IABMAS

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Meeting Agenda

IABMAS Technical Committee on Bridge Load Testing

Wednesday June 26th, 13:00 – 14:30, Room: Galoppen 9+10

Mission: *Bridge Load Testing is a field testing technique that can be used to obtain more information about the performance of bridges. In particular, diagnostic load tests can be used to quantify elements of structural performance such as transverse distribution, unintended composite action, repair effectiveness, etc. and the information of a diagnostic load test can serve to develop field-validated models of existing bridges that can be used to develop a more accurate assessment of the bridge's performance. Proof load testing can be used to demonstrate directly that a bridge can carry a load that is representative of the live load, provided that the bridge does not show signs of distress. Other types of load testing include testing for dynamic properties, and parameter-specific tests. Load test data as well as the analytical assessment of the data can be used to make more informed decisions and manage the life-cycle performance and maintenance of bridges.*

Aspects of bridge load testing that are of particular interest to bridge owners are having an overview of the typical uses for bridge load tests, the decision on when to load test or not, which information to obtain from the load test, and how this information can be used to reduce the uncertainties regarding the tested bridge. This committee is eager to learn about and disseminate the potential for applying new technologies for bridge load testing through learning from technologies used in other industries.

Associated with bridge load testing, the following topics are also of importance to this committee: instrumentation used during load testing and the interpretation of the obtained measurements during the load test, determination of required load, method of load application, methods of updating assessments using collected field data, the link between load testing and structural health monitoring, the uncertainties (probabilistic aspects as well as risks during test execution) associated with load testing, the interpretation of load test results, laboratory testing of bridge components to improve assessment methods in the field, and optimization of related costs keeping adequate reliability to spread their use worldwide.

The IABMAS Bridge Load Testing Committee aims to be an international committee of participants from academia, industry, and bridge owners, which provides a forum for the exchange of ideas on bridge load testing. Best practices as well as the insights from the development of national codes and guidelines will be exchanged among participants from countries that use load testing for the assessment of their *existing bridges, those who are exploring the possibilities of this method, and those who are in the process of standardizing the procedures or developing guidelines.*

Goals:

- *Organize dedicated sessions to the topic of load testing at IABMAS conferences.*
- *Develop national IABMAS group events on the topic of load testing.*
- *Exchange information on the use of load testing in different countries.*
- *Exchange lessons learned and best practices.*
- *Inform about case studies of bridge load testing.*
- *Communicate load testing guides or standards that have been developed.*
- *Provide a forum for new ideas and applications of technology.*
- *Identify potential research topics.*
- *Establish international collaborations.*
- *Liaise with relevant committees internationally outside of IABMAS and liaise with the national IABMAS groups.*

Committee Members

Eva Lantsoght	**Ho-Kyung Kim**
Jesse Grimson	**David Kosnik (TRB AKB40 liaison)**
Mitsuyoshi Akiyama	Marcelo Marquez
Sreenivas Alampalli	**Johannio Marulanda**
Numa Bertola	**Armin Mehrabi**
Fabio Biondini	**Piotr Olaszek**
Tulio Bittencourt	Pavel Ryjacek
Alok Bhowmick	Marek Salamak
Matteo Breveglieri	**Gabriel Sas**
Anders Carolin	**Jacob Schmidt**
Hermes Carvalho	Tomoki Shiotani
Joan Ramon Casas	**Hisatada Suganuma**
Rolando Chacon	**Matias Valenzuela**
Dave Cousins	**Michal Venglar**
Dan Frangopol	**Esteban Villalobos Vega**
Monique Head	David Yang
Robert Heywood	**Yuguang Yang (fib TG 3.2 liaison)**
Boulent Imam	Gloria Zhang
Alex Lazoglu	**Ales Znidaric**
Daniele Losanno	

Visitors: Michel Ghosn, Jesper Jensen

1. Administrative

1.1. Welcome and introduction

The meeting was called to order at 13:04 by Eva Lantsoght. All attendees introduced themselves with their name and affiliation.

1.2. Review and approval of agenda

The agenda was approved unanimously.

2. Strategic Planning and Discussion

2.1. Membership

The following members have decided to step down: Jonathan Bonifaz, David Jauregui (replaced by Gloria Zhang), Shane Kuhlman, and Gregor Schact (replaced by Alex Lazoglu).

The committee welcomes new member Dr. Hisata Suganuma ("Suga"). He introduced his relevant experience with a short presentation. The slides of this presentation are attached to these minutes.

2.2. Website

On the IABMAS website, the committee information is updated. We are grateful to Prof. Akiyama for posting and maintaining the information about the committee on the website.

3. Old Business

3.1. Development of joint bulletin of proof load testing of concrete structures with fib TG 3.2

The committee discussed the status of the document. The most recent meeting of the working group, with the authors from IABMAS BLT and fib TG 3.2 was held on March 8th.

From the fib TG 3.2, our liaison Yuguang Yang gave an update about the TG 3.2 meeting held in April. Most of this meeting focused on the topic of assessment of corroded members, and the topic of proof load testing (and bulletin) was not discussed in TG 3.2.

Gabriel Sas asked about the expected time for the deliverable. In terms of planning, Eva Lantsoght indicated that it is expected to have a first draft of some chapters by the end of the year. To keep the momentum is important to deliver in due time. Currently, extended outlines (including bullet points of the different paragraphs to write) have been developed, and authors have been assigned. More volunteers are still welcome. Tulio Bittencourt, Matias Valenzuela, and Dave Kosnik expressed interest in contributing. Discipline is expected by those who committed to write to make this joint effort a success. A meeting will be planned after the summer with the working group to touch base, and in advance of the main committee meeting.

To coordinate the writing, a shared Dropbox has been developed. The folder contains the overall overview of the document, as well as separate documents for each chapter. These chapters will be drafted individually, and then compiled for review by a review group by the parent committees (IABMAS BLT and fib TG 3.2).

In terms of overall structure, the originally planned chapter 6 has been removed, as the contents overlap with originally planned chapters 8-10.

Michel Ghosn informed about documents that have been developed in Canada and the USA. The committee would be interested in learning more about the relevant references from Canada.

Matias Valenzuela asked about the description on examples or methodologies around the world. The discussion revolved around including chapters on state of the art case studies. The committee plans to cite relevant reports and references where these are available.

Joan Ramon Casas asked about the current approval of the document, and the responsibilities between fib and IABMAS on this shared effort. As the document will be published as a fib bulletin, Eva Lantsoght needs to follow up with fib to see the internal approval for this bulletin. Yuguang Yang asked about the editorial requirements from fib to consider these during the document writing stage. There are also open questions about the final figures – whether fib typesetters can improve these, or if we should deliver figures that comply with the fib editorial requirements.

Finally, it was discussed whether a similar document on metal structures could be developed, and if the committee should also address composite structures in the future. These topics will be considered as future business.

3.2. Collaboration with other IABMAS TCs

The committee discussed the collaboration between the IABMAS BLT committee and the IABMAS committees on SHM and Bridge Management. The committees plan for workshop at IABMAS 2026 (postponed from 2024) on digital twins, as a topic of mutual interest between the three technical committees.

Rolando Chacon presented on the potential collaboration with CEN/442/WG9, and the needs from the WG regarding the input from the bridge engineering community. The slides of this presentation are attached to these minutes.

The main topics to address are how to combine information from an asset considering all sources of information (monitoring, load testing, …) into a bridge management system.

Matias Valenzuela suggested to liaise with PIARC for digital twins at the higher levels of the infrastructure network, for which a section can be included in the white paper the three technical committees are working on in preparation for the workshop. Sreenivas Alampalli suggested reaching out to the ICC within TRB.

The committee plans to add a placeholder on the relation between load testing and digital twins in the fib – IABMAS bulletin that the committee is developing.

4. New Business

4.1. Research updates

Matteo Breveglieri mentioned a database from Switzerland of historical load tests that is being developed. Those who are interested can reach out to Matteo for the data and potential collaboration on this effort.

Numa Bertola informed the committee about a recently performed load test. The papers of this project have been added to these minutes.

Matias Valenzuela informed about a case study in Chile using both steel and concrete – these cases have been presented during the Fall 2022 meeting of the committee and can be consulted in the minutes (https://iabmas.w.waseda.jp/resources/Minutes_load_fall_2022.pdf).

Jesper Jensen suggested the importance of load testing in the topic of reuse of bridges. Fabio Biondini relates this topic to the ongoing research in Italy of Bridge 50. Yuguang Yang and Eva Lantsoght informed about the ongoing work in the Netherland on the reuse of existing bridge girders in new construction.

Michel Ghosn asked about load testing to give insights into the performance of the foundation. Jesper Jensen confirmed that a load test should be able to address the complete asset.

Jacob Schmidt mentioned the importance of proof load testing and the need for research to address several challenges. Matias Valenzuela suggested guidelines and the need to turn research into practical recommendations.

4.2. Ideas for future MS

At IABMAS 2024, the committee organized a successful min-symposium with 5 sessions. Potential MS for 2026 will be discussed in due time.

4.3. Upcoming conferences and events

Committee members introduced the following upcoming conferences and events:

- SDSS Stability and Ductility of Steel Structures: September 8th – 10th 2025 in Barcelona, Spain

https://sdss2025.upc.edu/

- IALCCE 2025: July 15 – 19 in Melbourne, Australia https://www.ialcce2025.org/
- IALCCE workshop on Life Cycle Management: October 6th – 8th in IJmuiden, the Netherlands: https://ialcce-lcm.org/welcome-2024/
- The Weigh in Motion conference will be organized in Slovenia in 2026

5. Adjournment

The meeting was adjourned at 14:25. The next meeting will be held during the 2024 Fall semester, virtually.

Self introduction and Brief present Bridge loading works with our technique

20240626
IABMAS Bridge Load Testing Meeting Summer 2024

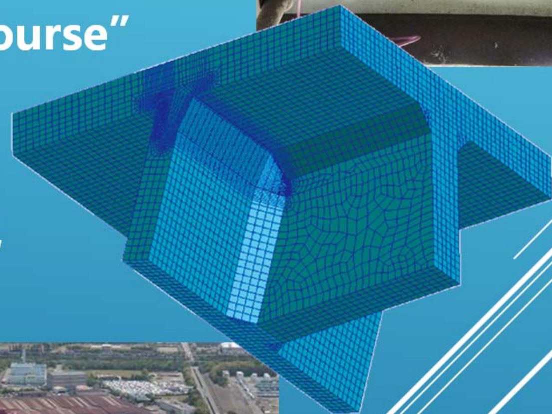
Hisatada SUGANUMA, TTES CEO

SELF INTRODUCTION

Hisatada SUGANUMA, from Japan.

Work Experience and Education

2013-2015	Specially Appointed Associate Professor, Tokyo Tech. “Social Infrastructure Sensing Solutions Research Course”
2005	Dr.E, Tokyo Institute of Technology Title “Development of orthotropic steel deck system with high fatigue resistance.“
2004	Founded TTES, inc. as CEO
2000-2002	Worked for IHI as bridge designer



Technology introduction using one project as an example.

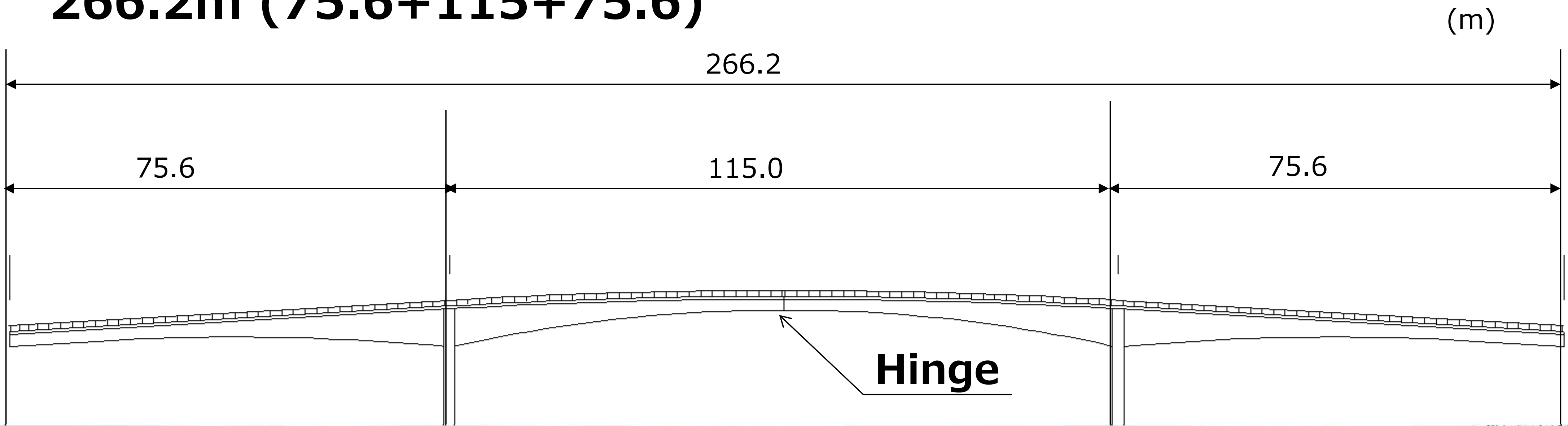
Kumamoto Prefecture

The Earthquake struck Kumamoto Prefecture in April 2016, with a magnitude of 6.2

After the earthquake,
As a criterion for resuming transportation, We decided to conduct Bridge Loading Test to obtain the initial information on the bridge deflection.

PC 3 Span Continuous Girder Bridge (Hinged)

266.2m (75.6+115+75.6)

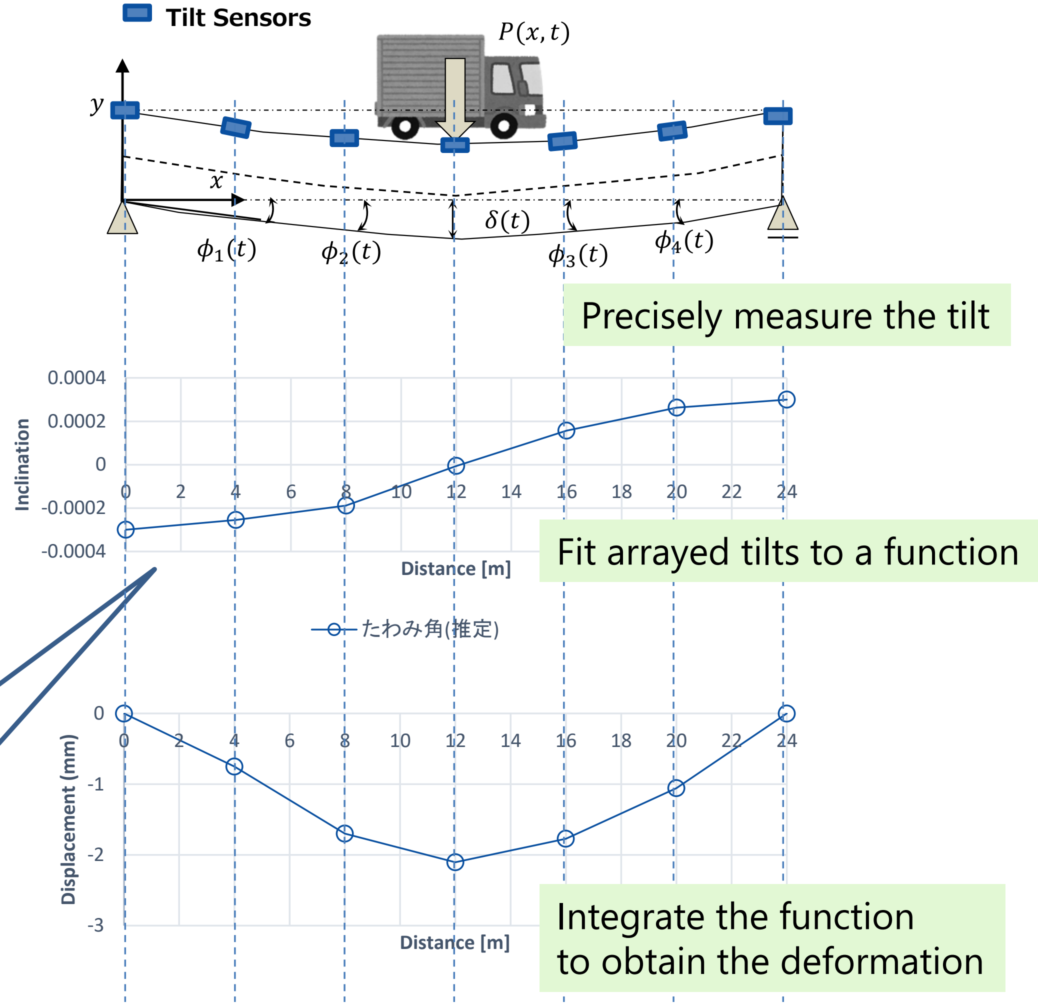


Applied technique

DEGRIS®
ディグリス

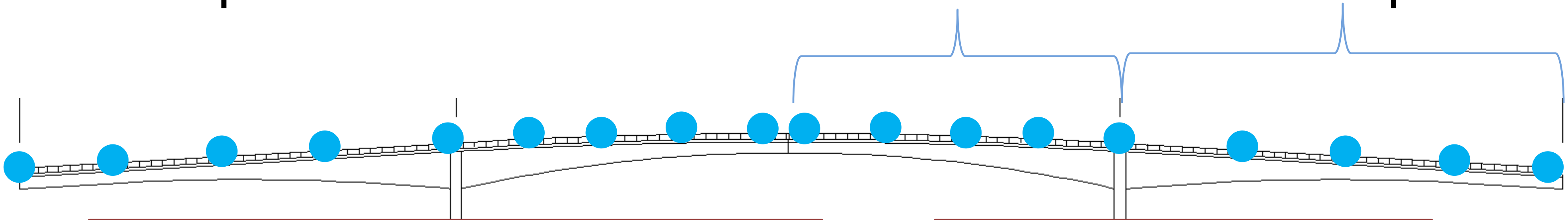
Special technique to obtain the deformation from the multi-arrayed tilt sensors.

$$\delta = \int \varphi \, dx$$



Applied Sensing Technique

5 Special Tilt sensors are installed in each span

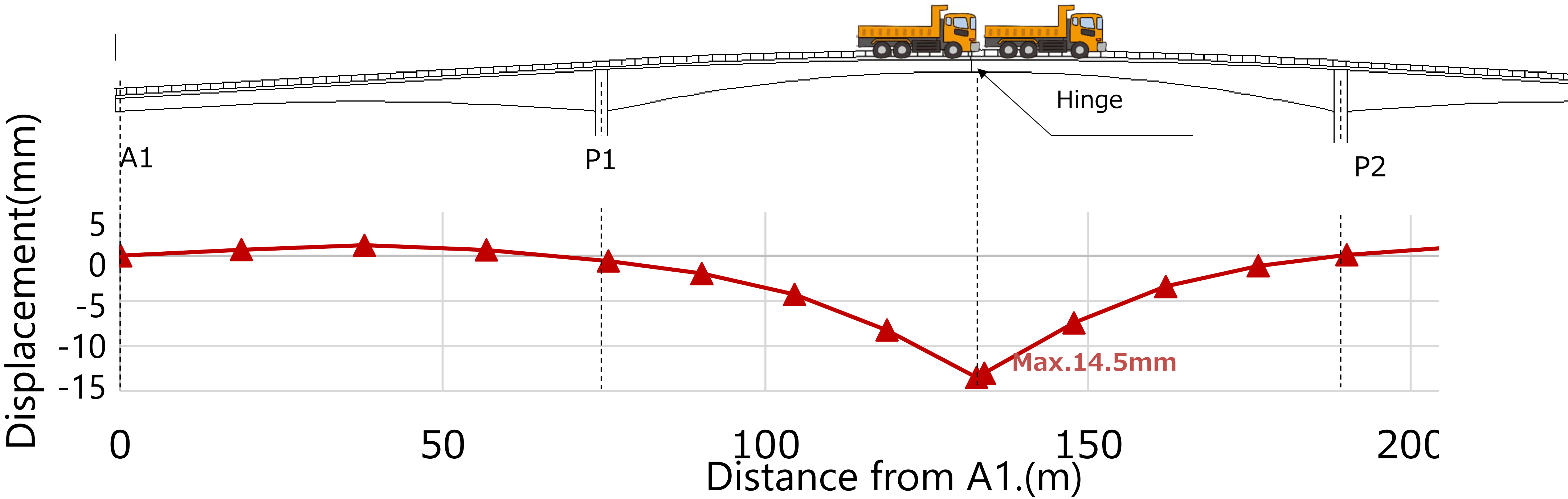


Works were conducted only on bridge deck

Bridge load Testing

Results from our method

TTES



We obtained the initial deform condition.
The hinge's action was also confirmed.
Local manager can conduct our method by self, in preparation for the sudden accident.

More details were reported in IABMAS 2022 in Barcelona.
“Investigation on Load Capacity Evaluation of Existing Bridge based on Deflection”

Tokyo Tech Engineering Solutions, INC.

Hisatada SUGANUMA

Email：suganuma@ttes.co.jp

*Bridge Maintenance, Safety, Management, Digitalization and Sustainability –
Jensen, Frangopol & Schmidt (eds)*

Combining monitoring information and UHPFRC strengthening to extend bridge service duration

Numa Bertola* & Eugen Brühwiler
Laboratory for Maintenance and Safety of Structures, Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland

ABSTRACT: As many bridges are approaching the end of their supposedly theoretical service duration, finding novel technical solutions to extend their service duration is crucial, also for reasons of sustainability. In this article, two strategies (structural performance monitoring, and strengthening with ultra-high-performance fiber-reinforced cementitious composite (UHPFRC)) are introduced to avoid prematurely replacing structures. The case study of the Ferpècle road bridge (Valais, Switzerland) is presented since the two strategies were combined in 2023 to extend its service duration. This bridge is one of the first prestressed concrete bridges in Switzerland. Built in 1958, the structure consists of a single girder with a 34.5-meter span resting on abutments in the form of reinforced concrete piers. As the deck has a width of only 5.3 meters, bridge owners have decided to widen it to 7.9 meters in order to include two road lanes and a pedestrian way. Despite its good condition, the bridge must be strengthened as its load-bearing capacity (bending moment at mid-span) would be largely insufficient with the new deck width. To increase its load-bearing capacity while widening the bridge deck by 50%, an intervention with UHPFRC has been made. The innovative intervention enables clamping the abutments with the bridge deck to modify the static system to obtain a semi-rigid frame to reduce the bending moment at mid-span. Two load tests using the latest sensing technologies, before and after the intervention, have enabled the quantification of the design capacity and the validation of this pioneering intervention. This case study demonstrates the potential of novel technologies to extend bridge service duration, thereby improving the sustainability of the construction sector.

1 INTRODUCTION

High-performance fiber-reinforced cementitious composite (UHPFRC) has been used in structural designs for over twenty years in many countries (Graybeal et al., 2020). The UHPFRC mix consists of a matrix composed of fine-coarse particles (cement, sand, and silica fumes up to 1 mm in size), water, additives, and a large number of short and slender steel fibers (Brühwiler and Denarié, 2013). Steel fibers (accounting for at least 3 vol-%) give this material its specific mechanical properties and high durability due to its impermeability in service (Brühwiler, 2016).

The mechanical properties of UHPFRC are summarized by (Brühwiler, 2020). UHPFRC has significant characteristic tensile strength (up to 16 MPa) and compressive strength (up to 150 MPa). The elastic modulus is 45-50 GPa, and the material exhibits strain-hardening behavior in tension until 2 ‰. Tensile strength is usually increased by the addition of reinforcing bars (called R-UHPFRC), as for traditional reinforced-concrete structures (Oesterlee, 2010). Technical specification SIA 2052 ("Technical Leaflet on UHPFRC: Materials, Design and Application," 2016) is used to design UHPFRC elements, as well as reinforced concrete (RC) - R-UHPFRC composite elements.

With over 350 applications, Switzerland is a forerunner in using R-UHPFRC both for the construction of strengthening existing structures and new structural designs (Bertola et al., 2021b).

*Corresponding author: numa.bertola@epfl.ch

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Regarding the strengthening of existing structures, R-UHPFRC has been used on numerous occasions to improve the load-bearing capacity of bridges, such as the Chillon Viaduct (Brühwiler and Bastien Masse, 2015), the Guillermaux Bridge (Hajiesmaeili et al., 2019) and, more recently, the Riddes Viaduct (El Jisr et al., 2023).

This article presents a recent application of R-UHPFRC for the rehabilitation, strengthening, and widening of a prestressed concrete bridge in Switzerland. The project involves widening the simply-supported bridge deck from 5.3 m to 7.9 m (+50%) by only intervening on the deck. The idea behind the reinforcement is to modify the static system by clamping the abutments to form a monolithic structure. This elegant intervention significantly strengthens the bridge through the parsimonious use of R-UHPFRC while preserving the existing structure. Monitoring campaigns before and after the intervention have enabled the validation of the intervention design.

2 BRIDGE EXAMINATION

2.1 *Presentation*

The Ferpècle Borgne Bridge is a prestressed reinforced concrete double-girder structure (TT cross-section) located in the Swiss Alps in the small village of Les Haudères (Valais) at an altitude of 1450 meters. The bridge was built in 1958 according to the plans drawn up by the engineering firm B.Deléglise - P.Tremblet in Sion, who took over Robert Maillart's engineering office in Geneva, which became Bureau Tremblet, now T Groupe.

The static system is a simply-supported beam with a 34.5-meter span, resting on abutments with side walls approximately 7 meters long (Figure 1). With a beam height of 1.75 meters, the slenderness of 1/20 is audacious for a simple beam. Visual inspection of the structure using the risk approach (Bertola and Brühwiler, 2021) showed that the bridge was in "defective" condition (rating of 3 out of 5), while structural elements are in "acceptable" condition.

2.2 *Structural examination*

With regard to the strength of materials, a C45/55 concrete grade (updated from the C30/37 at the construction) has been selected, leading to a compressive strength of $f_{cd} = 26\ MPa$. The tensile strength of the "Box-Tor-Caron" reinforcing steel was accepted at $f_{sd} = 300\ MPa$. For prestressed bars, an ultimate strength of $f_{pd} = 730\ MPa$ was assumed. Load levels are defined in the Swiss standards for existing structures SIA 269 (Swiss Society of Engineers and Architects, 2011). Structural safety is evaluated based on the concept of the degree of compliance n (Brühwiler et al., 2012) using design values of both structural resistance R_d and action effects E_d.

$$n = Capacity/Demand = \frac{R_d}{E_d} \tag{1}$$

A three-dimensional finite-element model was made in DIANA software to examine the structural safety. This modeling was carried out as realistically as possible, taking into account non-structural elements such as curbs and the asphalt pavement. In addition, each rebar and prestressing tendon have been included in the model. Prestressing is taken from the resistance side.

This model allows the calculation of stresses directly in reinforcing bars and prestressing tendons (Figure 3). For the ultimate limit state (ULS), traffic loads are placed at the most unfavorable locations (at mid-span for bending verifications and close to supports for shear verifications). The stresses in critical prestressing tendons are almost equal to their yield point. Using the numerical model, it is possible to determine the overall degree of compliance by progressively increasing the live-load until failure. A degree of compliance for the mid-span bending verification n_M equal to 1.05 was obtained, showing that the structural safety of the structure in its current state is guaranteed. Analogously, the degree of compliance for the shear verification n_V is equal to 1.10.

Nonetheless, it can be anticipated that after widening (from 5.3 m to 7.9 m), this structural safety will no longer be satisfied. A strengthening scheme will be necessary.

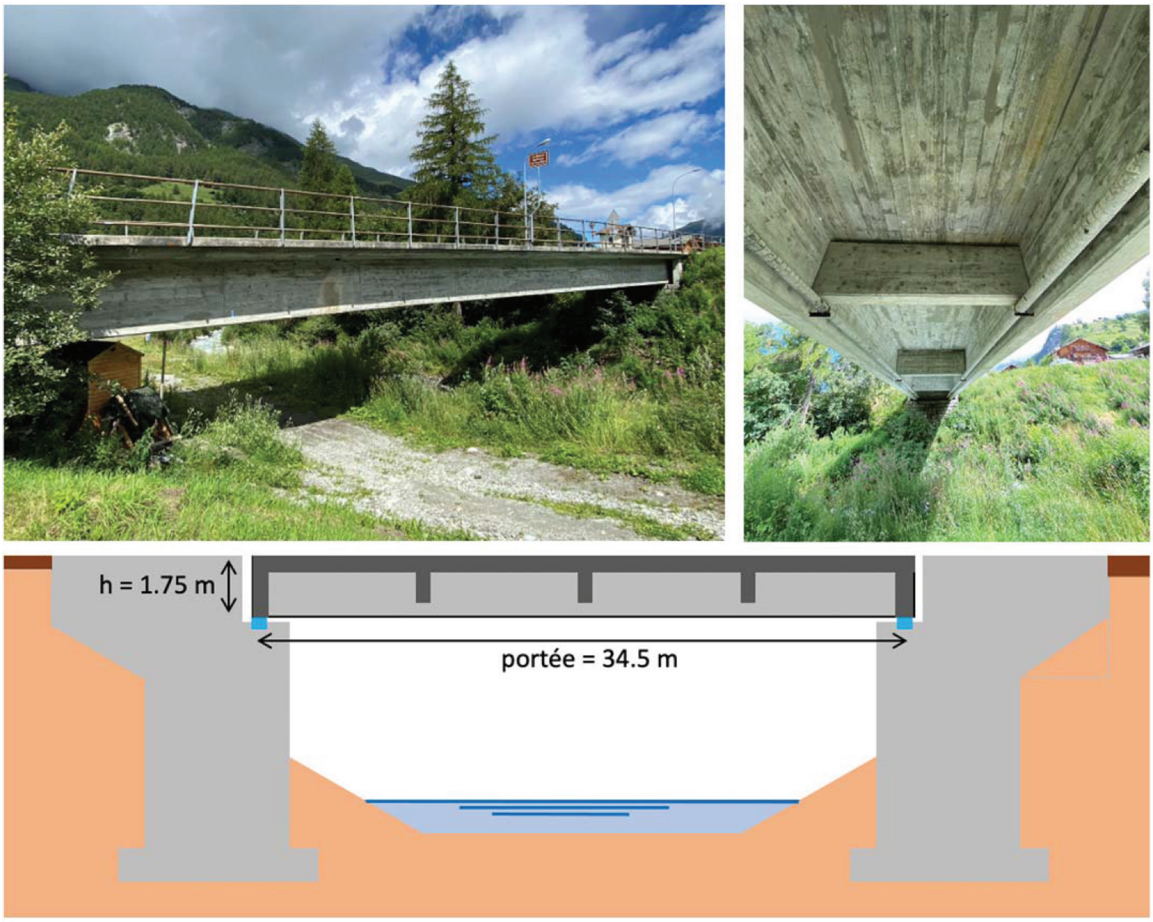

Figure 1. Presentation of the Ferpècle Bridge.

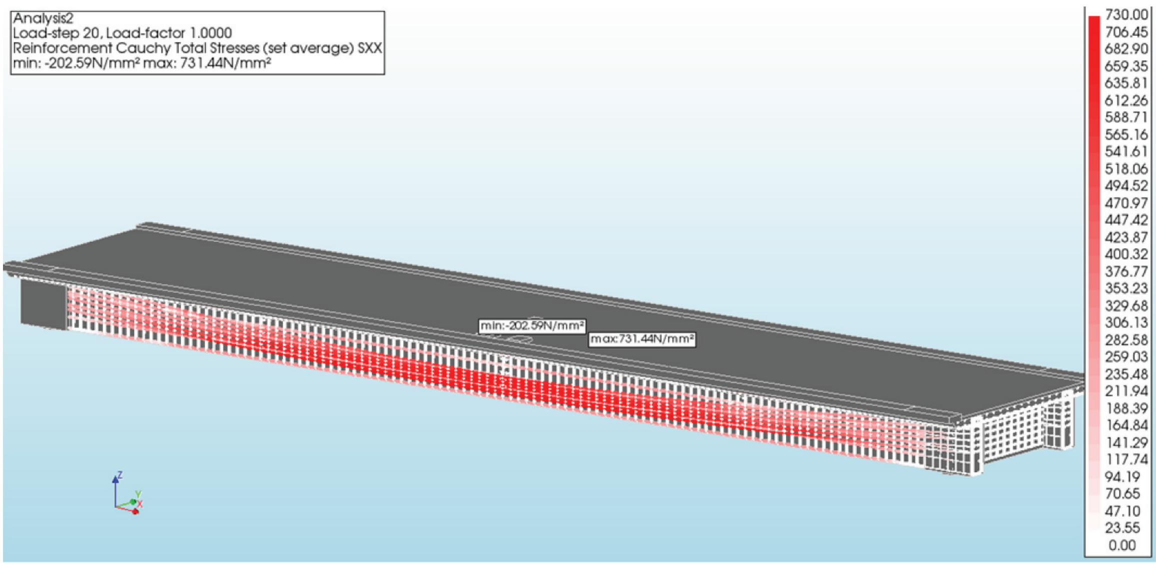

Figure 2. Finite element model and stress in prestressing tendons at ELU 2 (maximal bending at midspan).

3 INTERVENTION SCHEME

The widening of the deck from 5.3 m to 7.9 m, is made through a cantilevered full slab with a variable thickness, in R-UHPFRC (type UB; $f_{Utud} = 6.9 MPa$, $E = 45\ GPa$), that is anchored in the existing structure. At midspan, the deck thickness is increased from 25 to 27.5 cm (Figure 3). 20 mm of concrete from the existing slab is hydro-jetted, and the UHPFRC layer of 45 mm is poured on site. Transverse and longitudinal reinforcing bars (ϕ14 @ 150 mm) have been included in the UHPFRC layer. The RC – R-UHPFRC structure works as a composite element.

At the bridge supports, a thicker layer of R-UHPFRC (70 mm) is cast. Moreover, significant reinforcement steel bars (ϕ22 @100 mm) are included to increase the positive bending capacity. To achieve a monolithic structure, the abutments are clamped with traditional reinforced concrete to the superstructure, connecting the two prestressed beams with the deck, the abutment bottom wall the side walls (Figure 4). This intervention thus eliminates the need for expansion joints. The concept behind this clamping in the longitudinal intervention is (1) to create a semi-integral structure and (2) (partially) connect the beam in the abutments. These abutments also act as "counterweights" to take up the positive bending moment at supports.

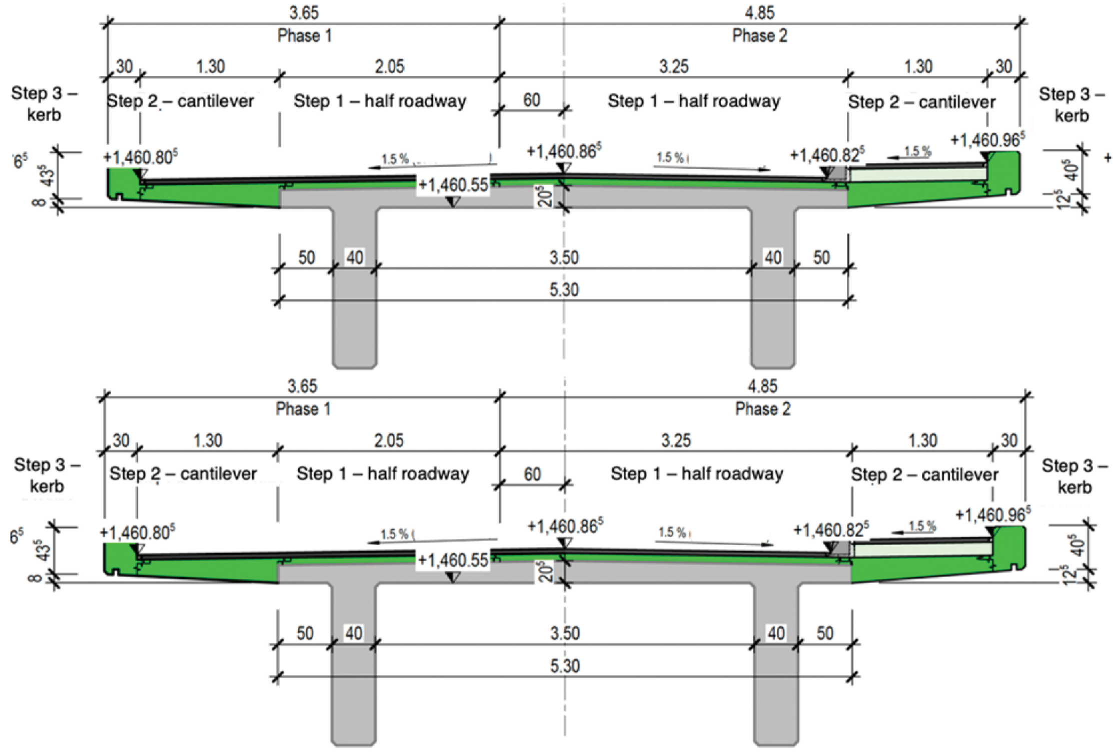

Figure 3. Cross-sections (in span and on supports) with new UHPFRC shown in green.

The concept of the intervention is to redistribute the bending-moment deficit at midspan to the supports. In this way, the static system is modified to form a semi-integral bridge with flexural rigidity at the supports, enabling it to take up this action. The new layer of reinforced UHPFRC (70 mm with (ϕ22 @100 mm) is used to create the necessary bending resistance at supports.

The numerical model is modified to predict the structural behavior after the intervention (Figure 5). For reliable predictions, the abutments are modeled and linked to the superstructure with UHPFRC. This model is used to verify the stresses in the UHPFRC tensile chord, beam compressive action, and abutment tensile reinforcements. Non-linear analyses are needed to effectively predict the strain-hardening behavior of UHPFRC in tension.

This new numerical model is used to evaluate structural safety. The overall degree of compliance obtained is 1.15. Model predictions show that the maximum stress in the new rebars at support is around 280 MPa, well below the yield point. However, some of the rebars in the abutment have stresses up to their yield stress at ULS, showing that this is a decisive factor in the design. In addition, the stresses in the UHPFRC (tension) and in the girder reinforced concrete

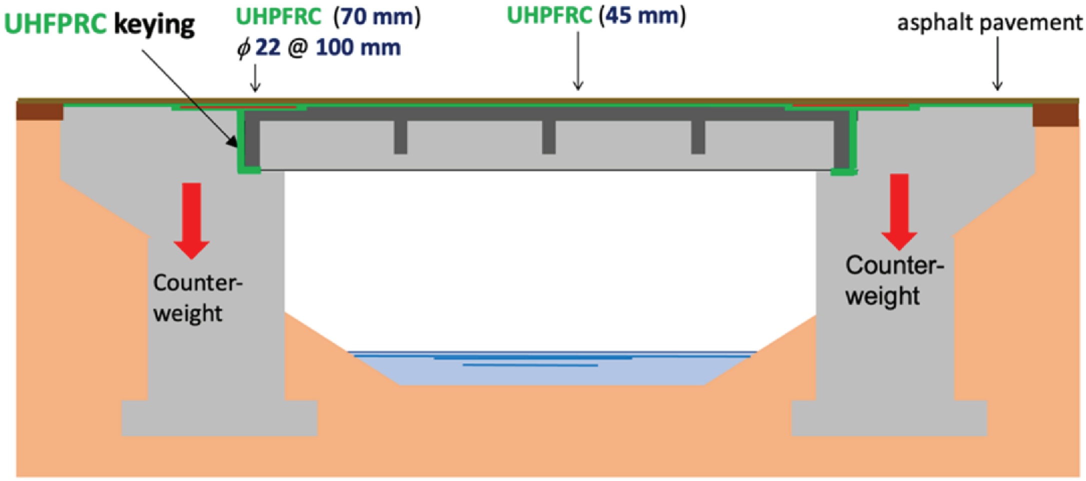

Figure 4. Scheme of the intervention (strengthening in the longitudinal direction).

(compression) are lower than their respective strengths. This difference is due to a greater participating width according to the numerical model than according to an analytical model.

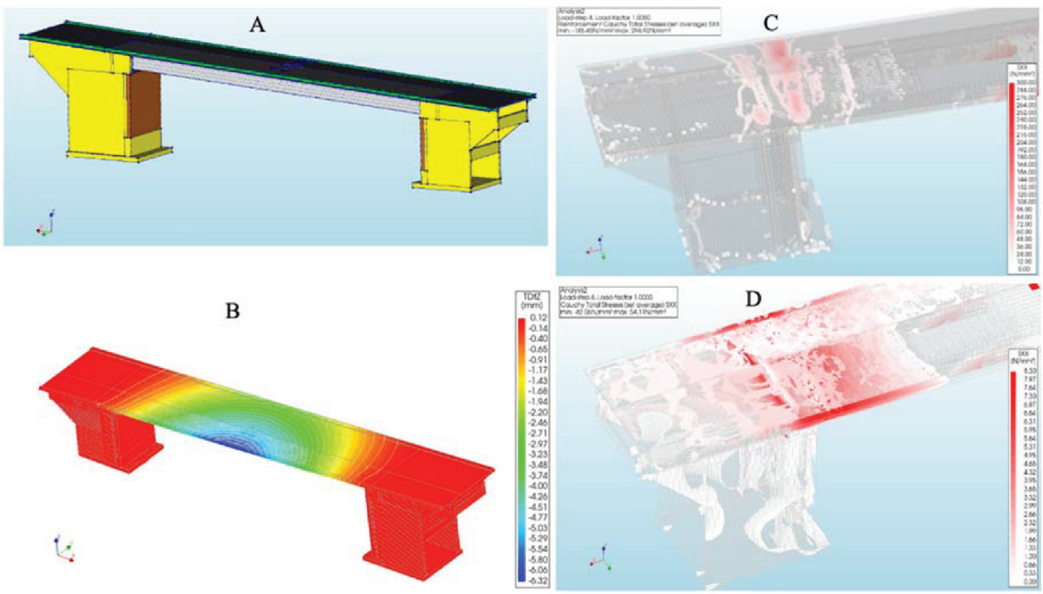

Figure 5. A) Finite element model of the bridge structure after intervention, B) Deformation under SLS load level; C) Tensile stresses in slab reinforcing bars at ULS; D) Tensile stresses in UHPFRC at ULS.

4 INTERVENTION WORK

The intervention was completed between April and November 2023. The work was carried out in two phases (upstream and downstream), enabling alternating traffic flow throughout the work.

In the first stage, scaffolding was erected, the asphalt pavement was removed from the entire deck, and the upstream curb was cut. Then, the formwork for the UHPFRC cantilever and the new curb was installed, and a new RC transition slab was poured. The UHPFRC is prepared directly on site. The deck and the new cantilever were cast in 3 stages (Figure 6), then the curb was cast in a single stage. Finally, the abutments were clamped. The work was then repeated on the downstream part of the structure.

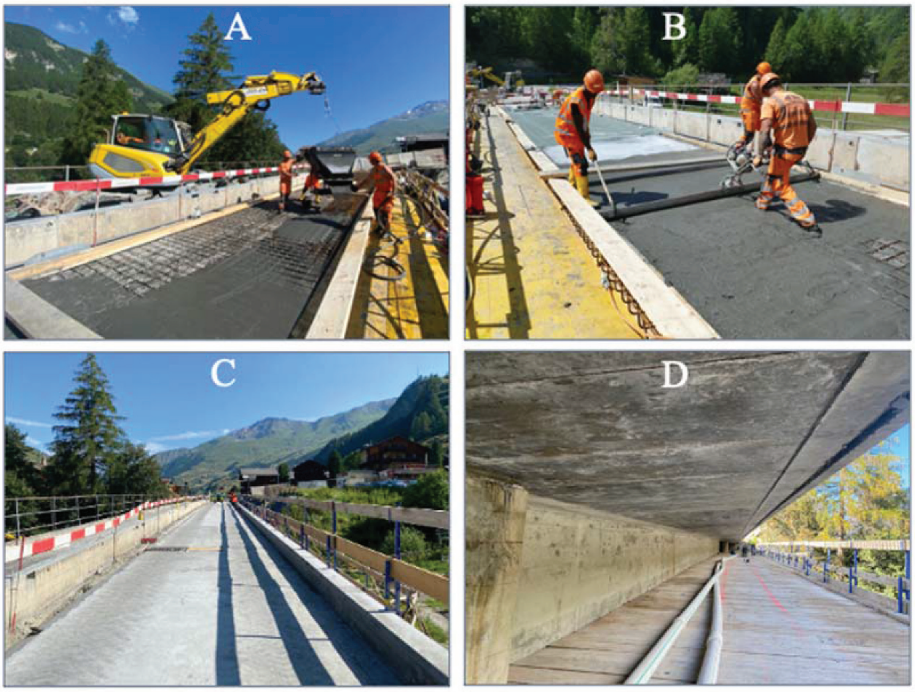

Figure 6. Photographs of the construction work. A, B) UHPFRC casting, C,D) results of the UHPFRC interventions.

5 VALIDATION THROUGH MONITORING

Two monitoring campaigns were performed prior to and after the structural intervention. The aim is to validate the change of the static system (from a simply supported beam to a fixed beam) and to update the material properties, such as the material elastic moduli. Each monitoring involves both static and dynamic excitations that are combined to model updating.

The first monitoring campaign (Phase 1) involved 3 static load tests with a 3-axle truck of 26,5 tons placed at quarter-spans and midspan. The second monitoring campaign (Phase 2) involved 5 static load tests with either one truck (to reiterate previous load tests of Phase 1) or two trucks to maximize the deflections. Additionally, dynamic load tests, which consist of a truck passing over the bridge at a given speed, were performed on both phases of the monitoring campaign.

In Phase 1, the monitoring system involved 10 deflection measurements made from the deck with a total station and targets on the bridge (supports, quartier spans, and midspan), and 10 accelerometers at the same locations. In Phase 2, the monitoring system involved 6 LVDT sensors on one side of the bridge on both girders.

Table 1. Measurements collected during monitoring campaigns.

Measurement	Before intervention	After intervention
1st modal frequency [Hz]	3.42	5.58 (+63 %)
Maximum deflection (extrapolation) [mm]	7.82	2.01 (-38.7 %)

Main data collected during these monitoring campaigns are shown in Table 1, where measurements prior to and after intervention are compared. As the first modal frequency is increased and deflections are reduced, it can be concluded that the rigidity of the structure has been increased significantly. After performing model updating (developed in later studies), it is shown that the global bridge behavior is significantly modified (Figure 7). Deformations predicted by the numerical models prior to and after monitoring match the measurements collected during load tests.

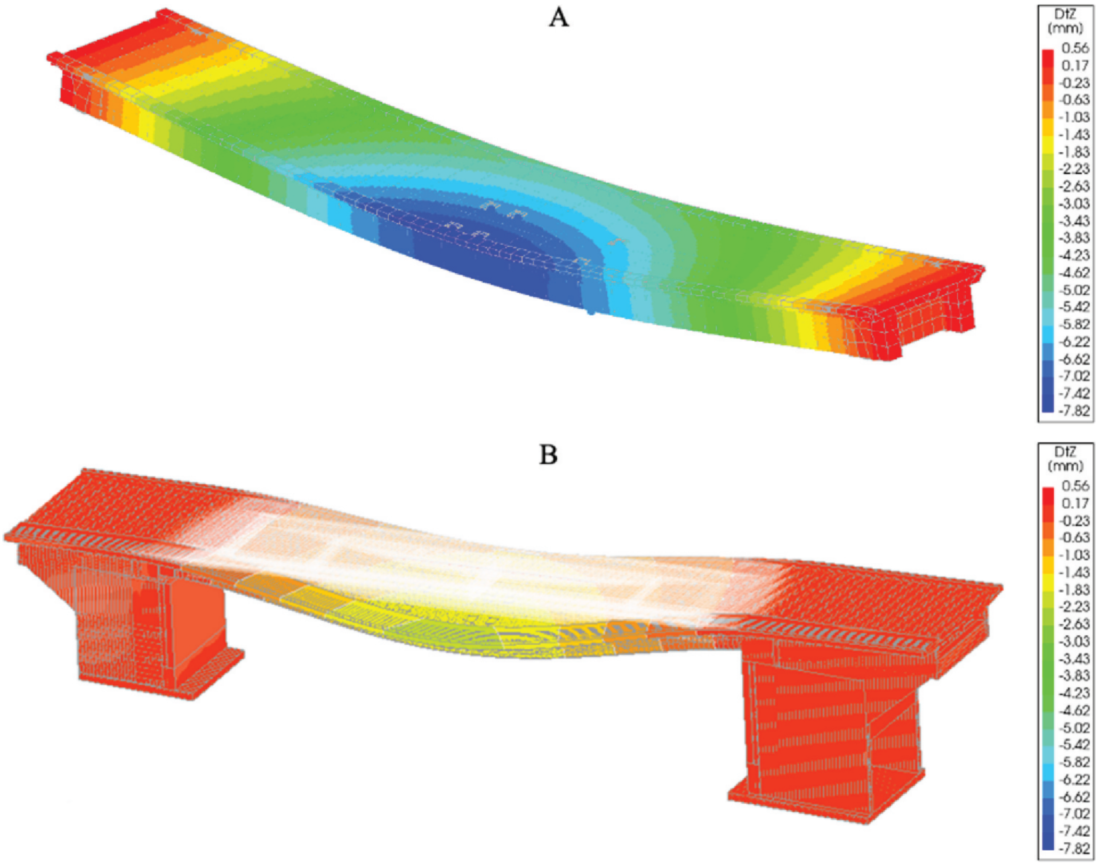

Figure 7. Bridge deflection behavior. A) Prior to monitoring; B) After monitoring.

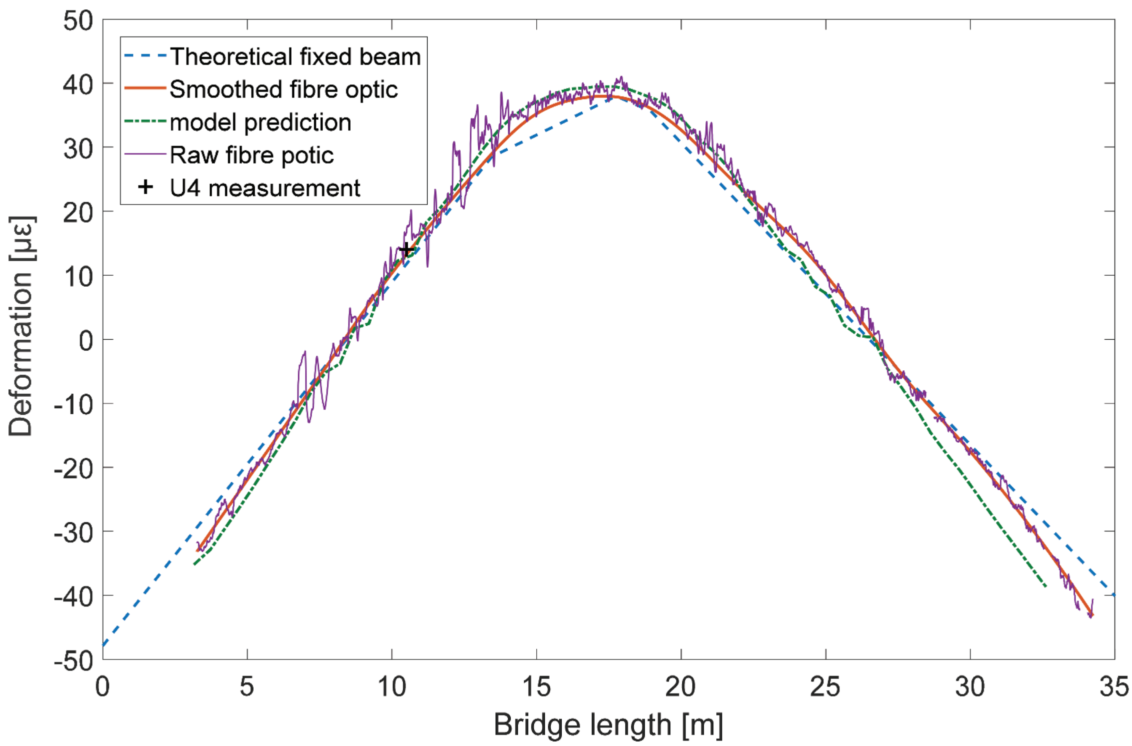

Figure 8. Comparison of model predictions, optical fiber strain measurements, and deformation of a theoretical fixed beam.

Two 32m-long optical fibers (SMARTprofile II from Smartec and a LUNA data acquisition system) were glued along both girders to validate the change of the static system. These optical fibers measure strain every approx. 3 mm along virtually the entire length of the structure. This corresponds to the equivalent of around 11,000 strain gages installed in series on each girder, enabling a much more detailed analysis than is usually the case where only a few strain gages are placed along the length of the bridge. Measurements are taken at a frequency of 5 Hz.

Strain predictions are compared with fiber optic measurements in Figure 8. The values in the cracks are removed from the fiber measurements ("raw fiber optic"). These values are then smoothened ("smoothed fibre optic") to remove local variations in the measurements and enable easier comparison. The theoretical deformation of a fixed beam with three concentrated loads (corresponding to the truck's three axles) is also presented. It can be seen that the predictions are very close to both the fiber optic measurements and the theoretical deformation. The average error is around 2 $\mu\varepsilon$. It can thus be concluded that the intervention resulted in the modification of the static system, where the bridge superstructure is being clamped to the abutments, creating a monolithic behavior of the structure. More in-depth analyses of the fiber-optic data will be made in future work.

6 CONCLUSIONS

This article presents the design, execution, and monitoring of the UHPFRC intervention on the Ferpècle bridge, one of the first prestressed concrete bridges in Switzerland. The project involved widening the bridge deck from 5.3 to 7.9 m (increase of about 50 %). The resulting need for reinforcement was met by redistributing actions (from midspan to the supports) based on the theory of plasticity at ULS. Strengthening only the top of the deck increases the structure's flexural load-bearing capacity by 44 %, while widening and rehabilitating the bridge. This case study demonstrates that UHPFRC can effectively strengthen existing structures by changing the static system. Compared with the demolition-reconstruction initially envisaged, the project is considerably less costly (-75 %) and has smaller associated carbon-dioxide emissions (- 55 %). The intervention was validated through an innovative monitoring scheme involving strain, acceleration, and deflection data. Measurements collected during load tests match the predictions of the finite-element models and correspond to the behavior of a fixed beam.

ACKNOWLEDGEMENTS

The authors are thankful to the Küpfer Geometres SA (M. Vaïk Küpfer) and IRMOS companies (Dr. Panagiotis Martakis and Dr. Yves Reuland) for the data acquisition during the load tests.

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Determining the structural properties of concrete bridges through the combination of static and dynamic load testing

Numa BERTOLA [1,2], Yves REULAND[3], Eugen BRÜHWILER [2]
[1] University of Luxembourg, Esch-sur-Alzette, Luxembourg
numa.bertola@uni.lu
[2] EPFL – Swiss Federal Institute of Technology, Lausanne, Switzerland,
eugen.bruehwiler@epfl.ch
[3] ETH – Swiss Federal Institute of Technology, Zurich, Switzerland,
reuland@ibk.baug.ethz.ch

Abstract. Examining structural safety requires assumptions regarding several properties of the bridge structure, such as the material properties, boundary conditions, and self-weight. The traditional approach is to assume conservative values for each bridge property, following the conventional new-design philosophy. Nonetheless, this approach leads to conservative evaluations of bridge capacity and may lead to the inaccurate conclusion that the structure is deficient. Over-conservative in structural safety assessments has large negative environmental and economic impacts on global infrastructure management. Another approach is to conduct multiple tests and monitoring activities on the structural system to determine the values of these bridge properties more accurately. This paper presents a methodology to determine several parameters, including the structural stiffness, the boundary conditions, and the self-weight of concrete bridges based on data from static and dynamic load testing. The methodology is used on a prestressed concrete bridge in Switzerland. This bridge from 1958 has a single span of 35 meters and has been significantly strengthened and widened in 2023. By accurately identifying the self-weight, this study shows the potential of bridge monitoring for a more sustainable and economic infrastructure management.
Keywords: Bridge load testing, Structural identification, Existing bridges, Structural health monitoring; Fiber optic sensor.

1. Introduction

Most bridges in many countries like Switzerland have been built after the Second World War and are approaching, according to today's understanding, their theoretical end of service duration. Replacing all these structures will have significant environmental and economic impacts [1], so it is necessary to accurately assess their structural capacity to prioritize infrastructure maintenance[2]. In practice, civil-infrastructure management is mostly based on subjective visual inspection [3]; novel data-informed frameworks are needed for accurate structural performance evaluation.

Significant research efforts have been made to develop structural health monitoring systems that detect and quantify damage on structures [4]. Nonetheless, these methods mostly detect local loss of rigidity in the structure (for instance, due to concrete cracking), but it does not mean that structural integrity (mostly governed by steel reinforcement) is affected [5].

Another approach is to use sensor data on bridges to re-evaluate the structural properties [6]. Methodologies involve detecting structural rigidity and boundary conditions through load testing [7], identifying long-term prestressed losses [8], or identifying live load levels on the bridge through bridge weigh-in-motion [9], or a combination of these methods [10]. These methods have allowed to uncover significant reserve capacity in numerous case studies [11].

Nonetheless, one aspect that has often been neglected in updating bridge properties, is the potential of updating the bridge self-weight. For concrete bridges, it is common that the self-weight represents around 70% of the total loads on the structure. The precise identification of the bridge weight enables the reduction of the safety factor on the bridge self-weight. However, precisely identifying the bridge self-weight can be challenging as this structural property can only be identified through inverse analyses from dynamic excitation. Moreover, this inverse analysis is also affected by other bridge parameters, such as the structural rigidity and boundary conditions that are typically also imprecisely defined.

In this study, a methodology to precisely identify the self-weight is proposed. This methodology combines both static and dynamic load testing, as well as multiple sensing technologies (accelerometers, deflection sensors, and fiber optics), to obtain precise self-weight estimation on the bridge. This new information allows the discovery of untapped reserve capacity in the structure, especially for ultimate limit states.

2. Methodology to identify bridge self-weight

The methodology to identify the bridge self-weight is shown in **Fig. 1** through the combination of static and dynamic load testing. First, the structural model is generated. Three-dimensional finite-element models are recommended to improve the precision of structural-behavior predictions. Non-structural elements should also be included in the analysis as they influence the structural stiffness under service conditions. Parameters that have the largest influence on structural behavior (boundary conditions, concrete elastic modulus, …) are selected. Uncertainties from remaining parameters are estimated (such as secondary parameters, model simplification, mesh size).

Then, static and dynamic load tests are performed on the structure. The boundary conditions are first updated through the deformation shape. This deformation shape can be measured through linearly-continuous monitoring systems, such as fiber optics. Another option is to perform local measurements at supports. Next, the stiffness of the structure is obtained through model calibration using static measurements (such as deflection, deformation, inclination) and previously achieved boundary-condition identifications. Finally, the self-weight is identified through model calibration using dynamic properties, like the natural frequency, of the bridge given the previously identified values of bridge stiffness and boundary condition.

As it is impossible to estimate precisely the boundary-condition and rigidity values due to remaining uncertainties and measurement errors, it is crucial to account for the propagation of uncertainties through the identification process. These uncertainties lead to the definition of the updated safety factor for the bridge self-weight.

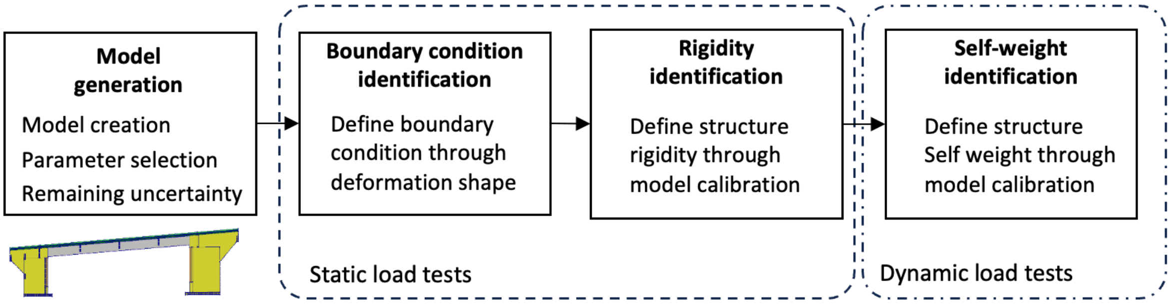

Fig. 1. Methodology to identify bridge self-weight combining static and dynamic load testing.

3. Case study

3.1 Bridge presentation

The Ferpècle Bridge is a prestressed reinforced concrete structure with a double-girder cross-section located in the Swiss Alps at an altitude of 1450 meters. The bridge was built in 1958 and needed to be widened in 2023. The initial static system is a simply-supported beam with a 34.5-meter span, resting on abutments with side walls approximately 7 meters high (**Fig. 2**). With a beam height of 1.75 meters, the slenderness of 1/20 is audacious for a simply-supported beam structure.

An intervention has been performed with UHFPFRC in 2023 to widen the deck from 5.3 to 7.9 meters. The intervention consisted of a cantilevered UHPFRC full slab with a variable thickness. Moreover, the abutments have been clamped to the superstructure, modifying the static system and achieving a monolithic half-frame structure. The initial bending-moment deficit at mid span is thus redistributed to the supports, where the new layer of UHPFRC (70 mm with (ϕ22 @100 mm)) is used to create the necessary bending resistance.

With regard to material characterization, a C45/55 concrete grade (updated from the C30/37 defined at the construction stage) has been selected for the existing bridge concrete. The tensile strength of the reinforcing steel was accepted at $f_{sd} = 300\ MPa$. For prestressed bars, an ultimate strength of $f_{pd} = 730\ MPa$ was assumed.

Load levels are defined in the Swiss standards for existing structures SIA 269 [12]. Action effects due to the loads are presented in characteristic values in **Table 1**. The self-weight of the bridge creates the largest bending moment on the structure. Thus, reducing the self-weight safety factor has a large impact on structural safety evaluations.

Table 1. Action effects of loads.

Load	Bending moment (characteristic value) [kNm]	Relative part (%)
Self-weight	14500	60
Live loads (distributed)	5900	25
Life loads (concentrated)	3600	15

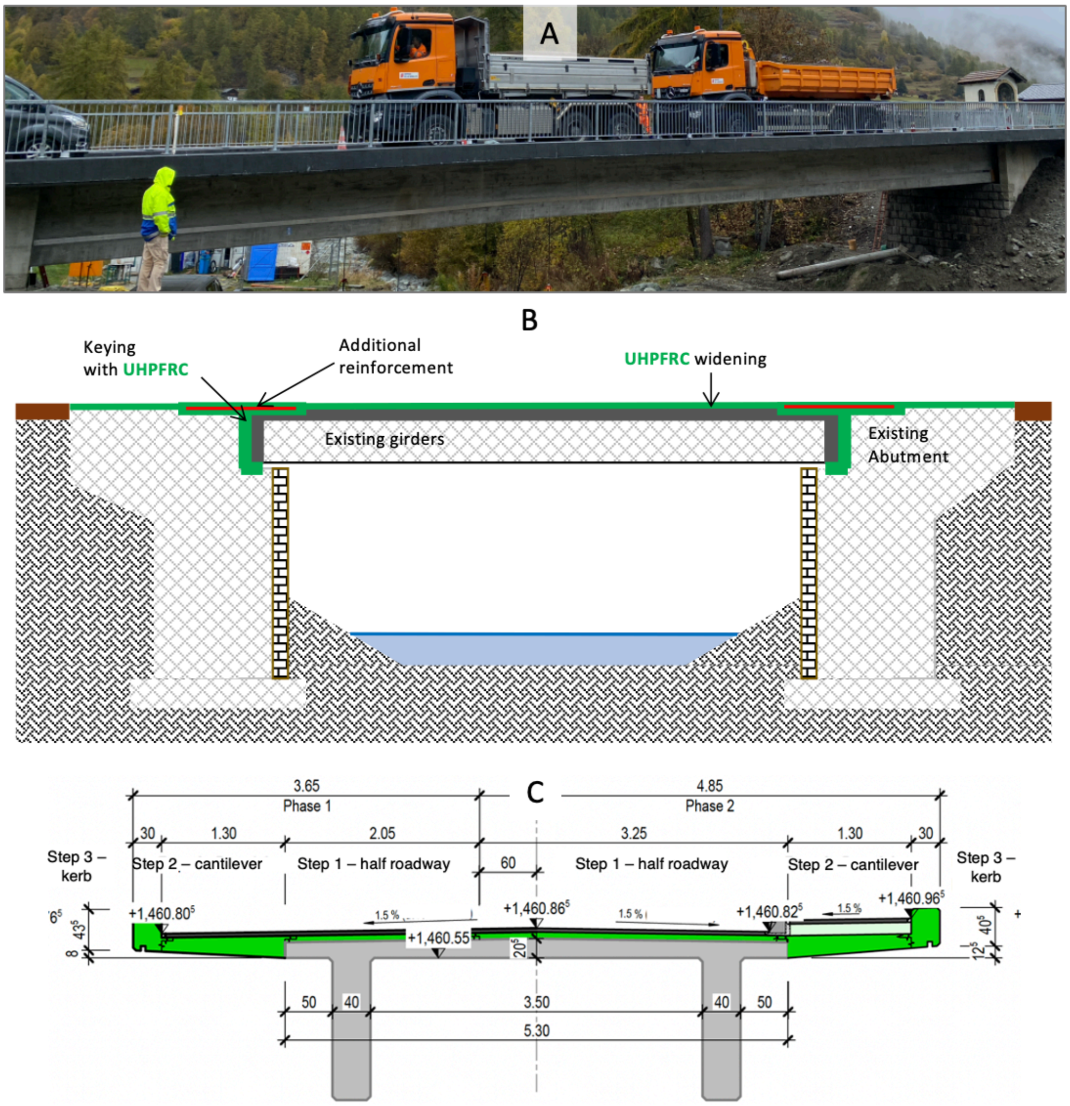

Fig. 2 Presentation of the bridge. A) Photograph of the bridge during load test; B) Longitudinal view of the intervention; C) Cross-section of the intervention.

To validate the structural intervention, a numerical model of the structure has been built using the DIANA software (**Fig. 3**). The model involves shell elements, and all reinforcement bars and prestressed tendons have been explicitly included. To increase the accuracy of the model prediction, non-structural elements (pedestrian ways, curbs) have been added to the model. Moreover, the abutments have also been modelled to accurately replicate the complex structural system. The tensile strain-hardening behaviour of the UHPFRC has also been precisely modelled. Precise constitutive laws of concrete and steel properties are considered. The structural safety is assessed through non-linear analyses to account for stress redistribution in the structure. Predictions of structural behaviour during load tests are made through linear analysis, as materials are expected to remain in the elastic domain under the test loads.

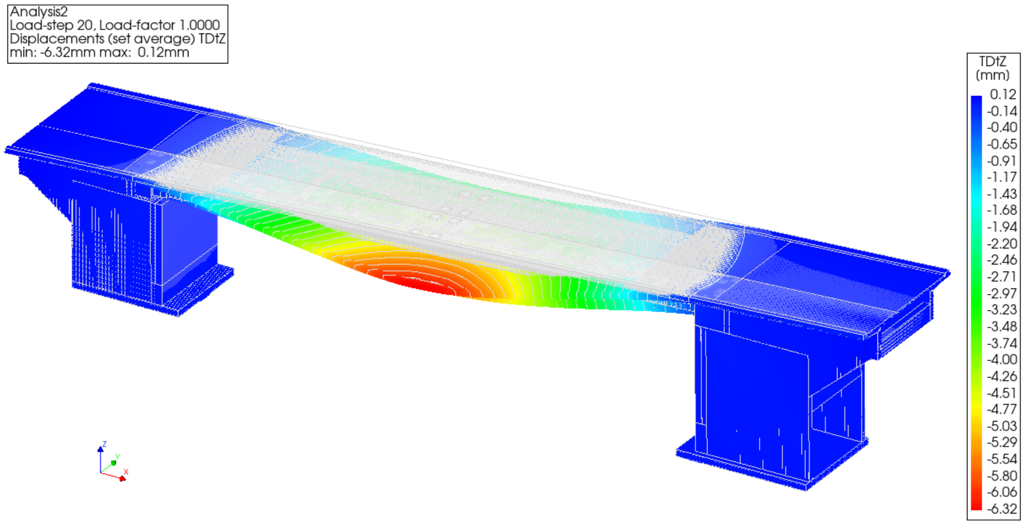

Fig. 3. 3D finite-element model of the structure built with shell elements in DIANA software, and model predictions during static load tests. The deformed model is due to the load case of ..??..

3.2 Monitoring campaign

Static and dynamic load tests were performed on the 31st of October 2023. Static load tests consisted of two trucks of 26 tons placed at multiple locations, while the dynamic load tests involved exciting the bridge with a moving truck. In this study, only the most unfavourable static load test, which consisted of placing the two trucks next to each other at midspan, is considered.

The monitoring system involves 6 LVDT sensors, two continuous fiber optics running throughout the entire bridge span (approximately 12'000 measurement points for each fiber), and 9 accelerometers. The sensor locations and load test configuration are shown in **Fig. 4**. It is important to note that the monitoring campaign occurred prior to casting the asphalt layer.

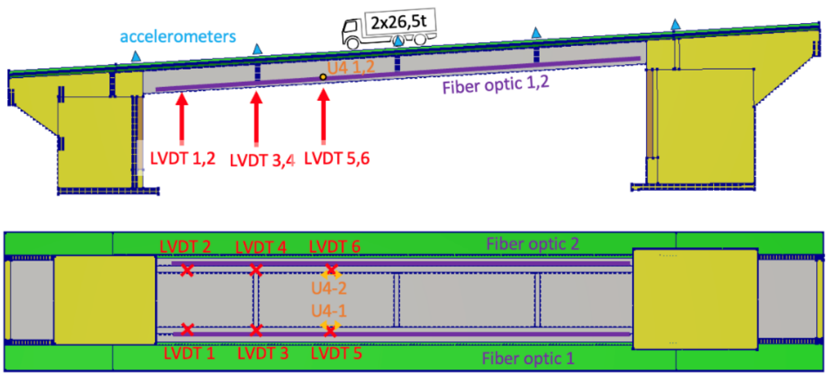

Fig. 4. Sensor network installed on the bridge.

3.3 Updating boundary conditions using fiber optic measurements

The first step of the methodology involves the identification of the boundary conditions based on distributed monitoring. In this study, the fiber-optic measurements are used to define whether the clamping of the boundary conditions during the intervention led to a fixed beam during service conditions as designed.

A strain analyses of theoretical fixed and simply supported beams under the static loads (2x3 axles for a total of 53 tons placed at midspan of the bridge) are made without accounting for the beam rigidity (**Fig. 5**). These theoretical deformations are compared to the fiber-optic measurements throughout the beam length as well as finite-element model prediction.

The fiber-optic measurements demonstrate that the bridge behaves like a fixed beam during the static load tests. Fixed boundary conditions are thus considered in subsequent analysis. Moreover, the comparison between field measurements and finite-element model predictions shows an uncertainty of 6 % at midspan. This uncertainty will be considered when defining the safety factor of the updated self-weight.

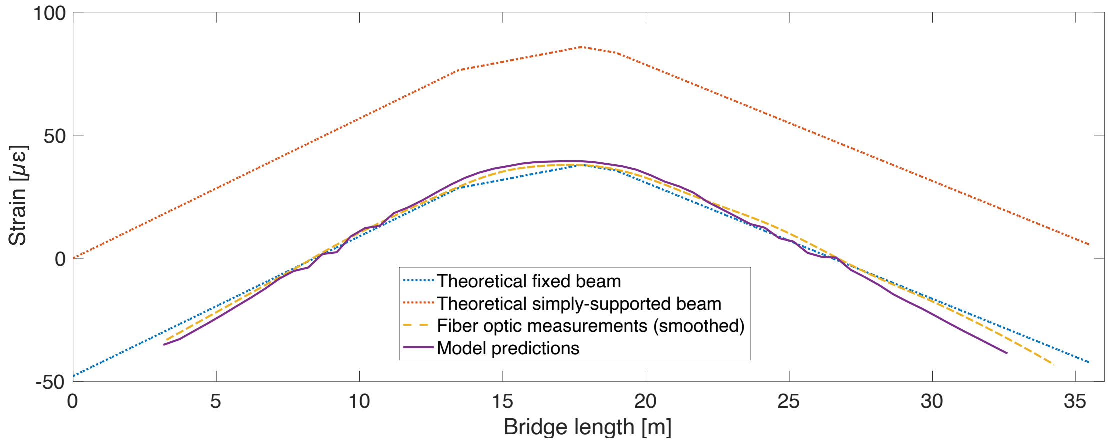

Fig. 5. Identification of boundary condition using fiber optic measurements

3.4 Updating rigidity through static load testing

The first step consists of updating the boundary condition and rigidity properties of the bridge based on the static measurements. Based on a sensitivity analysis, two main parameters have been shown to influence the deflection and strain predictions of the numerical model: the elastic modulus of prestressed concrete and the elastic modulus of UHFPRC. The connection between the bridge superstructure and the abutment is assumed to be perfectly monolithic. The remaining parameters, such as the elastic modulus of the concrete for pedestrian sidewalks, is estimated to impact predictions by less than 1%. The mesh size has also been reduced within the limits of computational efficiency to minimize its impact on the model prediction (estimated to affect the predictions by less than 1%).

After model calibration based on LVDT sensor measurements, the elastic modulus of concrete is estimated to be 40 GPa, while the UHPFRC elastic modulus is equal to 45 GPa. The discrepancies between predictions and measurements range from 1.5 to 9.2 %, with an average value of 5.0 % (**Table 2**).

Table 2. LVDT measurements and calibrated model predictions.

	LVDT 1	**LVDT 2**	**LVDT 3**	**LVDT 4**	**LVDT 5**	**LVDT 6**
Unit	mm	mm	mm	mm	mm	mm
Measurements	0.365	0.228	2.28	1.37	3.44	2.06
Predictions	0.34	0.24	2.07	1.35	3.37	2.17
Difference [%]	6.85	-5.26	9.21	1.46	2.03	-5.34

3.5 Updating bridge self-weight

Once the bridge stiffness and boundary conditions are updated, the equivalent density of the concrete can be updated. The range of the equivalent density is taken to be relatively large (between 2000 and 2900 kg/m^3) to implicitly account for potential differences in element sizes (such as thickness of the deck, girder width). For this analysis, it is assumed that the UHPFRC density ρ_U is equal to 2600 kg/m^3.

The dynamic tests consisted in using a truck (26,5 tons) running over the bridge as well as ambient vibration monitoring. Predictions and natural-frequency measurements based on the dynamic tests show a discrepancy between typical concrete density (2300 to 2500 kg/m^3) within the 5-% threshold ranges around the measured value. This result demonstrates that the equivalent density of concrete is close to the expected value. The discrepancy between measured and predicted values for ρ_c equal to 2400 is about 3.3 %. Moreover, an analysis including conventional safety factors (i.e., 1.2 for existing concrete and 1.35 for new UHPFRC) for concrete and UHPFRC shows that the natural frequency would be about 20 % lower, which is not plausible given the monitoring results.

The safety factor on the bridge self-weight is now evaluated by combining the three monitoring discrepancies using the Euclidian distance, Equation (1). The obtained value is then multiplied by a factor $\gamma_{g,2}$ equal to 1.05 (Equation 2) to account for uncertainty in the calculation between self-weight action and action effects in structural-analysis model [13]. The γ_g obtained is equal to $\gamma_g = 1.14$. This value is then taken to update structural verifications.

$$\gamma_{g,1} = \left(1 + \sqrt{\sum_i^3 r_i^2}\right) \tag{1}$$

$$\gamma_g = \gamma_{g,1} * \gamma_{g,2} \tag{2}$$

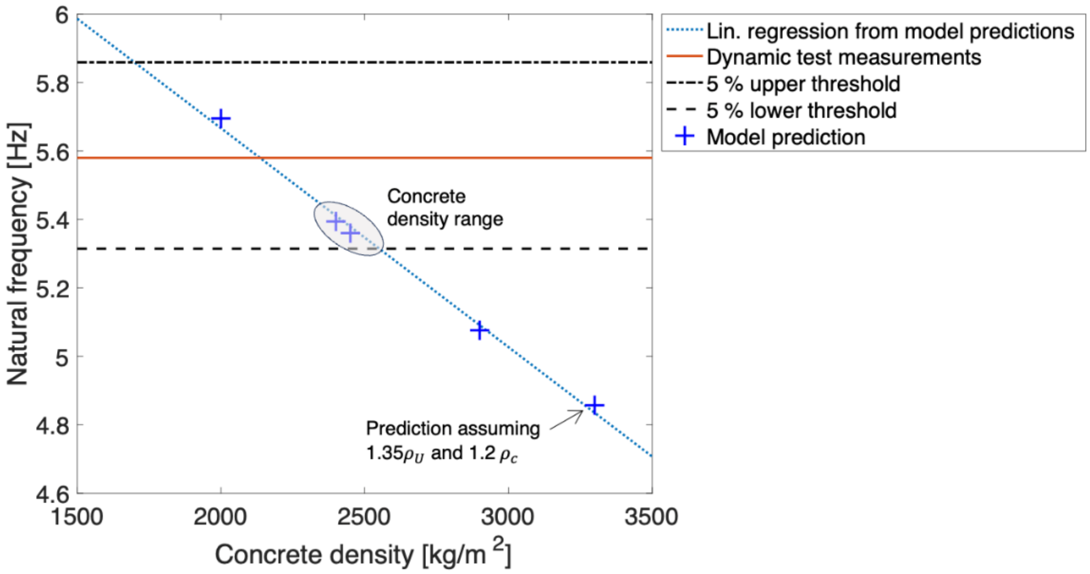

Fig. 6. Comparison of model predictions and natural-frequency measurements.

3.6 Impacts on structural verifications

Structural safety is evaluated based on the concept of the degree of compliance n [14] using design values of both structural resistance R_d and action effects E_d (Equation 3). The structural safety is evaluated based on the two most critical verifications at ultimate limit states: the bending moment at support and the shear on the girders. The impact of the model updating on the degrees of compliance with structural verifications is shown in **Table 3**. For both structural verifications, the increase in the degree of compliance is significant, especially for the bending verifications. This result demonstrates the potential of the proposed methodology to discover untap reserve of capacity in concrete bridges.

$$n = Capacity/Demand = \frac{R_d}{E_d} \tag{3}$$

Table 3. Structural safety evaluation prior to and after self-weight model updating.

	Bending moment	**Shear**
Prior self-weight updating	1.02	1.29
After model updating	1.14	1.35
Difference [%]	+11.7	+ 3.9

4. Conclusions

This study emphasises the importance of the self-weight in the examination of concrete bridges. Action effects due to the bridge structure self-weight are usually significantly larger than the ones of live loads. Updating the load factor and the self-weight is thus a promising solution to unlock an untapped reserve of capacities for ultimate limit states. A 3-step procedure is proposed that combines information from fiber-optic sensors, static and dynamic load tests to update bridge self-weight as well as the associated load factors. The methodology has been applied to the Ferpècle Bridge in Switzerland, which has been strengthened in 2023. Thanks to the proposed methodology, an additional 11,7 % of reserve capacity in bending is revealed, which could be significant in upcoming examinations of the bridge, for instance, if live loads increase in the future. The proposed methodology supports engineers and bridge owners for more sustainable management of existing concrete bridges.

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Load Testing in bridges
An opportunity to formally digitalize the bridge environment

Rolando Chacón
Associate Professor
Department of Civil and Environmental Engineering
Universitat Politècnica de Catalunya, Spain

Stefan Wagmeister
Austrian Standards
CEN/ TC 442

Proposal for a preliminary (PWIP)

Lessons learned from a H2020 Project (42 Months)

GENERAL INFORMATION

Status	Active
Sector	B33 - BUILDING DESIGN
Work Field	Information technology
Parent	CEN - CEN TC
Sub-Committee	CEN/TC 442/WG 1 - Strategy and Planning CEN/TC 442/WG 10 - Strategy and planning CEN/TC 442/WG 2 - Exchange information CEN/TC 442/WG 3 - Information Delivery Specification CEN/TC 442/WG 4 - Support Data Dictionaries CEN/TC 442/WG 5 - Chairperson's Advisory Group CEN/TC 442/WG 6 - Infrastructure CEN/TC 442/WG 7 - Horizontal role CEN/TC 442/WG 8 - Competence CEN/TC 442/WG 9 - Digital twins in AECOO sector

Bridge Life-Cycle

Architectural design

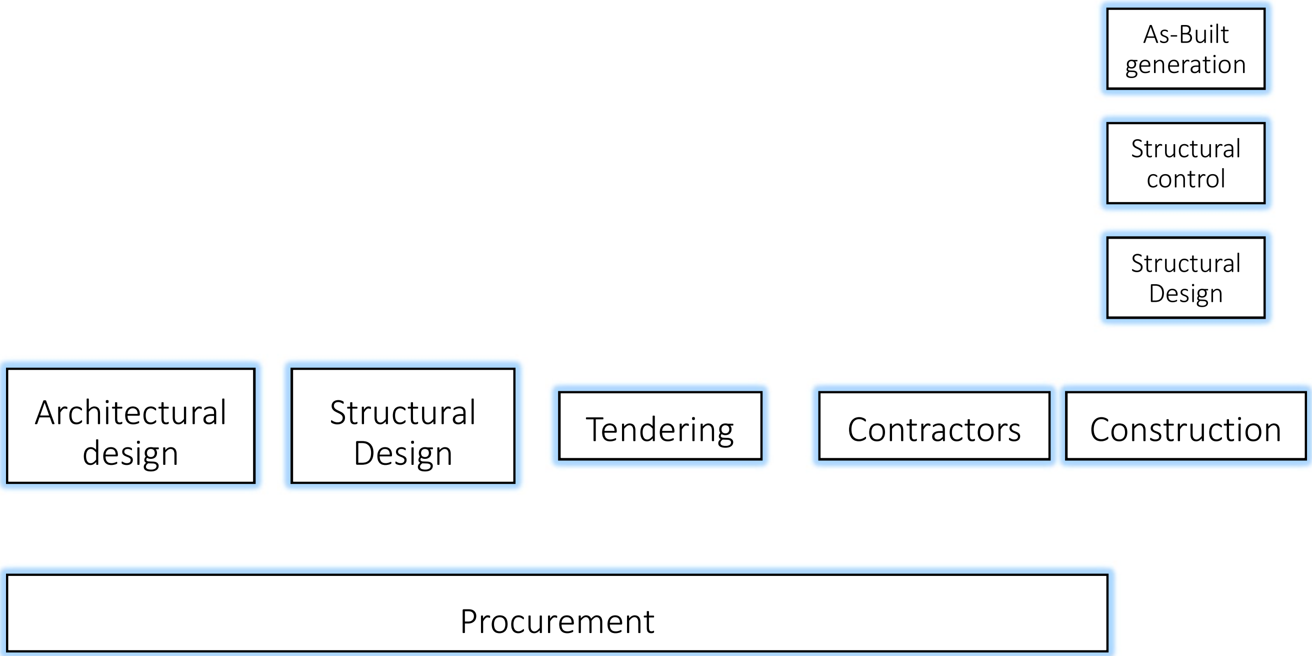
Structural Design

Tendering

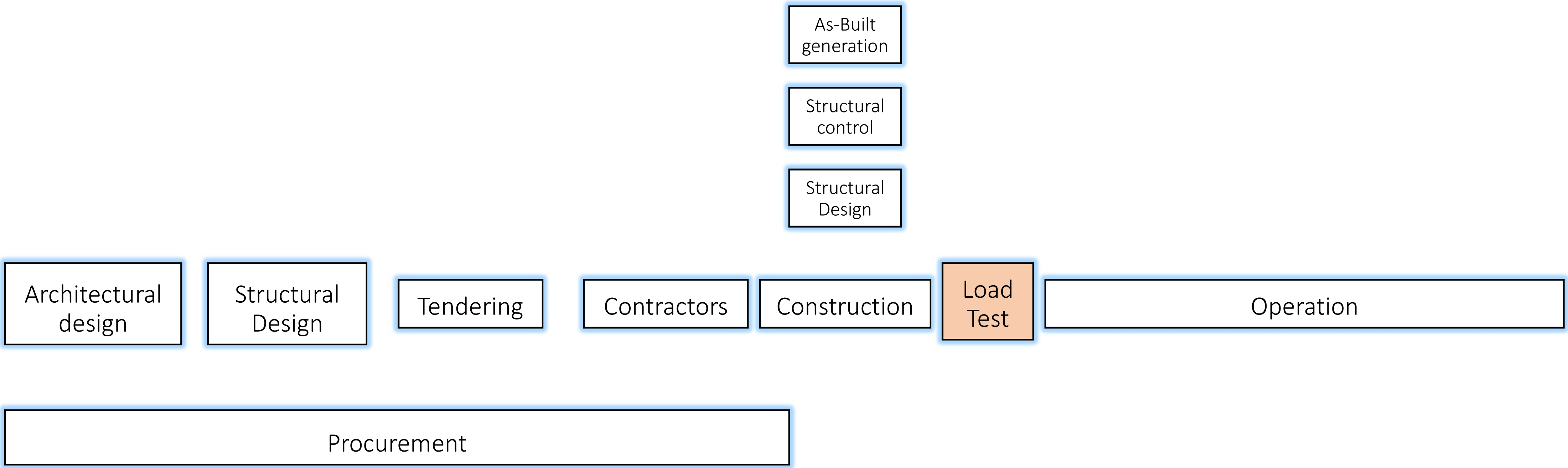
Contractors

Procurement

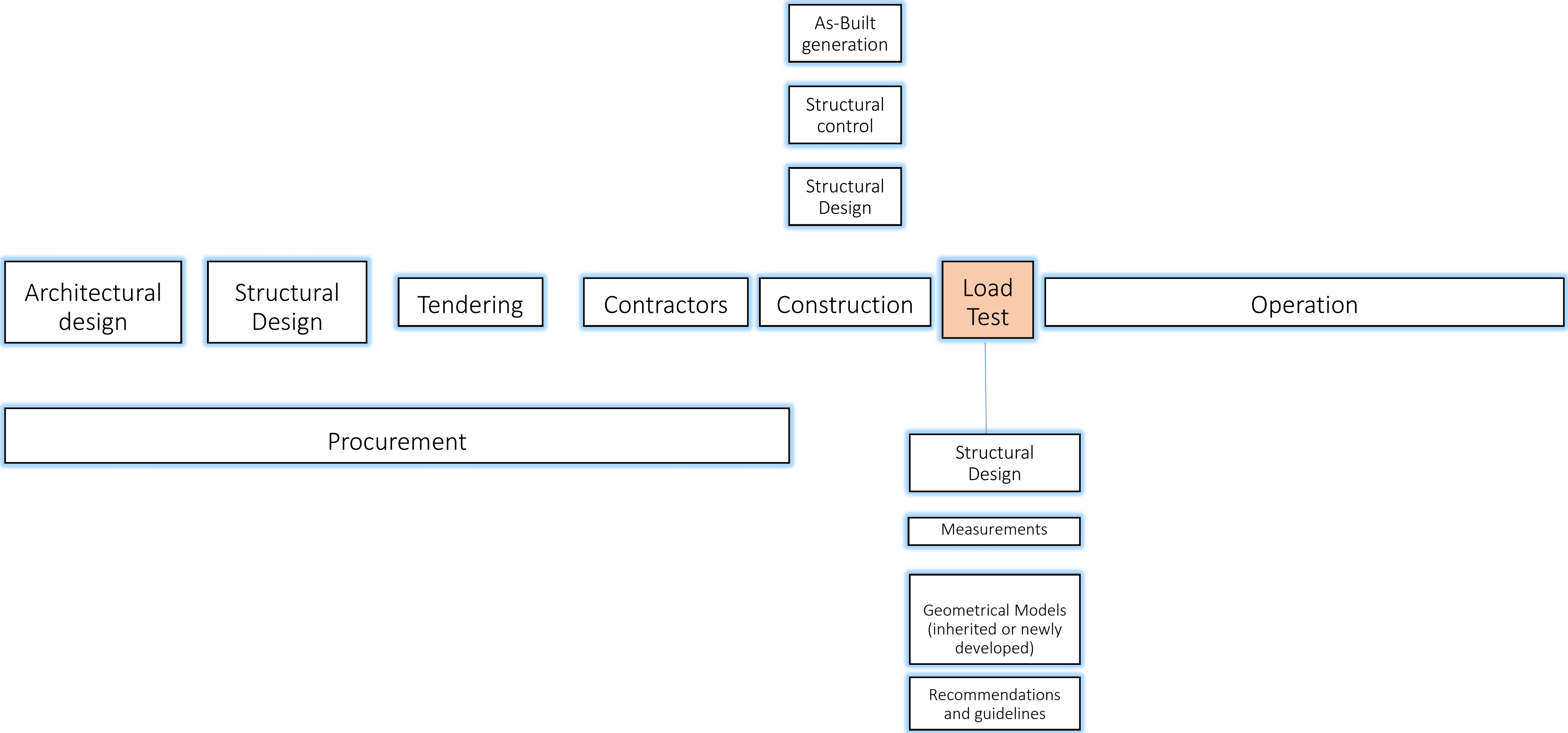
Bridge Life-Cycle



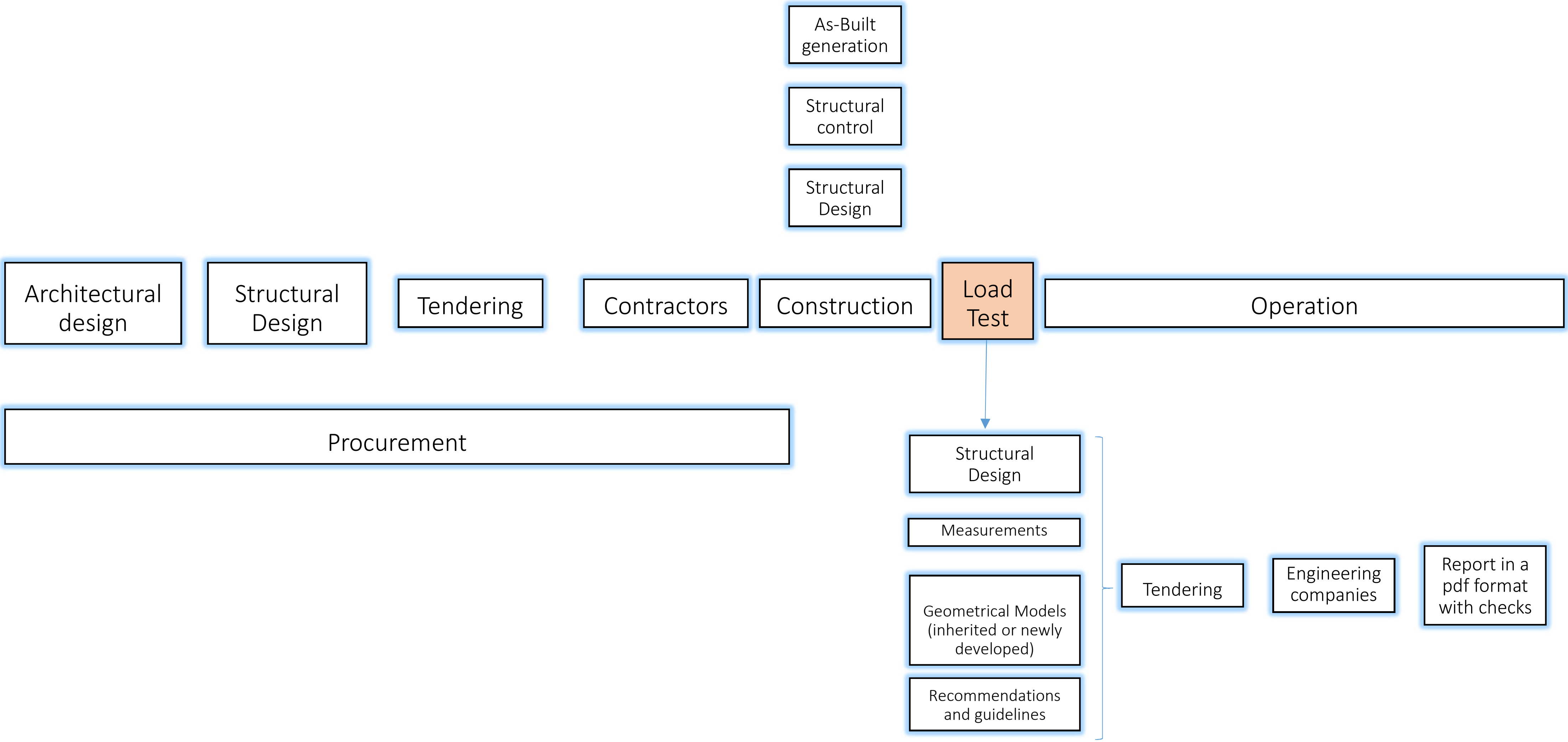
Bridge Life-Cycle

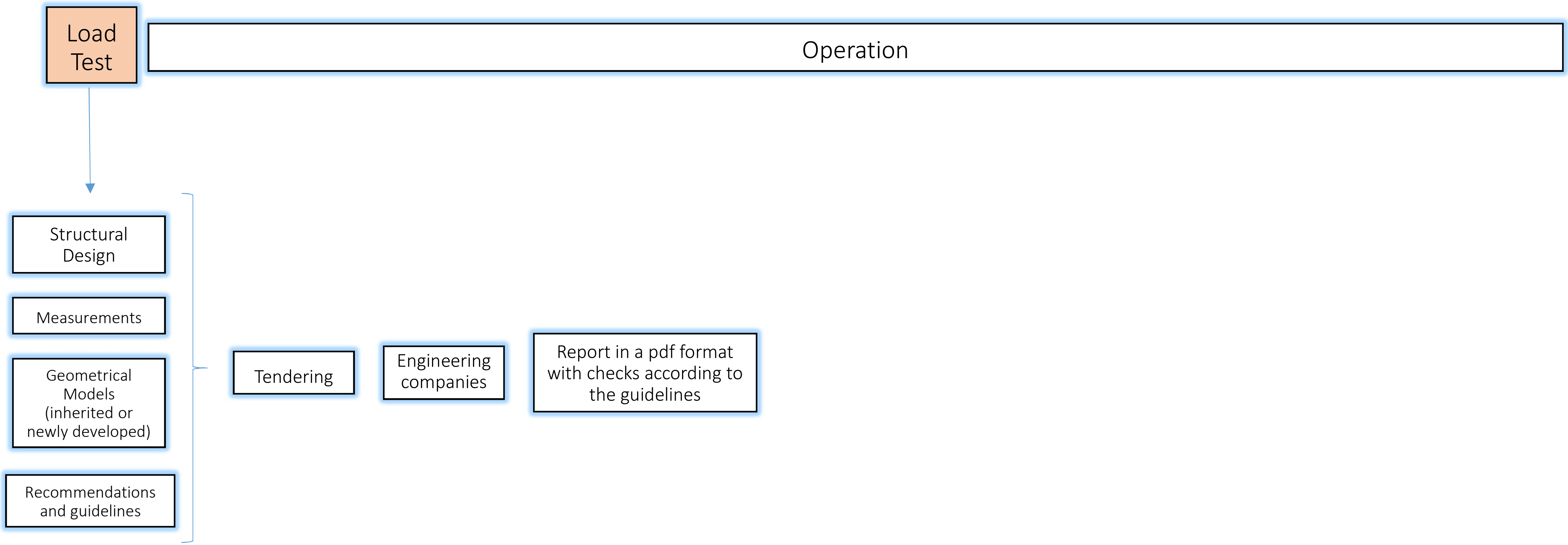


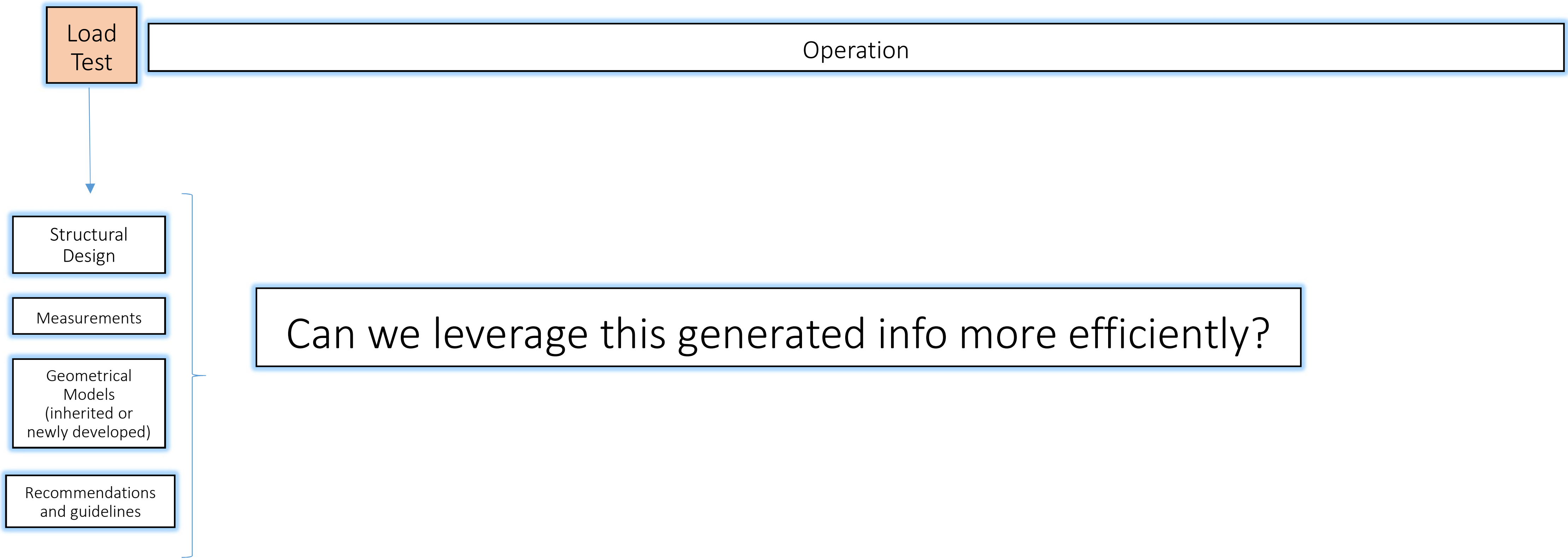
Bridge Life-Cycle



Bridge Life-Cycle




Load Test
Operation
Structural Design
Measurements
Geometrical Models (inherited or newly developed)
Recommendations and guidelines
Tendering
Engineering companies
Report in a pdf format with checks according to the guidelines


Load Test
Operation
Structural Design
Measurements
Geometrical Models (inherited or newly developed)
Recommendations and guidelines
Can we leverage this generated info more efficiently?

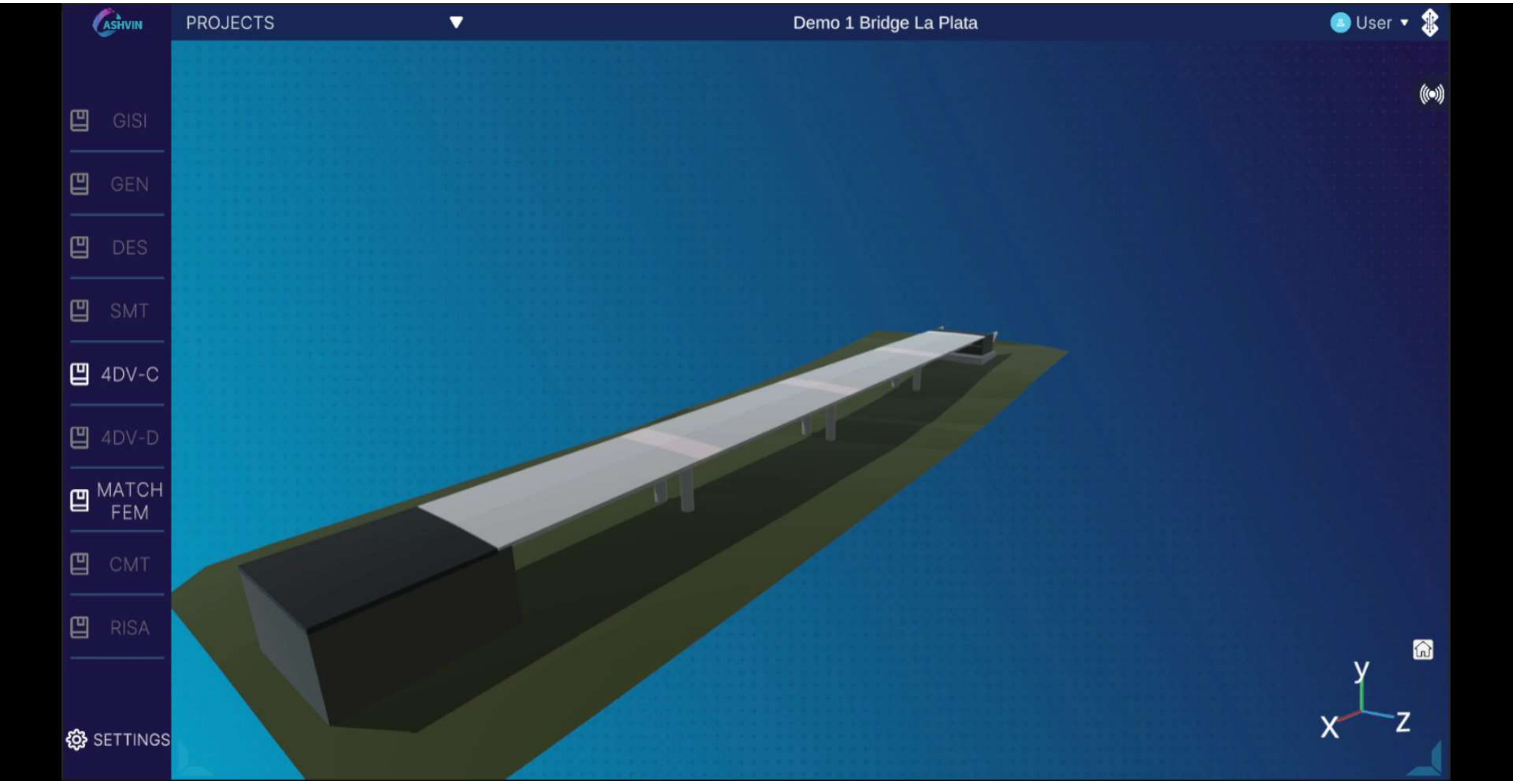
Staff

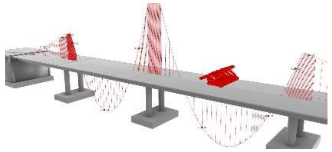
Data collection

Logistics

Equipment

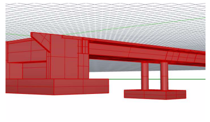
The deployment of a load test in its present form, implies a lot of resources





Structural Design

Measurements



Geometrical Models (inherited or newly developed)

Recommendations from ADIF (Management of Rail Infrastructures, Spanish public company)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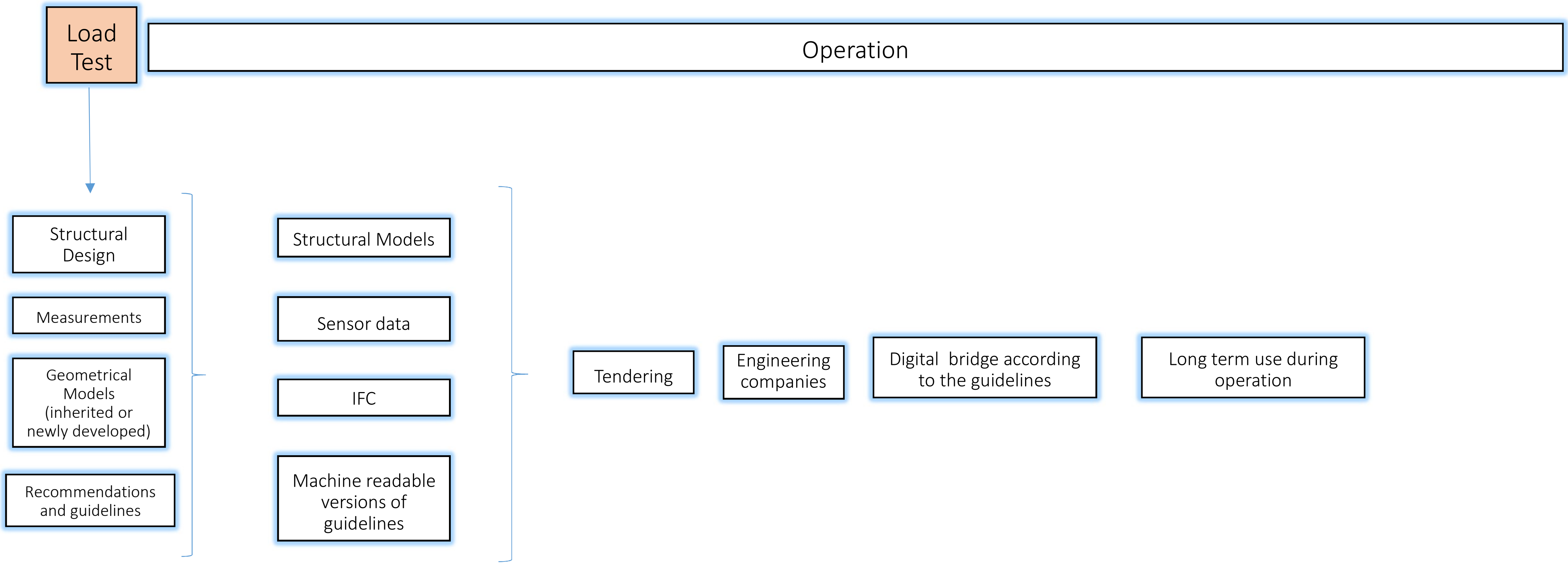
#3=IFCPERSON($,'Hector J','Posada C',$,$,$,$,$);
#4=IFCORGANIZATION($,'UPC',$,$,$);
#5=IFCPERSONANDORGANIZATION(#3,#4,$);
#6=IFCAPPLICATION(#4,'1.0','IfcFEM','IfcToFEM');
#7=IFCUNITASSIGNMENT((#8,#9,#10,#11,#12,#13,#14,#17,#20,#22,#24,#26,#28,#30));
#8=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#9=IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#10=IFCSIUNIT(*,.PLANEANGLEUNIT.,$,.RADIAN.);
#11=IFCSIUNIT(*,.PRESSUREUNIT.,.MEGA.,.PASCAL.);
#12=IFCSIUNIT(*,.FORCEUNIT.,.KILO.,.NEWTON.);
#13=IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#14=IFCDERIVEDUNIT((#15,#16),.LINEARFORCEUNIT.,$,$);
#15=IFCDERIVEDUNITELEMENT(#12,1);
#16=IFCDERIVEDUNITELEMENT(#8,-3);
#17=IFCDERIVEDUNIT((#18,#16,#19),.LINEARMOMENTUNIT.,$,$);
#18=IFCDERIVEDUNITELEMENT(#12,1);
#19=IFCDERIVEDUNITELEMENT(#10,-1);
```


The deployment of a load test in its present form, has been digitalized in a series of bridges

Preliminary idea for new work item proposal



Challenges

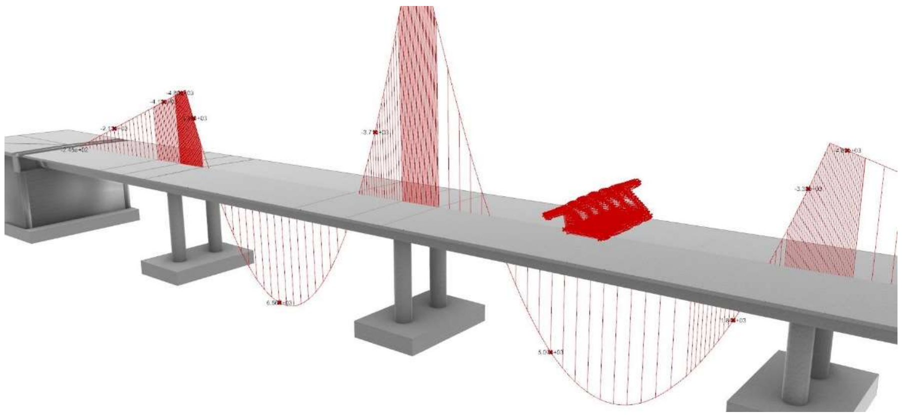
Recommendations vary from one country another

Requirements

Definition of ontologies by countries

Challenges

Structural models used for design require to be shared between stakeholders. Open Structural models are not common.



Information delivery specification / Liability

New horizon

Tendering in the bridge sector in Spain must adhere to the “Plan BIM”. A gradual transition 2024-2030 for new contracts

Promotes IFC or open formats

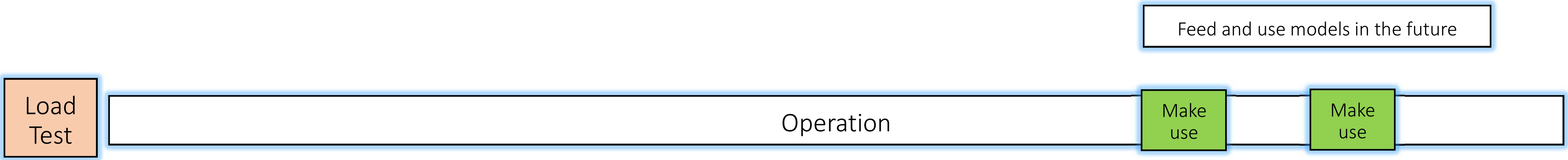
TABLA DE CALENDARIO Y NIVELES BIM (PLAN BIM)

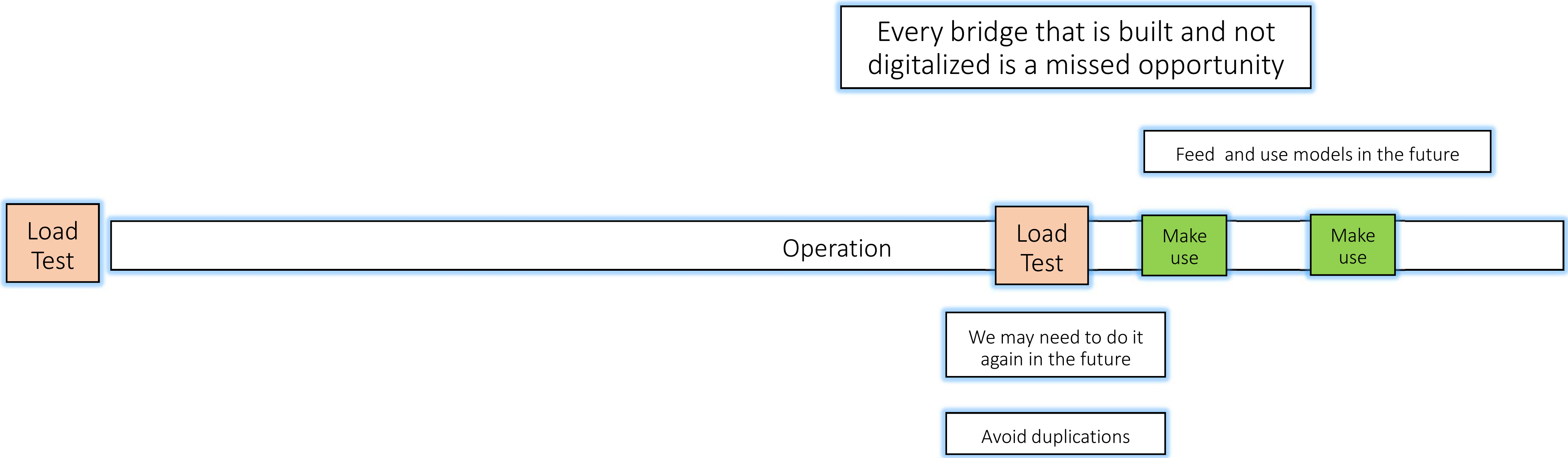
Valor estimado del contrato	2024 1 de abril	2025 1 de octubre	2027 1 de octubre	2030 1 de abril
> 5,538 M€	Nivel inicial	Nivel medio	Nivel avanzado	Nivel integrado
< 5,538 M€, y > 2 M€	Nivel recomendado inicial	Nivel inicial	Nivel medio	Nivel avanzado

M€: millones de euros

Fuente: **Plan BIM**. Comisión Interministerial para la incorporación de BIM en la contratación pública

If all information is gathered and connected digitally from the beginning




Every bridge that is built and not digitalized is a missed opportunity
Feed and use models in the future
Load Test
Operation
Load Test
Make use
Make use
We may need to do it again in the future
Avoid duplications

Project PWIP

Who should be involved?

Working Group 6. Infrastructure

Working Group 9. Digital Twins for the Built Environment

National Mirror Committees

Collaboration with Eurocodes can be added

The bridge community is represented by IABMAS

INTERNATIONAL ASSOCIATION FOR BRIDGE MAINTENANCE AND SAFETY

Who should be responsible?

Meetings with WG6 ---WG9

GENERAL INFORMATION

Status	Active
Sector	B33 - BUILDING DESIGN
Work Field	Information technology
Parent	CEN - CEN TC
Sub-Committee	CEN/TC 442/WG 1 - Strategy and Planning CEN/TC 442/WG 10 - Strategy and planning CEN/TC 442/WG 2 - Exchange information CEN/TC 442/WG 3 - Information Delivery Specification CEN/TC 442/WG 4 - Support Data Dictionaries CEN/TC 442/WG 5 - Chairperson's Advisory Group CEN/TC 442/WG 6 - Infrastructure CEN/TC 442/WG 7 - Horizontal role CEN/TC 442/WG 8 - Competence CEN/TC 442/WG 9 - Digital twins in AECOO sector

Project PWIP

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Meetings with WG6 ---WG9

This is a sensitive project. Needs to be led by CEN TC250. Eurocodes

Status	Active
Sector	B02 - STRUCTURES
Parent	CEN - CEN TC
Sub-Committee	CEN/TC 250/SC 1 - Eurocode 1: Actions on structures CEN/TC 250/SC 10 - EN 1990 Basis of structural design CEN/TC 250/SC 11 - Structural Glass CEN/TC 250/SC 2 - Eurocode 2: Design of concrete structures CEN/TC 250/SC 3 - Eurocode 3: Design of steel structures CEN/TC 250/SC 4 - Eurocode 4: Design of composite steel and concrete structures CEN/TC 250/SC 5 - Eurocode 5: Design of timber structures CEN/TC 250/SC 6 - Eurocode 6: Design of masonry structures CEN/TC 250/SC 7 - Eurocode 7: Geotechnical design CEN/TC 250/SC 8 - Eurocode 8: Earthquake resistance design of structures CEN/TC 250/SC 9 - Eurocode 9: Design of aluminium structures CEN/TC 250/WG 1 - Policy, procedures and links with other standards CEN/TC 250/WG 2 - Assessment and Retrofitting of Existing Structures CEN/TC 250/WG 3 - Structural Glass CEN/TC 250/WG 4 - Fibre reinforced polymer structures CEN/TC 250/WG 5 - Membrane Structures CEN/TC 250/WG 6 - Robustness CEN/TC 250/WG 7 - EN 1990 Basis of structural design

Load Testing in bridges
An opportunity to formally digitalize the bridge environment

Rolando Chacón
Associate Professor
Department of Civil and Environmental Engineering
Universitat Politècnica de Catalunya, Spain

Stefan Wagmeister
Austrian Standards
CEN/ TC 442