mostostal Warszawa S.A., k.dul@mostostal.waw.pl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

viaduct Breda

Railway viaduct located in Rotterdam, Netherlands

Year of construction: 1877
Material:
Type of case study: **Reason for initiation of assessment:**
Predominant verification type: **Predominant verification scale:**

Summary of case study

it is used as railway line Breda - Rotterdam

Information gathered by Asma manai, TNO, asma.manai@tno.nl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Viaduct SS335

Road Bridge located in Dora D'Oulx, A32, Italy

Coordinates: (45,040743, 6,825109)
Year of construction: 1960
Material: Concrete, Prestressed
Type of case study: Consulting
Reason for initiation of assessment: Monitoring
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The SS335 is a prestressed concrete bridge built in the early 60s, composed by two independent carriageways, each having nine simply supported spans. The structure is locatel along the A32 highway connecting Turin to Bardonecchia. The typical span is 35m long with a cross section made by a prestressed concrete slab having constant height of 1.5m.

During the strenghtening works the clinometers raw data were analyzed to evaluate the plastic deflection recovery after the external pre-stressing was applied to the deck. Vibration-based damage detection techniques were used to identify the changes in the dynamic response of the system, such as Operational Modal Analysis (OMA) techniques, Power Spectral Density (PSD) and Frequency Domain Decomposition (FDD). A stable peak-picking analysis has been performed to track the natural frequencies evolution in the long-term period. Non-Linear Finite Element Analysis (NLFEA) and a model updating procedure were used to simulate the bridge behavior both in damaged and strengthened state. The FE model was also used to simulate a set of possible damaged scenarios to calculate the thresholds in terms of plastic rotations and frequency shifts for the long-term monitoring.

Following an inspection, some cracks were found at the inner surface of the slab, due to the failure of a significant number of pre-stressing tendons caused by a diffuse corrosive phenomenon. Strengthening works were necessary, the solution chosen was the adoption of an external pre-stressing system. The Sacertis SHM system installed in April 2019 was developed for both the short and long-term monitoring. Each span is equipped with a chain made by five biaxial MEMS clinometers and five triaxial MEMS accelerometers. The system is completed by two gateways, one per carriageway and a power line communication to connect all the devices to the network. In each sensor box are present a temperature and humidity detectors. Prior information available were: drawings, design documents, results of thorough investigation of the damaged span. A calibrated non-linear FE model based on the static load test and dynamic characterization of the structural response (in both the damaged state and after the strenghtening works) has been used to determine the warning and alarm thresholds levels.

Information gathered by Paola Darò, SACERTIS Ingegneria Srl, paola.daro@sacertis.com

This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Viaducts in A59

Road Viaduct located in Noord Brabant, Netherlands

Coordinates: (51,693709, 5,229525)
Year of construction: 1960
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Post event and anticipated damage
Predominant verification type: Engineering judgement
Predominant verification scale: Damage/deterioration location

Summary of case study

This project is about the monitoring of 19 viaducts in and over highway A59 in the Netherlands. These viaducts are all made of reinforced concrete and are build in the 60-ies.

The aim of the project is to follow in time the deformations in the viaducts. These results are not used for structural calculations, but to get more insight in the behavior of the viaducts.

The development of the expansion of the decks of the viaducts, due to ASR, is measured with sensors. Both in vertical direction (thickness of the deck) and in horizontal direction (width of joints at the ends of the deck).

Information gathered by Huibert Borsje, TNO, huibert.borsje@tno.nl

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Voestbrücke Bypass LZ34 A+B

Road Bridge located in Linz, Upper Austria, Austria

Coordinates: (48,3197401, 14,2992308)
Year of construction: 2020
Material: Steel
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: Engineering judgement
Predominant verification scale: Structural component

Summary of case study

Suspension bridge. A:L=290m W=17m B:L=351m W=17m Crossection: Boxgirder orthothropic structure

cable forces and natural modes of vibration have been checked

Within the scope of this special inspection, the dynamic effects of the traffic loads on the supporting structure are to be recorded and the load-bearing capacity and functional capability are to be evaluated in comparison with the statics, as well as recommendations for the further service life with regard to structural maintenance measures are to be given in particular. In the present investigation of the two VOEST bypass bridges LZ34A and LZ34B, the main focus is on the bridge cables and the bridge deck (primary load-bearing system). The vibration measurement will be used as a zero measurement for future investigation. All measurements are carried out under traffic load. The vibration measurements contain two focal points: - Non-destructive measurement of the bridge cables. This is based on the exact measurement and evaluation of the effective forces in the stay cables. The determined actual cable forces are compared with the target values of the statics, which allows conclusions to be drawn about the condition of the cables. The geometric parameters of the cables and the cable weight are made available for evaluation. - Non-destructive, two-dimensional, dynamic measurement of the bridge deck Is carried out on the basis of deck measurements in the respective spans. This makes it possible to comprehensively describe and quantify the relevant load-bearing behaviour of the bridge deck and any changes over time. is to be used as the zero measurement. The natural frequencies and natural modes of vibration are to be recorded.

Information gathered by Fritz Binder, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Vransko bridge

Road Bridge located in Vransko, Slovenia

Coordinates: (46,248389, 14,968806)
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Pure research interest, Plans for change of bearings from elastic neoprene to asphalt.
Predominant verification type: Reliability-based
Predominant verification scale: Structural system

Summary of case study

The highway bridge is a simple supported 25 meter span bridge with two independent superstructures, one for each travel direction. One such superstructure consists of five prefabricated prestressed concrete girders that are I-shaped with a height of 1.4 meter, and a monolithic concrete bridge deck with thickness 0.24 meter. The bridge is located in Slovenia near the village of Vransko.

The assessment is performed in three steps incorporating different information gained by B-WIM measurements. An initial reference point was determined based on design codes for new structures. In step one, measured influence lines were incorporated and in step two, the model was calibrated to measured load distribution over the girders. The third step was to define and use a site specific load model. The reliability index increased significantly during the step-by-step assessment.

No deterioration processes or damages are reported. The aim of the case study is to demonstrate how a numerical model for a bridge can be calibrated using BWIM data in a step-by-step procedure.

Information gathered by Frida Liljefors, Norwegian University Of Science And Technology, frida.liljefors@ntnu.no

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

VÖEST Brücke LZ34

Road Bridge located in Linz, Upper Austria, Austria

Coordinates: (471618,62, 491623,42)
Year of construction: 1972
Material: Steel
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Structural deterioration
Predominant verification type: Engineering judgement
Predominant verification scale: Structural component

Summary of case study

Suspension bridge Boxgirder L=411m W=25

Non-destructive measurement of the bridge cables. This is based on the exact measurement and evaluation of the effective forces in the stay cables. The determined current cable forces are compared with the values of the zero measurement in 1999 or the 1st follow-up measurement in 2008, whereby conclusions can be drawn about the condition of the cables. The comparison is made both with the SET forces (according to the previous measurements) and with the plastic limit tensile forces (=> static load of the stay cables). - Non-destructive, two-dimensional, dynamic measurement of the bridge deck using a sensor grid of acceleration sensors along both pavement alignments in longitudinal direction. This allows the relevant load-bearing behaviour of the bridge deck and any changes over time to be comprehensively described and quantified.

Information gathered by Fritz Binder, Asfinag Baumanagement GmbH, fritz.binder@asfinag.at

This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Wanda's Bridge

Road Bridge located in Kraków, Poland

Coordinates: (50,054616467801985, 20,050410484121212)
Year of construction: 2002
Material: Concrete, Steel
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The bridge was built in 2002. The bridge is situated in Kwidzyn over Wisla River. It has a total length 352,47 m and width 15,2 m. The bridge in a eight-span arrangement. On the bridge are two-lane road and bicycle paths.

The case of study of Wanda Bridge is to research all points where it is possible to find some damages. Generally point of initiation of assessments is structural deterioration. Monitoring of that bridge allows to eliminate all potential damages in qualitative criteria. All measurements sensors is point mounted along bridge. Also very important is structural analysis. In this case it concerns ultimate limit state and fatigue limit state. The physical intervention of that bridge is repair or strengthening.

The bridge over Wisla River was constructed generally for roadway and pedestrian use. The most important damage for this bridge is excessive deformation and displacements. It is very important for dynamic behaviour of the bridge. It is used four performance indicator: deformation, displacement, other loads (e.g. temperature) and vibrations. The signal of sensors could monitoring dynamic response. This leads to reduction risks of the deformation.

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Weidatalbrücke (RFB Göttingen)

Road Bridge located in Sachsen-Anhalt (Esperstedt), Germany

Coordinates: (51,41597612928387, 11,665187141821015)
Year of construction: 2007
Material: Concrete, Reinforced, Prestressed
Type of case study: Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities)
Predominant verification type: Examination of the external tendons in the course of a main examination
Predominant verification scale: Structural component

Summary of case study

The Weidatalbrücke crosses the Weidatal at a height of approx. 45 m on the A38 federal motorway near Esperstedt. The separate superstructures with prestressed concrete box girder cross-sections have spans of 40.00 / 54.00 / 87.50 / 169.00 and 102.50 m. All pillars are designed as non-accessible reinforced concrete cross-sections. The superstructures are constructed using a mixed construction method and are prestressed with internal tendons in the carriageway and floor slab and external tendons in the box girder. The structure is deeply founded in axes 10 to 50 on large bored piles. The diameter is in axis 10 to 30 and in axis 50 D = 1.30 m and in axis 40 D = 1.50 m. The abutment axis 60 is flat in the slope. Due to the slope thrust to be taken into account, the foundation of the axis 40 pillar consists of an overlapping bored pile wall arranged in the shape of a box.

The testing of external tendons is one of the focal points. With a test matrix, the test methods are compiled in the course of the main test and, in the event of anomalies, also as part of an object-related damage analysis, and a recommendation for the scope of the test is given. The examination includes a visual examination of the anchorages, the tendons and deflections as well as an endoscopic examination of the anchorage area and the deflections. Furthermore, a gradient measurement of the superstructure, a tensioning force determination via frequency measurement, magnetic inductive tendon testing, an ultrasonic test of the tendon anchorages, a tensioning force zero measurement with the frequency method, an inclinometer measurement and a geodetic measurement were carried out. A test matrix summarizes the recommended test methods, the scope of tests and the frequency of tests on the external tendons of the Weidatal Bridge as a supplement to DIN 1076.

The results of the clamping force measurement indicate that the actual time-dependent deformations from creep and shrinkage are greater than assumed in the static calculation. Apparently the creep and shrinkage processes at the bridge are not yet complete. The measurement results of the inclinometer measurement and the final geodetic measurement from the construction phase were used as reference measurements. As a result, no significant shifts in the slope were found. The movement down the slope is approx. 2 mm over the entire measurement period. This also corresponds to the maximum value that was recorded at the geodetic measuring points and is therefore not critical.

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This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Weigh in Motion (system near Moerdijk bridge)

Coordinates: (51,75803, 4,64436)
Year of construction: 1998
Material: WIM system is embedded in the road (system itself is a measuring device)
Type of case study: Main reason for the WIM station is enforcement of overloaded axles and/or vehicles
Reason for initiation of assessment: The data is used for a more accurate estimate of the current and expected passing axles and vehicles. Moreover the date is used for determining design loads (according to EN 1991-2)
Predominant verification type: Design value criteria
Predominant verification scale: Traffic network of assessment of any structural system

Summary of case study

Weigh in Motion systems are measuring devices for measuring traffic loads (axel loads, axle distances, vehicle loads, passage date and time). See https://en.wikipedia.org/wiki/Weigh$_in_motion$

The data is used for several reasons, varying from actual bridge specific load conditions to determining design loads for EN 1991-2. Moreover the data may be served for determining the expected damage (rainflow analyses taking into account the SN curve) of for probabilistic analyses for determining the design load regarding static load conditions for specific bridge details

The state of the structure is not appropriate. The data may serve as input for any structure

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Weikendorf bridge

Railway Bridge located in Weikendorf, Austria

Coordinates: (48,340716, 16,754357)
Year of construction: 1967
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Structural deterioration, Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Damage/deterioration location

Summary of case study

The single span reinforced concrete railway bridge was built in 1967 and repaired in 2014. The main bearing elements of the superstructure is a concrete girder and a concrete slab and the substructure consists of abutments and wing walls. It is located just outside of Weikendorf.

The initiation of the assessment was research interest. The purpose was to develop a probabilistic framework for predicting deterioration in the format of a semi-Markov process, based on inspection data from visual inspections and analytical models of the deterioration process. Inspection records in the form of condition rating was available and the additional data collected before repairing the bridge was used for developing the model. How the decision on repairing the bridge was taken is not covered in the present paper.

Spalling was observed and from measurements it was concluded that abutments were affected by chloride and carbonation and wing-walls by carbonation. Carbonation was chosen to be the dominant deterioration process and chloride content was ignored, even though in reality both phenomena induce corrosion. Carbonation depth was measured with phenolphthalein indicator and location of reinforcement was determined by concrete scanning.

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Örnsköldsvik bridge

Railway Bridge located in Örnsköldsvik, Sweden

Coordinates: (63,287060, 18,705770)
Year of construction: 1955
Material: Concrete, Reinforced
Type of case study: Research
Reason for initiation of assessment: Pure research interest
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The concrete trough railway bridge in Örnsköldsvik was built in 1955 with two spans and a length of 24 m. It was decommissioned due to the building of a new railway, the Bothnia Line. It was assessed and tested to failure in the European FP6 project Sustainable Bridges, Bien et al. (2007), Puurula et al, (2015), Sas et al. (2012).

The bridge was used as a test bed for inspection, assessment, monitoring and strengthening of the methods proposed in Guidelines for for Inspection and Condition Assessment (ICA), Load and Resistance Assessment (LRA), Monitoring (MON), and Strengthening (STR).

The bridge was tested to failure and was able to take about 6 times the load it was designed for without strengthening and about 8 times with strengthening with Near Surface Mounted Reinforcement (NSMR) of Carbon Fibre Reinforce Polymer (CFRP) Bars.

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.

Ötztaler Achbridge

Railway Bridge located in Tirol, Austria

Coordinates: (47,231881, 10,839856)
Year of construction: 2011
Material: Concrete, Steel, Reinforced
Type of case study: Research and Consulting
Reason for initiation of assessment: Required reliability check (by owner, authorities), Pure research interest
Predominant verification type: Design value criteria
Predominant verification scale: Structural system

Summary of case study

The "Ötztaler Achbrücke" railwaybridge is located on the Innsbruck - Bludenz route in Tirol, Austria and was completed in 2011. The three-field composite steel structure has a total length of 144.6 m, the spans of the individual fields are 42.0 m - 60.6 m - 42.0 m. The support structure consists of two abutments and two pillars, deeply founded. The longitudinally displaceable bearings are located on both abutments, while the pillars are rigidly connected to the bridge structure.

The time recording of the measurement data took place in the period from August 25, 2011 to June 30, 2013. On the basis of long-term measurements during this period, the stretching / displacement behavior of the rails in particular was described.

The air, rail and supporting structure temperatures as well as the longitudinal rail expansion and longitudinal displacements of the supporting structure were recorded for the period mentioned by the continuous measuring system.

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This project has received funding from the European Union's Horizon 2020 research research and innovation programme under grant agreement No 958171.

Åby river bridge

Railway Bridge located in Åby river, Kiruna, Sweden

Coordinates: (65,416156, 20,373620)
Year of construction: 1955
Material: Steel
Type of case study: Research
Reason for initiation of assessment: Structural deterioration
Predominant verification type: Qualitative criteria
Predominant verification scale: Structural system

Summary of case study

The bridge over Åby River on the main railway line in northern Sweden was built in 1955 with a length of 33 m. A code-based assessment carried out in 1994, indicated that the bridge was damaged because of fatigue. According to the report, it was the overlapping continuous plate in the stringer-to crossbeam connection that had insufficient capacity. There were no visible cracks in this location, Häggström (2016), MAINLINE (2014).

Measurements of strains and deflections were carried out, while the bridge was in service. Due to the risk for a fatigue failure and bumpy connections it was decided to exchange the bridge. The old bridge was moved to a new site, close to the old one, and loaded to failure.

It was found that the bridge could withstand loading corresponding to four times the highest permitted axle-loading, or twice the design load for new bridges, before exhibiting an obvious non-linear behaviour regarding vertical displacement in the mid span. The peak load was achieved at loading approximately 50

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This project has received funding from the European Union's Horizon 2020 research
research and innovation programme under grant agreement No 958171.