Equi Bridges
Engineering & Management

Ingeniería Forense Para Infraestructuras y Gestión de Activos

Matias Valenzuela
Laurent Rus

12.06.2025

ESCUELA DE INGENIERÍA EN CONSTRUCCIÓN
PONTIFICIA UNIVERSIDAD CATÓLICA DE VALPARAÍSO

IABSE
International Association for Bridge and Structural Engineering

Equi Bridges
Engineering & Management

Casos de Colapso

Matias Valenzuela
Laurent Rus

12.06.2025

ESCUELA DE INGENIERÍA EN CONSTRUCCIÓN
PONTIFICIA UNIVERSIDAD CATÓLICA DE VALPARAÍSO

IABSE
International Association for Bridge and Structural Engineering

Diseño

Errores

Concepto
Mal planteamiento
Suposición errónea
Suposición no realizada
Acción errónea
Resistencia incorrecta
Trayectoria de carga no reconocida
Trayectoria de carga no continua
Mal análisis numérico
Mal detallado
etc.

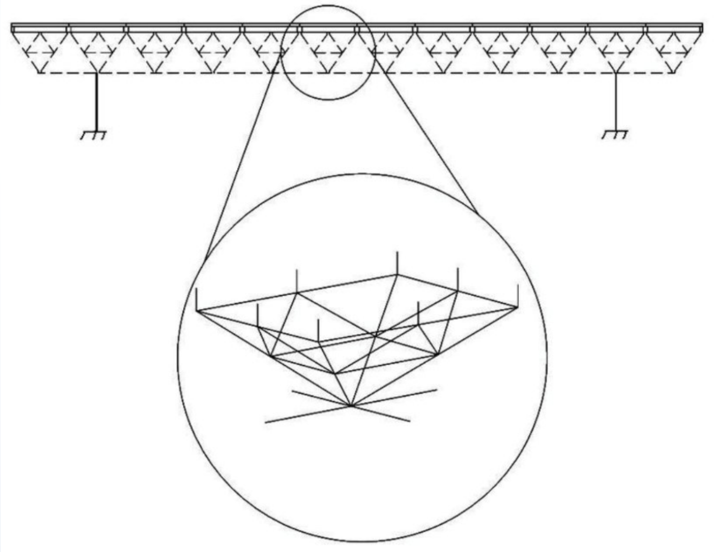
Omisión

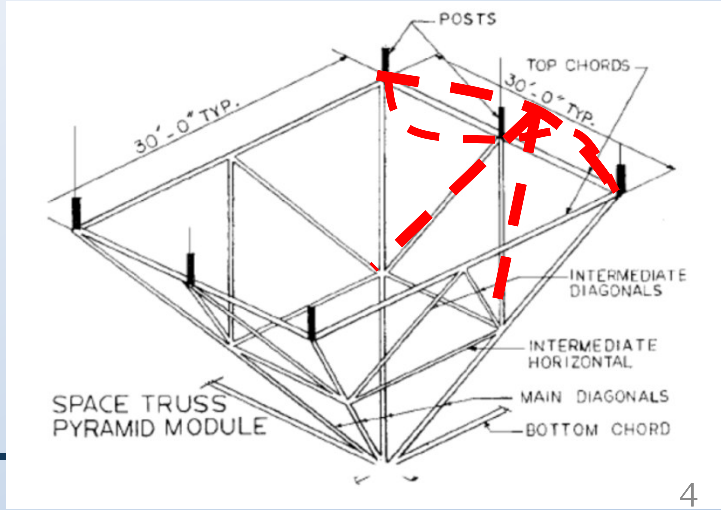
Omisión de una acción
Omisión de un comportamiento
Omisión de detalles en los dibujos ("Lo detallo en el plano del taller")
etc.

Errores de diseño

Concepto

Hartford Civic Center Coliseum,
1978, Hartford,
Connecticut, USA



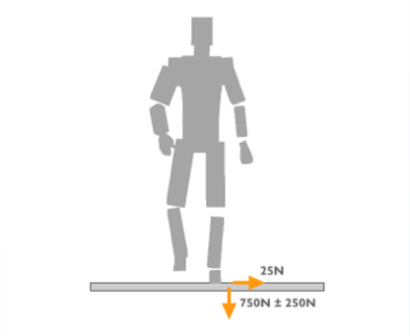


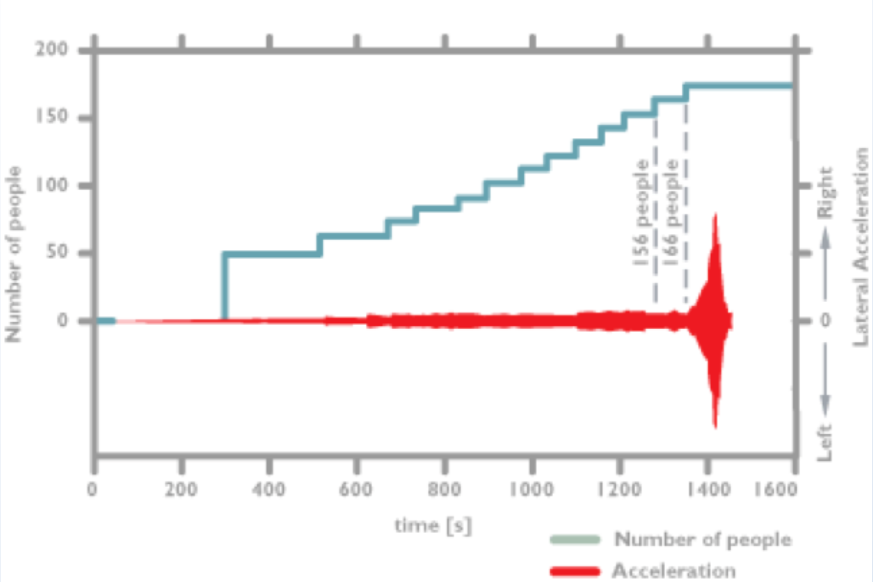
Report of Committee to Investigate the Coliseum Roof Failure, 1978, (Hartfort Civic Center) City of Hartford, Connecticut, USA

Omisiones de diseño

Omitir una acción

Millenium bridge, 2000, London, UK





www.arup.com/millenniumbridge/ (the page no longer exists)

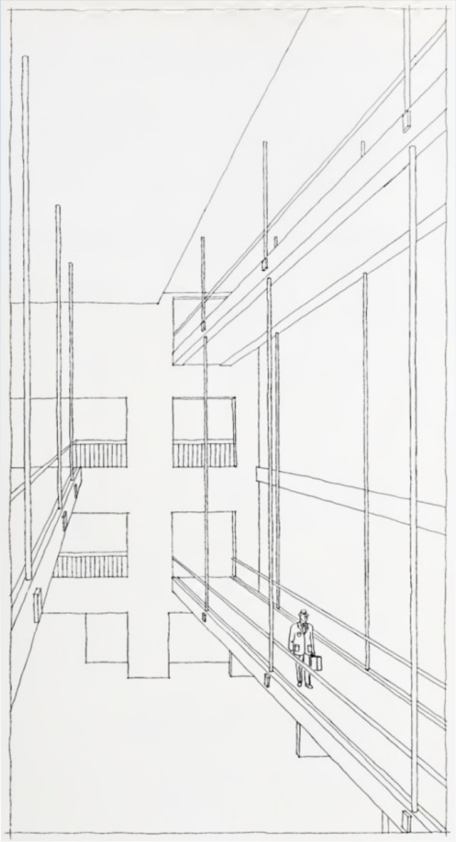
Planos de Taller

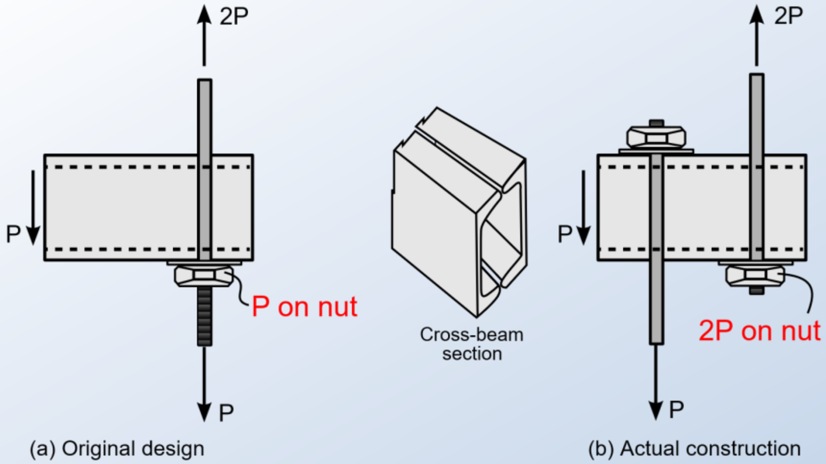
Equi Bridges
Engineering & Management

No hay planos de taller
El taller no entiende el diseño
El taller se desvía del diseño
No revisado por el diseñador
Error no reconocido por el revisor
Presentaciones fragmentadas y descoordinadas
El taller no aplica las revisiones/correcciones
Indicaciones ignoradas por el constructor
etc.

Planos de Taller

Kansas City Hyatt Regency Walkways Collapse, 1981, Kansas City, Missouri, USA

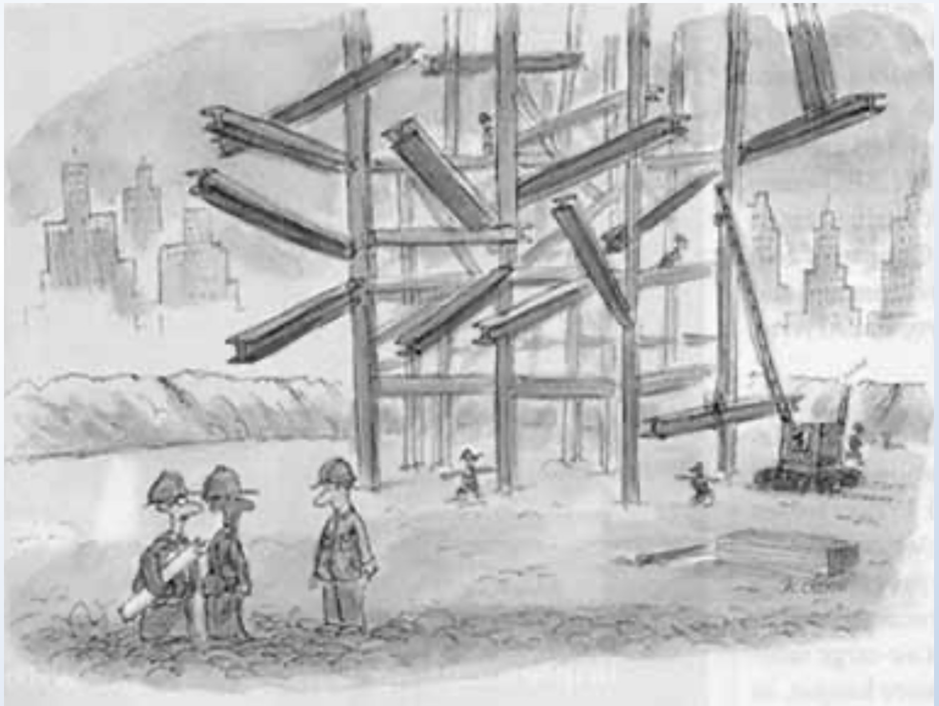


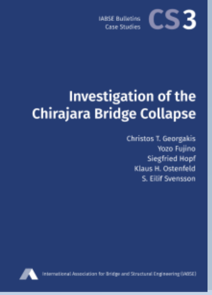


NBS Building Science Series 143, Investigation of the Kansas City Hyatt Regency Walkways Collapse, 1982

Construcción/renovación

Planos inadecuados o ambiguos
Falta de interacción entre el ingeniero y el contratista
Interacción de personas poco cualificadas
El ingeniero no está familiarizado con los detalles del diseño
El contratista no es competente para comprender
Instrucciones del ingeniero, o no son atendidas
Cambios sobre el terreno no aprobados o malinterpretados
Inspecciones de construcción
etc.


"We need to talk."



Puente de Chirajara (Colombia)

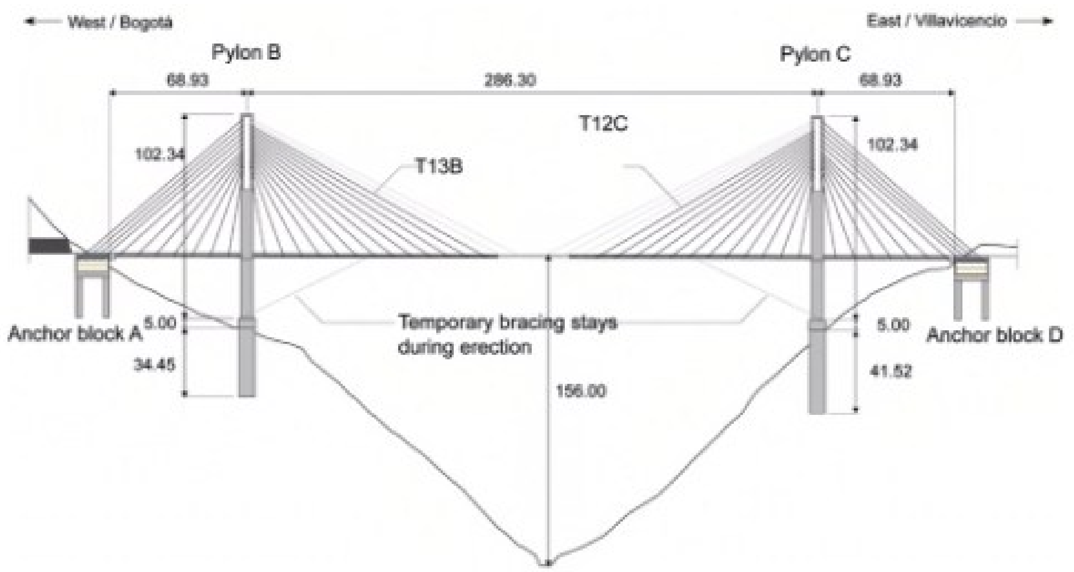


Fig. 1.2 General dimensions of the Chirajara Bridge. Members of the main span (cable + girder) shown in light grey shading had not yet been erected at the time of the collapse of Pylon B

Pylon C, identical to Pylon B, of the cable-stayed Chirajara Bridge

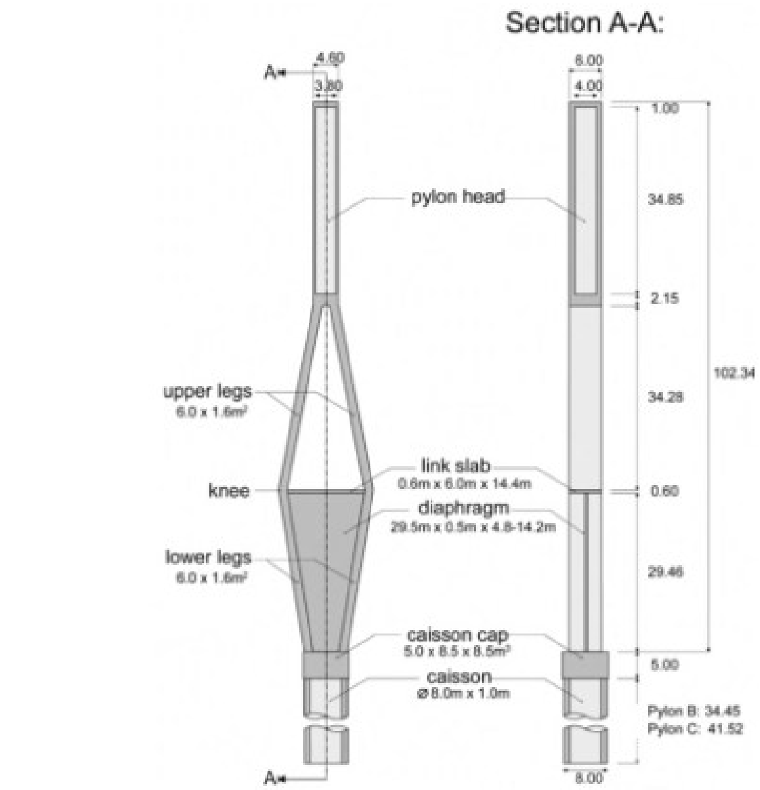


Fig. 1.3 Main dimensions of pylons

Extract from IABSE CS 3 Investigation of the Chirajara Bridge Collapse

Puente de Chirajara (Colombia)

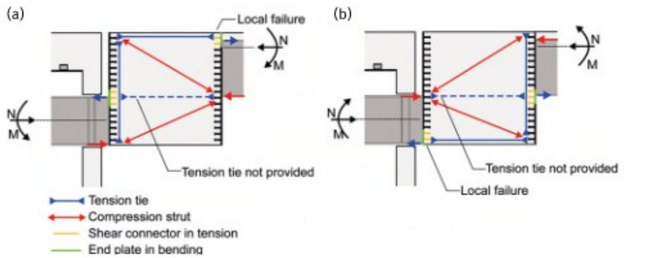


Fig. 2.3 Strut-and-tie model of transition beam
a) Girder exposed to negative moment
b) Girder exposed to positive moment

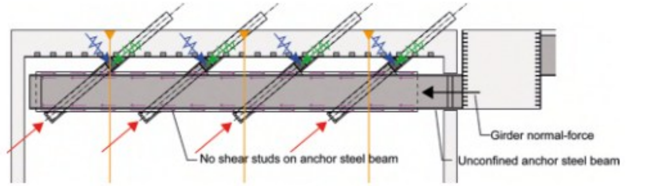


Fig. 2.4 Girder axial force transferred to composite anchor beam purely by bonding as no shear studs were provided

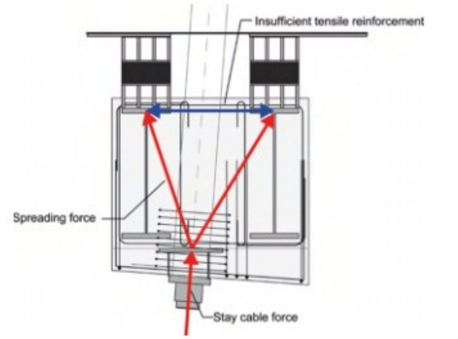


Fig. 2.5 Stay cable anchoring force introducing tensile stresses at top face of the anchor beam due to spreading out compressive forces

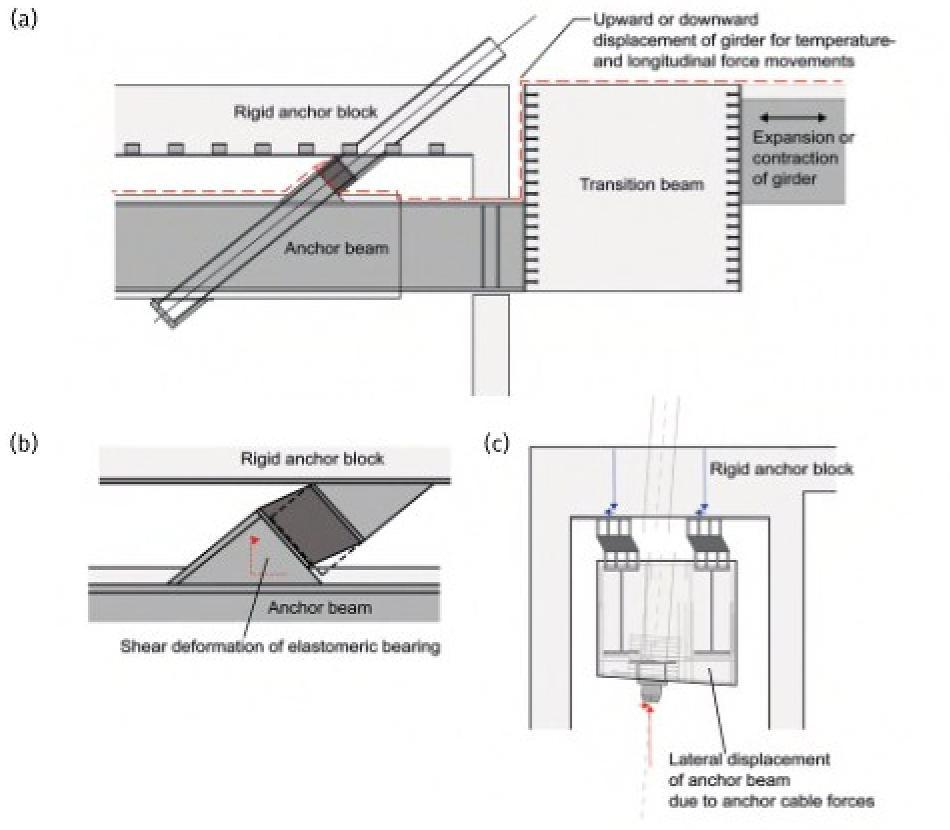


Fig. 2.1 Deformation of elastomeric bearings
a) Upward/downward displacement due to expansion / contraction of girder
b) Detailed displacement of elastomeric bearing
c) Lateral deformation of elastomeric bearings due to lateral anchor cable force

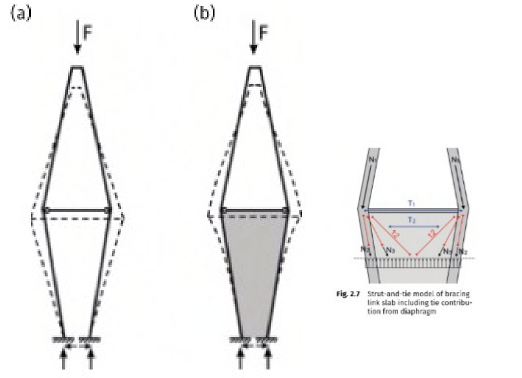


Fig. 2.8 Deformation of pylon with diamond shape configuration for vertical loads
a) Faulty design assumption, assuming linear deformation of pylon legs and diaphragm
b) Actual combined non-linear deformation shape of pylon legs and diaphragm

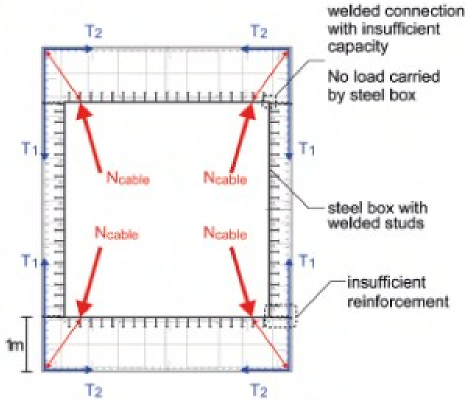


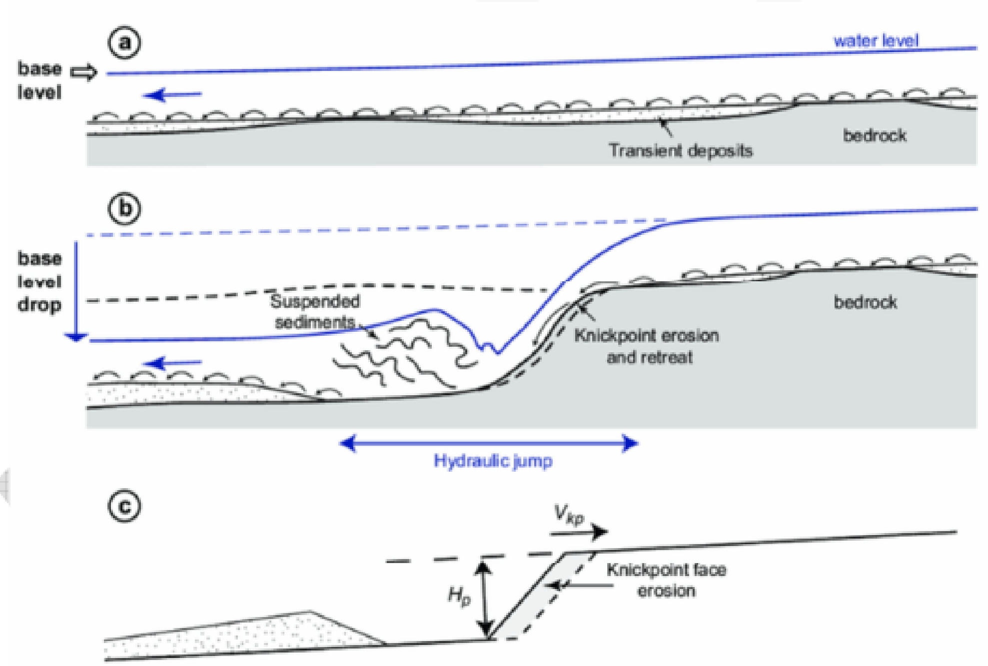
Fig. 2.9 Principal flow of forces due to horizontal components of stay cable forces

Extract from IABSE CS 3 Investigation of the Chirajara Bridge Collapse

Puente de Kamukobe (Republica Democrática del Congo)

Puente de Kamukobe (Republica Democrática del Congo)

Puente de Kamukobe (Republica Democrática del Congo)



Schematic longitudinal section of a river bed before (a) and during (b) the propagation of a knickpoint triggered by relative base-level fall. Blue arrows represent flow direction and black arrows the motion of the bedload. The black and blue dashed lines represent respectively the bedrock and water levels before knickpoint propagation. (c) Idealized representation of a knickpoint characterized by its velocity, V kp , and the depth of associated plunge pool, H p .

Figure 4.9: Extract from scientific paper "Experimental migration of knickpoints: influence of style of base-level fall and bed lithology" J.L. Grimaud, C. Paola, and V. Voller, Earth Surface Dynamics 4, 11-23, 2016;

Equi Bridges
Engineering & Management

Gestión de Activos

Matias Valenzuela

Laurent Rus

12.06.2025

ESCUELA DE INGENIERÍA EN CONSTRUCCIÓN

PONTIFICIA UNIVERSIDAD CATÓLICA DE VALPARAÍSO

IABSE
International Association for Bridge and Structural Engineering


non-linear structural analysis
masonry arch bridges
key performance indicators
machine learning algorithms
fatigue life
degradation models
asset management
probabilistic assessment
concrete bridges
analytical hierarchy process
extreme events
performance indicators
surrogate models
decision-making
bridge management system
bridge
deterioration
human error
performance indicator
indicators
resilience
risk analysis
reliability
durability
performance
quality control
bridges
roadway bridge
bridge failure
performance goal
predictive models
corrosion
bayesian networks
shape memory alloy
risk assessment
key performance indicator
bridge management
life cycle
quality control plan
climate change
strengthening
reinforced concrete
chloride ingress
visual inspection
critical infrastructures
bridge inspection
performance assessment
fragility curves
bridge maintenance
concrete structures
BIBLIOMETRIX

R&D Projects

COST ACTION TU1406 – Quality specifications for roadway bridges, standardization at a European level (*BridgeSpec*)

TU1406
COST ACTION

TEAM

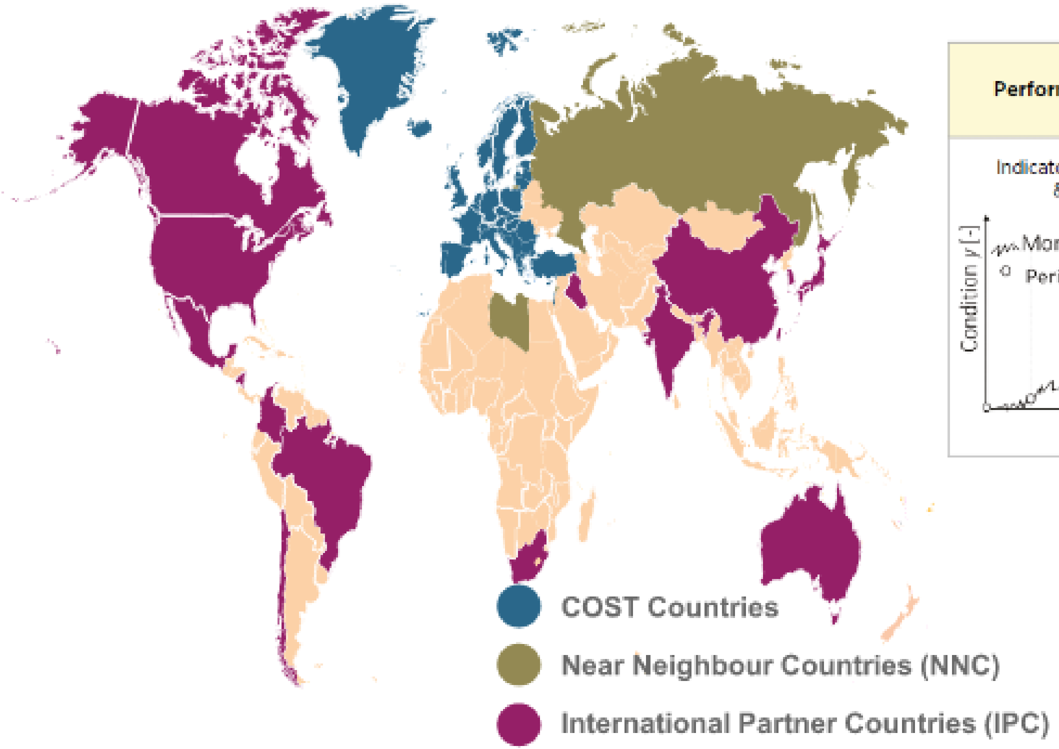
+ 57 participating countries

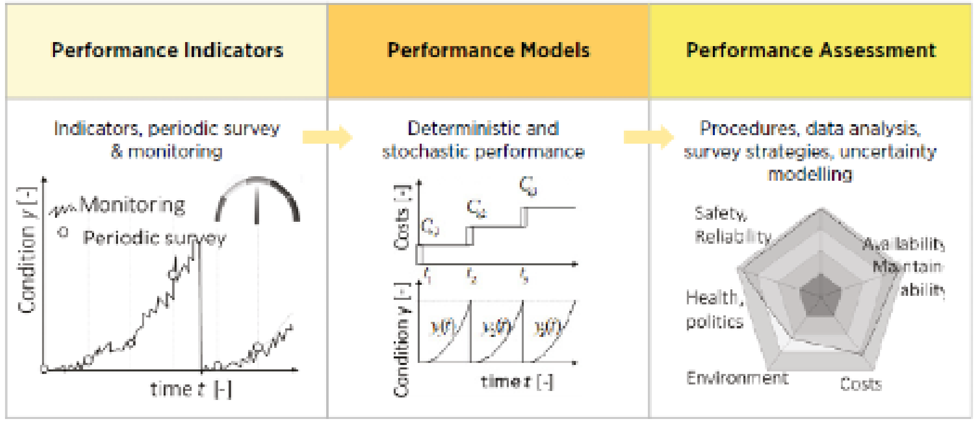
INFO

Financing entity: COST
Project Leader: UMinho
Partners: 38 COST Countries
Start date: 16/04/2015
End date: 15/04/2019
Overall budget: 855.000,00€
UMinho budget: 188.000,00€

DISSEMINATION

Website:
www.tu1406.eu
Journal and conference papers: 34
Technical reports: 4
Books & e-Books: 11
Pedagogical material: 4
PhD Theses: 2
Master Theses: 1





Road bridge management concept

Objectives: The main objective is to develop a guideline for the **establishment of QC plans in roadway bridges**, by integrating the most recent knowledge on performance assessment procedures with the adoption of specific goals.

isise Institute for Sustainability and Innovation in Structural Engineering

RAmCI

Universidade do Minho

R&D Projects

SAFEWAY – GIS-Based infrastructure management system for optimized response to extreme events of terrestrial networks

TEAM

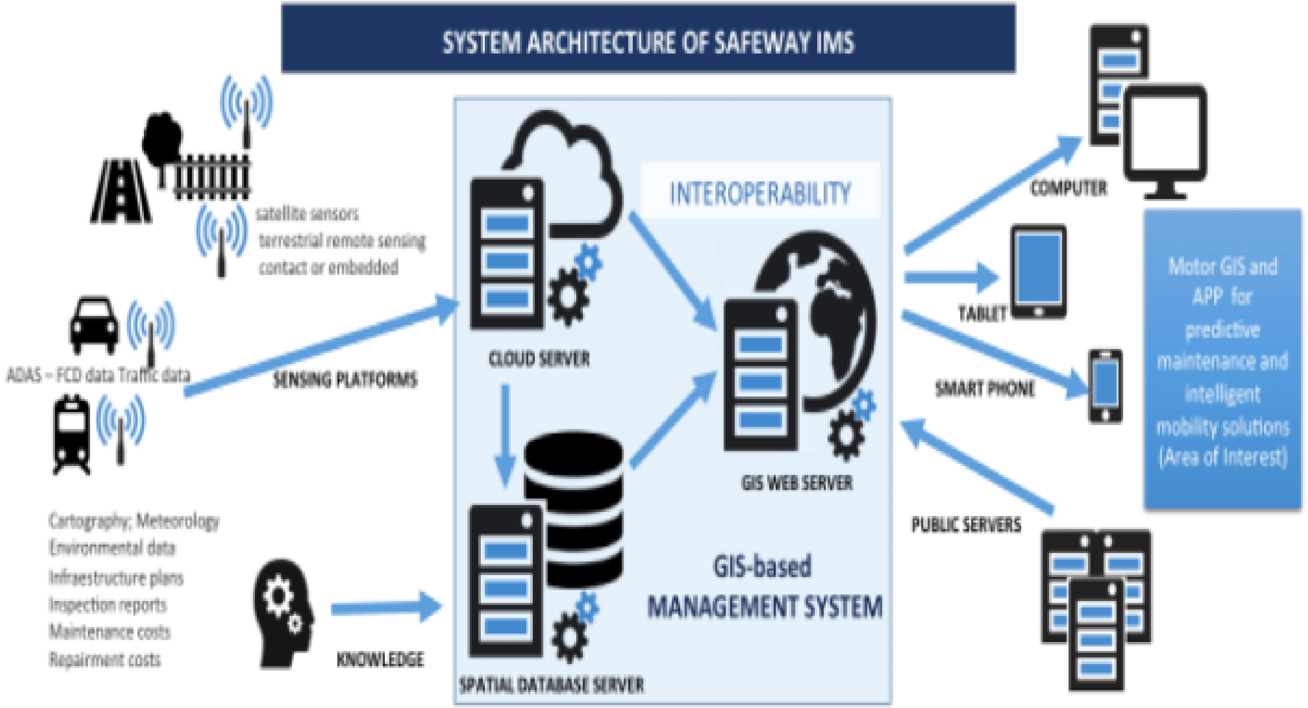
+ 7 PhD students

INFO

Financing entity: H2020
Project Leader: UVigo
Partners: 15
Start date: 01/09/2018
End date: 28/02/2022
Overall budget: 4.860.000,00€
UMinho budget: 370.000,00€

DISSEMINATION

Website: https://www.safeway-project.eu/en
Twitter: @SAFEWAY_EU
Journal papers: 5
Conference papers: 5
Technical Reports: 2
PhD Theses: 1



- *Flooding and land displacement in UK, the Netherlands and Spain*
- *Wildfires in Portugal*
- *Seismic and terrorism impact in Spain.*

Objectives: SAFEWAY's main aim is to **design, validate, and implement holistic methods, strategies, tools,** and technical interventions to significantly increase **the resilience of inland transport infrastructure** by reducing risk vulnerability and strengthening network systems to extreme events.

isise Institute for Sustainability and Innovation in Structural Engineering

RAmCI

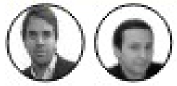
Universidade do Minho

R&D Projects

SIRMA - Strengthening Infrastructure Risk Management in the Atlantic Area

SIRMA

TEAM



+ 1PhD student

INFO

Financing entity: Interreg Atlantic
Project Leader: UMinho
Partners: 10
Start date: 01/04/2019
End date: 30/09/2022
Overall budget: 2.023.994,52 €
UMinho budget: 311.438,64 €

DISSEMINATION

Website: https://www.sirma-project.eu/
Twitter: @SIRMAPROJECT
Journal papers: 7
Conference papers: 13
Reports: 6

The SIRMA infrastructure partners have identified two test beds to be looked at for this project. One test bed is located on a coastal area in Portugal frequently facing tidal issues. The other test bed is in Ireland, where some bridges could have some scour and flooding risks associated with it.

Objectives: SIRMA aims to develop, validate, and implement **a robust framework for the efficient management and mitigation of natural hazards** in terrestrial transportation modes in the Atlantic Area, which considers both road and railway **infrastructure networks (multi-modal).**

isise Institute for Sustainability and Innovation in Structural Engineering

RAmCI

Universidade do Minho

R&D Projects

INFRACRIT – Development of a predict and management systems for Critical Infrastructures

TEAM

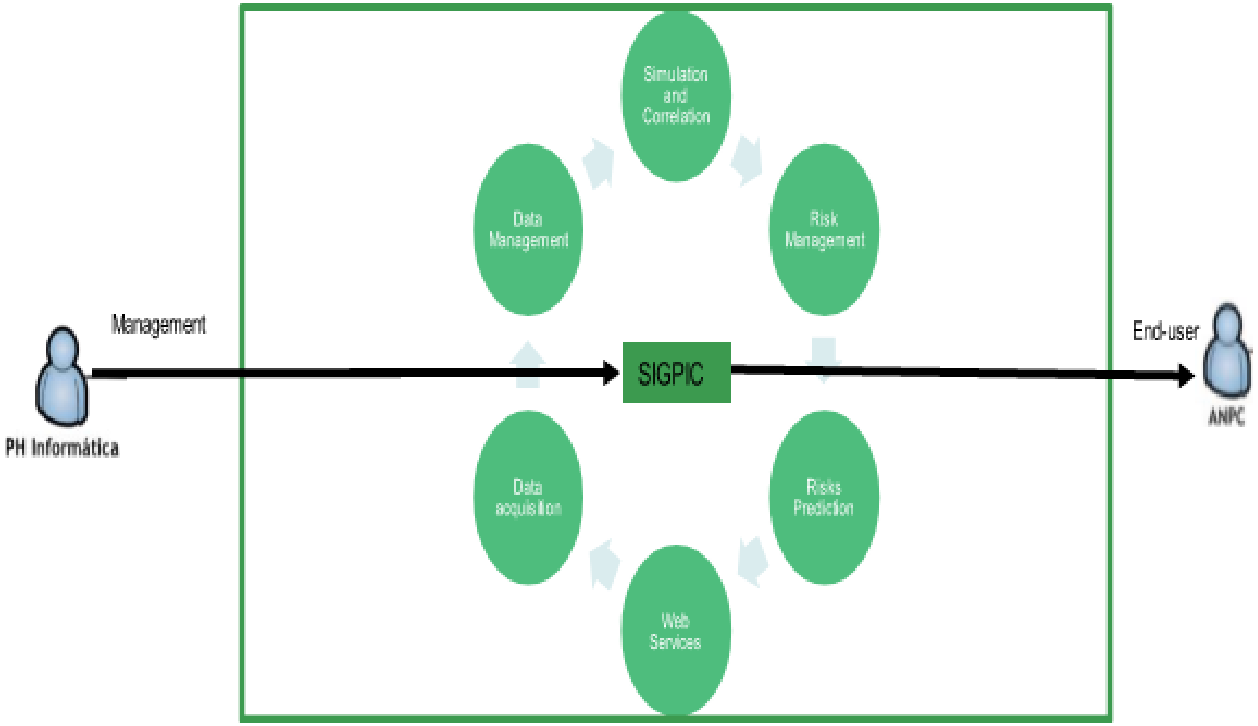
+ 1 PhD student

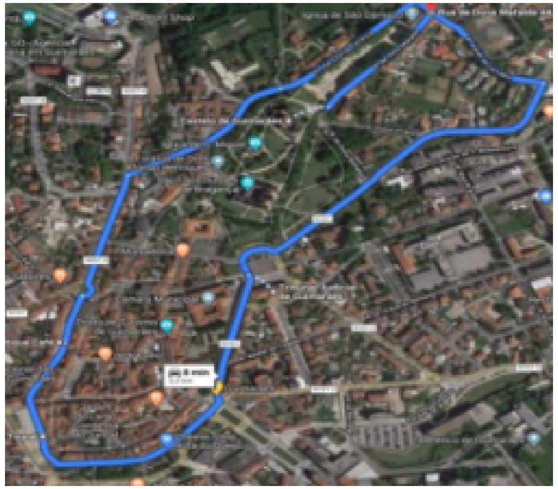
INFO

Financing entity: ANI
Project Leader: PH-Informática
Partners: 3
Start date: 01/09/2019
End date: 30/09/2022
Overall budget: 724.956,00€
UMinho budget: 240.715,48€

DISSEMINATION

Website: www.infracrit.pt
Journal papers: 1
Conference papers: 3
Reports: 2





Development of risk assessment and mapping of two Portuguese vulnerable regions: fire in Guimarães, and flooding in Vila Nova de Gaia.

Objectives: Creation of a **Risk Assessment framework focused on the Urban Critical Infrastructures (UCIs)** vulnerability and their interdependences against multiple natural hazards. Risk Assessment framework will be incorporated into a GIS platform, that will be used as a **support decision making for first responders and UCIs managers**.

isise Institute for Sustainability and Innovation in Structural Engineering

RAmCI

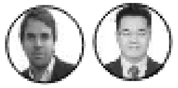
Universidade do Minho

R&D Projects

Cognitive CMMS - Cognitive Computerized Maintenance Management System

Cognitive CMMS

TEAM



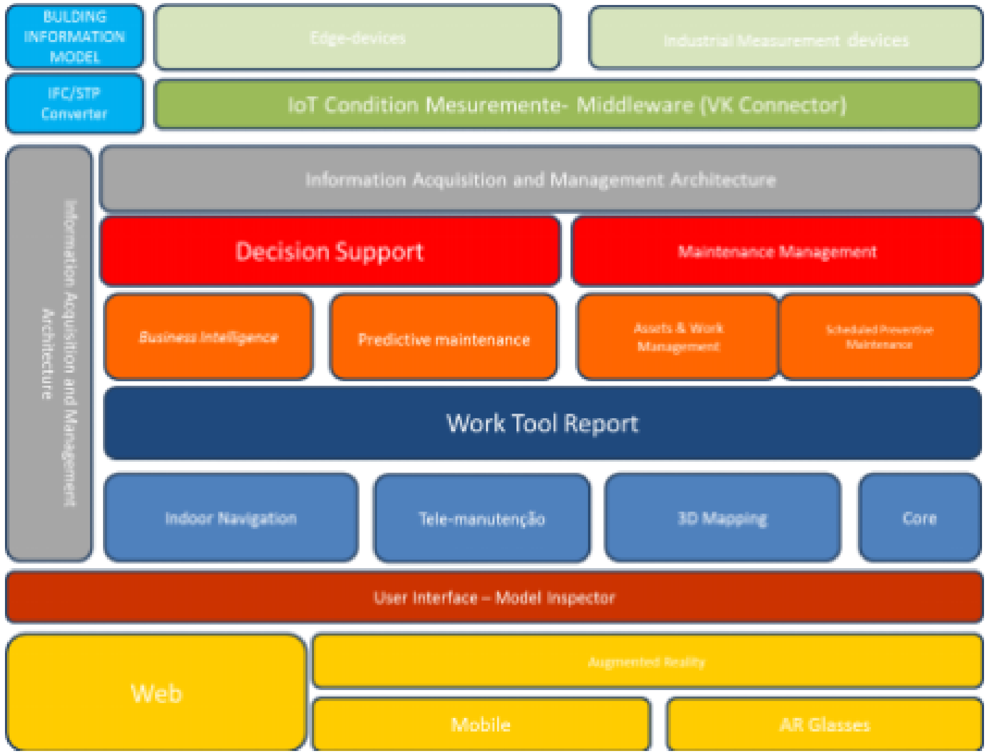
+ 1 PhD student

INFO

Financing entity: ANI
Project Leader: Valuekeep
Partners: 5
Start date: 01/10/2019
End date: 01/06/2022
Overall budget: 1.843.824,13€
UMinho budget: 284.817,00€

DISSEMINATION

Website:
under development
Conference papers: 1



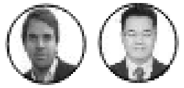
Objectives: Develop a solution that acts in a transversal way in **maintenance management (including maintenance actions)**. A platform that allows an integrated view (BIM 6D) on the management (Analytical Models, Stochastic Models, Neural Networks, and Machine Learning) of faults or anomalies that will allow **optimizing resources and maintenance operations** (via modern optimization techniques), in a context of predictive maintenance.

R&D Projects

GOA.BI – GOA Bridge Management System – Bridge Intelligence

GESTÃO DE OBRAS DE ARTE GOA

TEAM



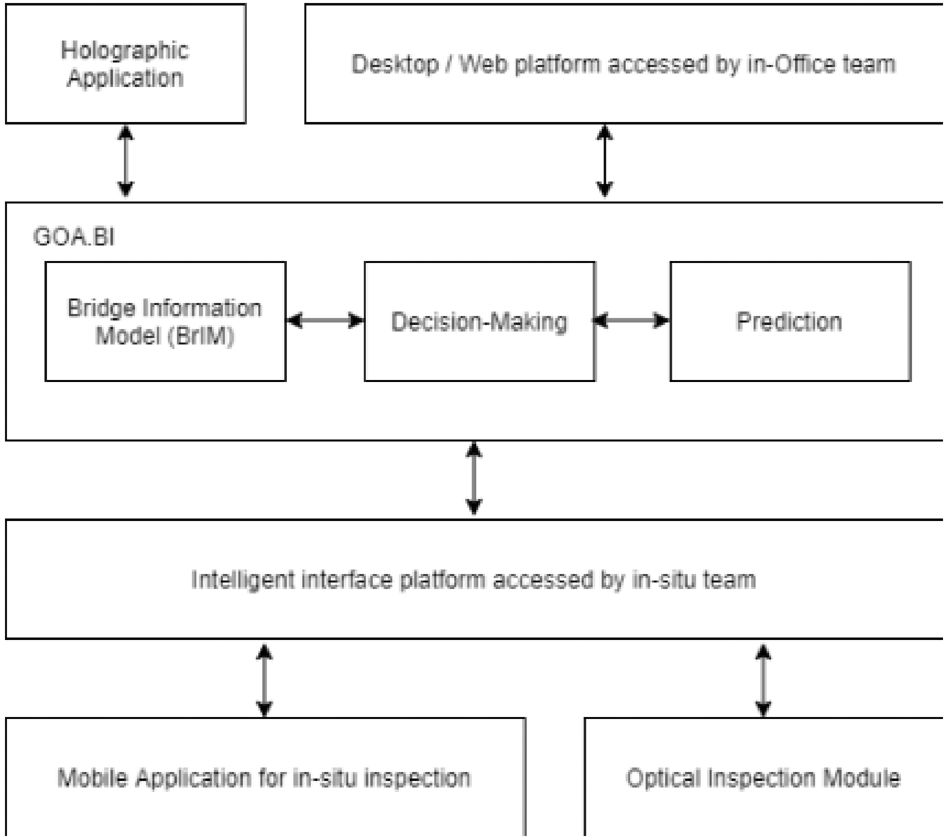
+ 1 PhD student

INFO

Financing entity: ANI
Project Leader: Betar
Partners: 3
Start date: 01/01/2021
End date: 30/06/2023
Overall budget: 1.144.733,71€
UMinho budget: 197.917,70€

DISSEMINATION

Website:
Under development
Conference papers: 5
Reports: 2



Objectives: Development of **a new generation BMS with digital features such as a BIM-based database**, mobile and automated inspection tools, and mixed reality tools to support the maintenance process, involving the analysis and visualization of the information existing in the BMS.

isise Institute for Sustainability and Innovation in Structural Engineering

RAmCI

Universidade do Minho

R&D Projects

CÂMARA MUNICIPAL VIANA DO CASTELO

Provision of Services for a Decision Support System for the Viana do Castelo Municipality Infrastructures

TEAM

+ 4PhD & 1Msc inspection team

INFO

Financing entity: Viana do Castelo Municipality
Start date: 22/05/2022
End date: 30/03/2024
Overall budget: 86.850€
UMinho budget: 86.850€

DISSEMINATION

Journal papers: 1
Reports: 1

I. Pre-inspection	II. Inspection	III. Post Inspection	Inspection report & Maintenance plans
Inventory	Damage registration	Condition state per component	
Inspection preparation		Global condition state	
		Recommendations & alerts	

(Source: sigcmvc.maps.arcgis.com/)

Objectives: Development of a framework and a tool for **supporting the Municipality of Viana do Castelo** in the **inspection and the decision-making process of pedestrian, roadway, and railway Infrastructures under their jurisdiction**, by using inspection forms and predictive modeling in a database to be incorporated into the SIG platform of the Municipality.

isise Institute for Sustainability and Innovation in Structural Engineering

RAmCI

Universidade do Minho

R&D Projects

NBSINFRA - CityNature-Based Solutions Integration to Local Urban Infrastructure Protection for a Climate Resilient Society

NBSINFRA

TEAM

+ 1 PhD student

INFO

Financing entity: Horizon Europe
Project Leader: Uminho
Partners: 18
Start date: 01/09/2023
End date: 31/08/2026
Overall budget: 4.810.585,55 €
UMinho budget: 386.597,37 €

DISSEMINATION

Website:
under development

Objectives: NBSINFRA supports the enhancement of the local urban critical infrastructures **protection against natural and manmade hazards through the Nature-based solutions (NBS)** co-design and co-creation for a climate change resilient society. To achieve those goals, NBSINFRA will establish five (5) representative European regions with an equal number of “City Labs”.

isise Institute for Sustainability and Innovation in Structural Engineering

RAmCI

Universidade do Minho

BIM / BMS

Matias Valenzuela
Laurent Rus

12.06.2025

Equi Bridges
Engineering & Management

ESCUELA DE INGENIERÍA EN CONSTRUCCIÓN
PONTIFICIA UNIVERSIDAD CATÓLICA DE VALPARAÍSO

IABSE
International Association for Bridge and Structural Engineering

Puente Chirre

Puente Chirre

Puente Chirre

Puente Huacamalal

Puente Huacamalal

Maintenance Strategies

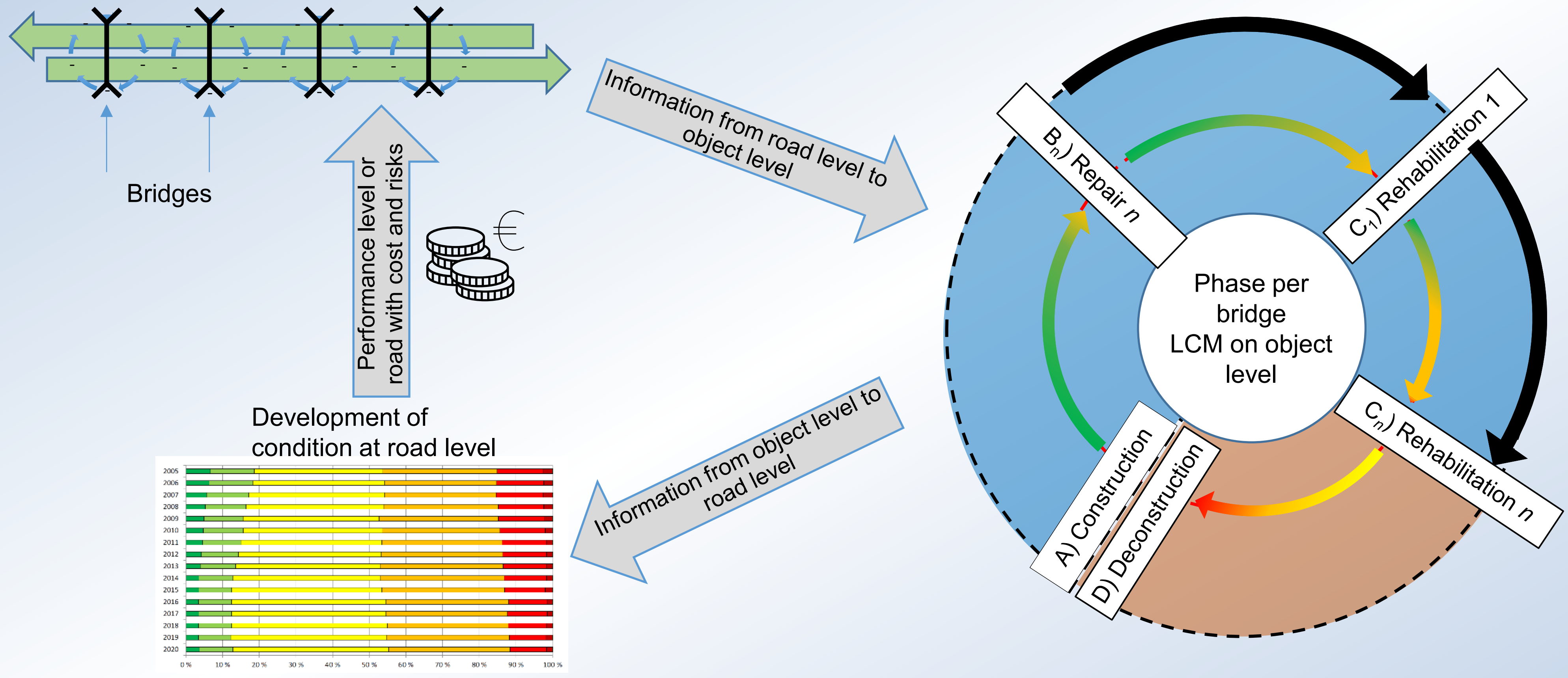
Basic strategies

- Preventive maintenance
- Condition-based maintenance
- Controlled deterioration

Aims

- Ensuring availability of roads
- Predict conditions
- Elaboration of budget for maintenance

Bridge Asset Management



Development of condition
for each bridge with damage mechanisms and
threshold condition
+ measure
+ cost

Use
+ structural and condition evaluation
+ monitoring
Evaluation of remaining service life until B, C or D

1st Use Phase

2nd Use Phase

Maintenance Strategies

Equi Bridges
Engineering & Management

Basic strategies

- Preventive maintenance
- Condition-based maintenance
- Controlled deterioration

Aims

- Ensuring availability of roads
- Predict conditions
- Elaboration of budget for maintenance

Preventive Maintenance

Avoid damages in early state

- Control bridge drainage
- Hydrophobic painting of relevant structural elements
- Replacement of water proofing before leakage and maintain pavement joints
- Replacement of concrete cover before initiation of reinforcement corrosion
- Replacement of damaged cement joints in stone bridges
- Eliminate the grow of plants on the structure

Condition based maintenance

Specific condition state starts project

- Projects triggered from inspection results
- For single structures 10 years after State 3
- Planification with constant number of bridges or budget per year
- Ensure an intervention free period of approx. 40 years after the rehabilitation

Controlled deterioration

Use until the end of life

- Postpone replacement
- Prepare the projects and aproval
- Allow for deterioration
- Monitor the condition
- Make sure that no emergency measures are required!

Rolling wave maintenance

Iterative process

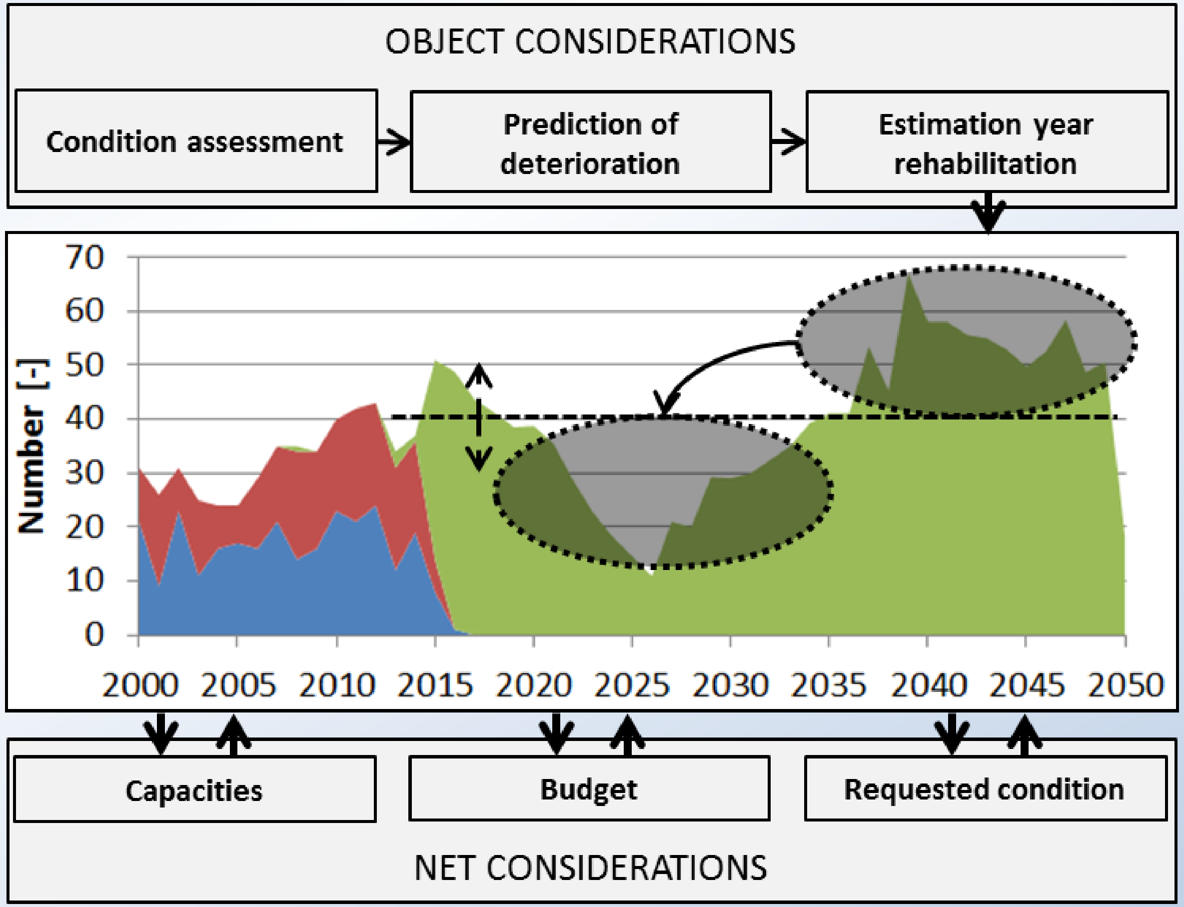
Object level considerations

- Condition assessment
- Prediction of deterioration
- Estimate of yearly measures

Net level considerations

- Required condition
- Financial ressources
- Human ressources

Aim for stable conditions



K. Schellenberg et al.: Defining a Bridge Maintenance Strategy – Some Practical Constraints, in: Challenges in Design and Construction of an Innovative and Sustainable Built Environment, 2016, S. 1477–1484.

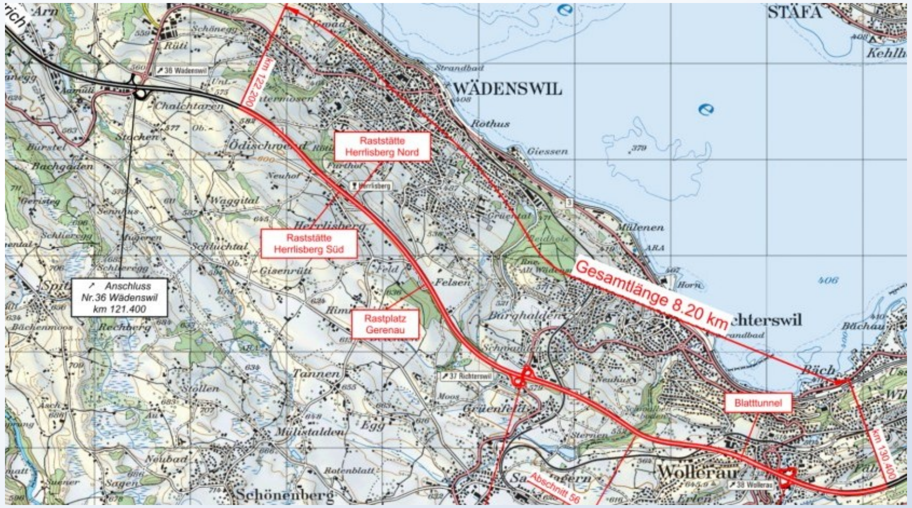
Maintenance Strategies

Combination of strategies

- Improvement of road system
  - Pavement
  - Widening of roads
  - Increase loading capacities
  - New roads due to additional river crossings
- Decentralization of measures
- Standardisation of solutions

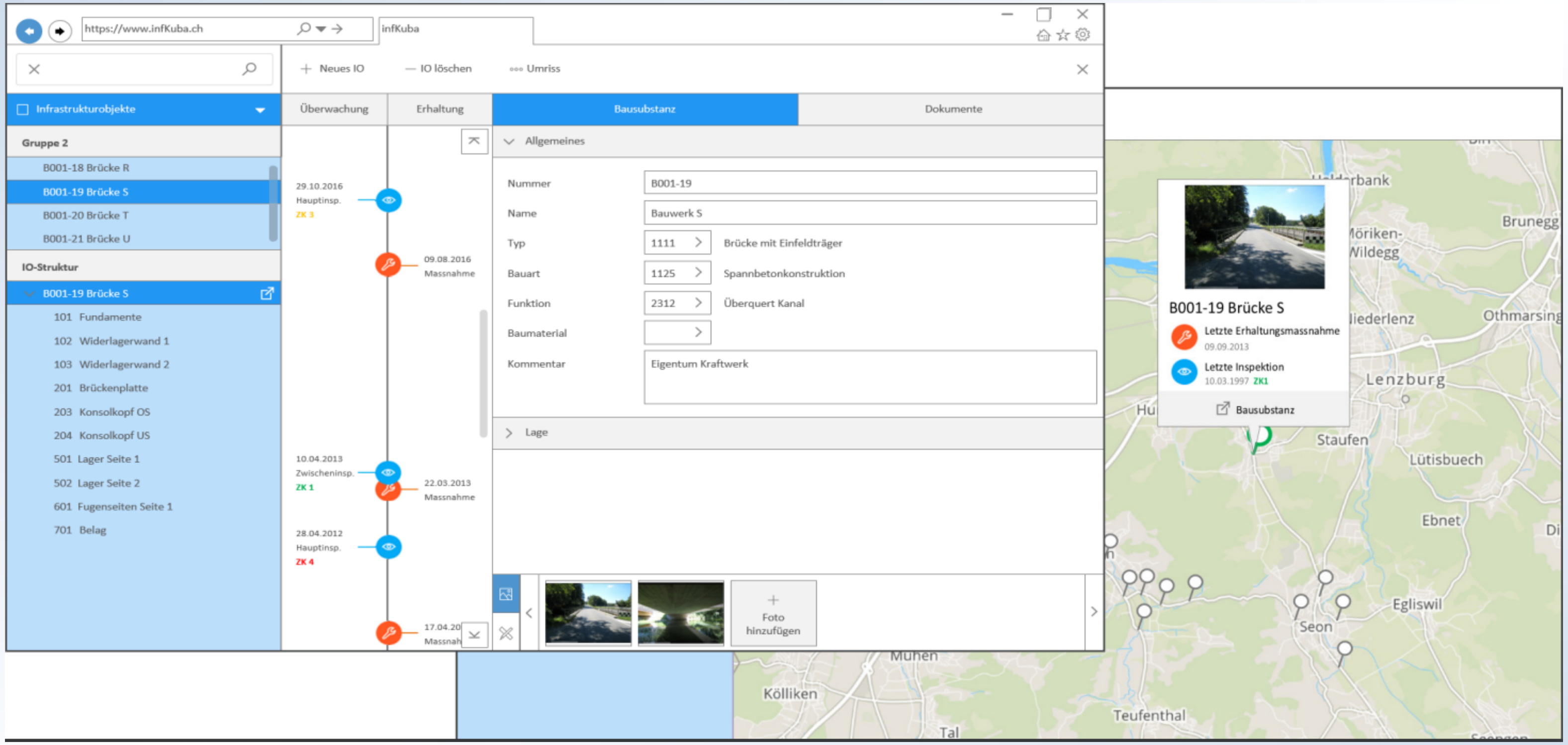
Optimisation on net level

- Reduce cost
- Reduce risk
- Maximize availability



Bridge Management Systems

- Latest BMS Infkuba introduced by approx. 50% of cantons



[BMS InfKuba, UnitSolutions/IMC]

Reduction of maintenance cost

Reduce the lifecycle cost of the infrastructure

- Cover long term needs (avoid lost investments)
- Careful planning with elaborated basics of design
- Increase service life
- Ensure quality of construction
- Repair damages before rehabilitation costs increase unproportional
- Reduce emergency measures by controlling conditions
- Build groups with repetitive work (campaigns)
- Say no to corruption

What is expected from BIM

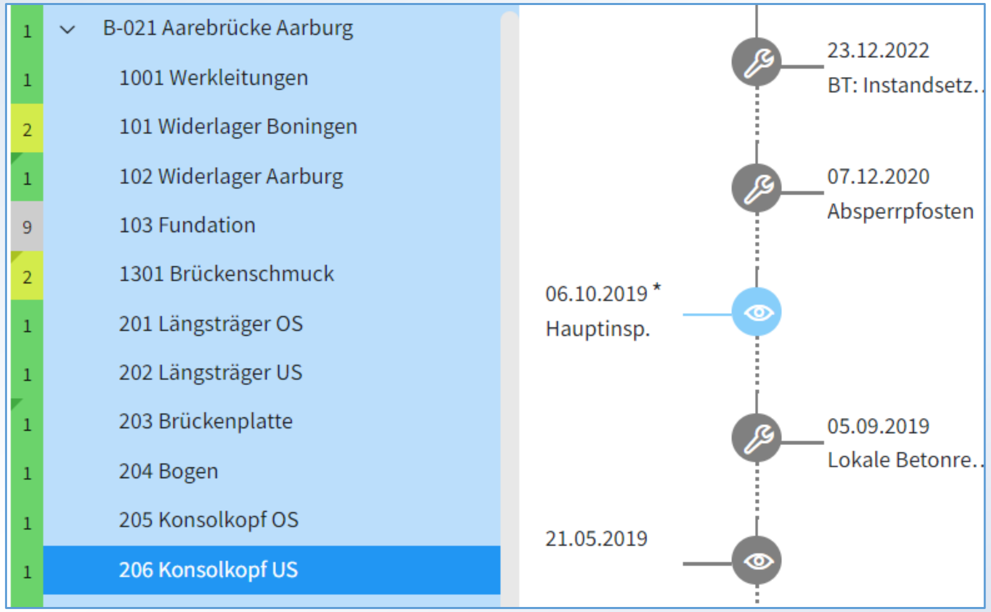
- Increase the profitability of the business

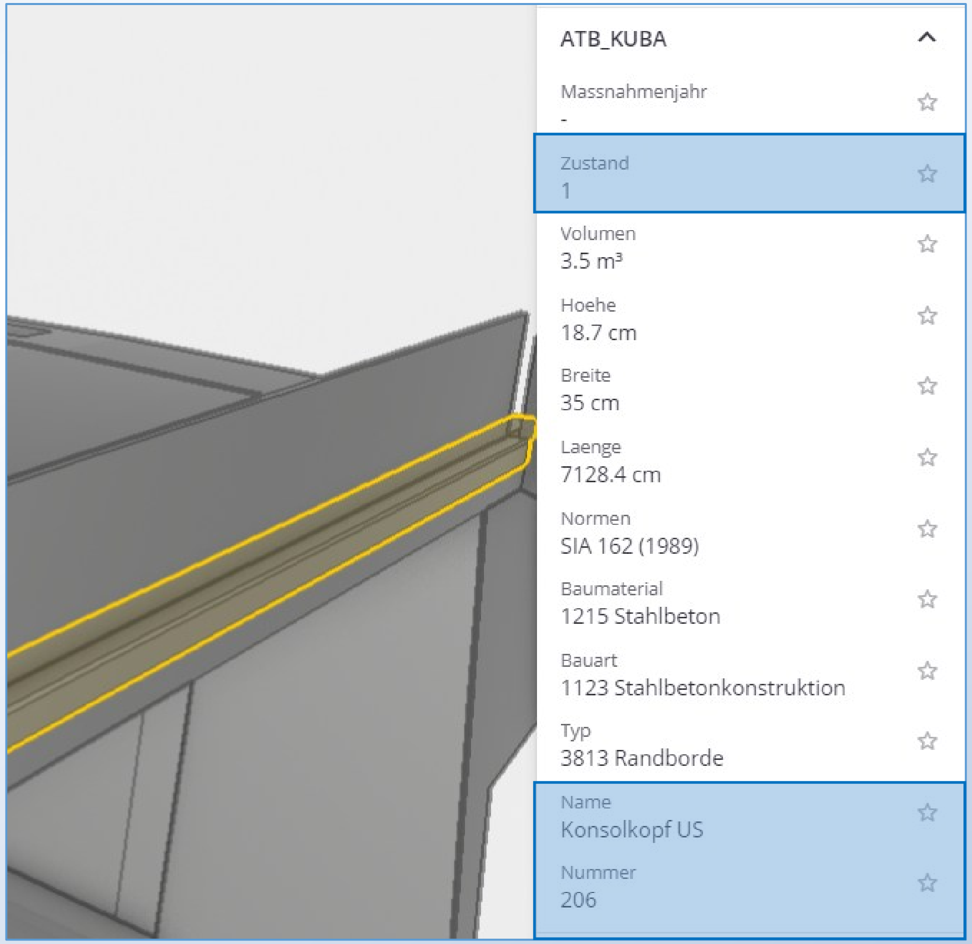
- More efficiency in projects

- Increase productivity of the team

Methodology

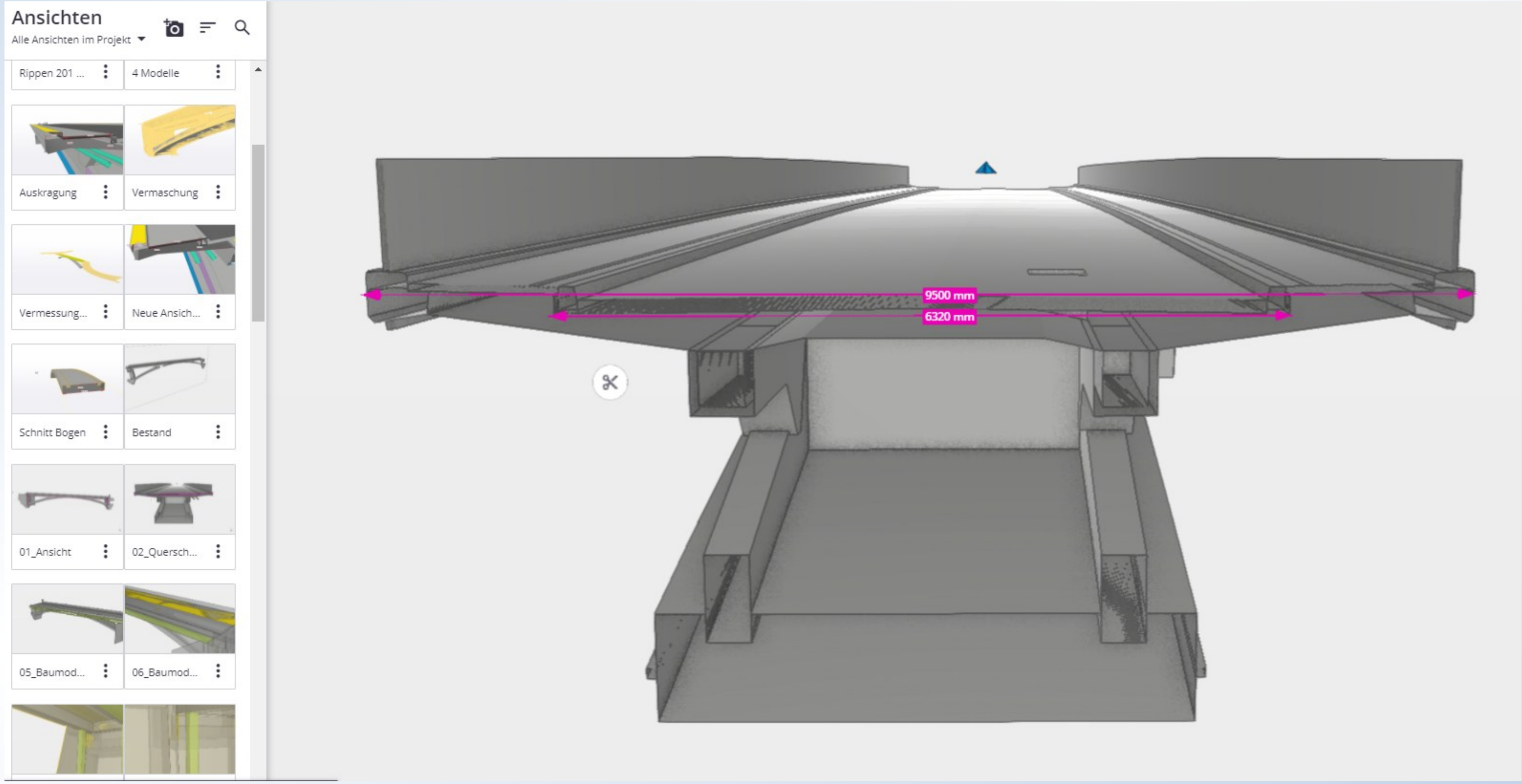
- BIM Models for 3D visualization
  - Information: not all but necessary
  - Linked to management system (e.g. InfKuba)





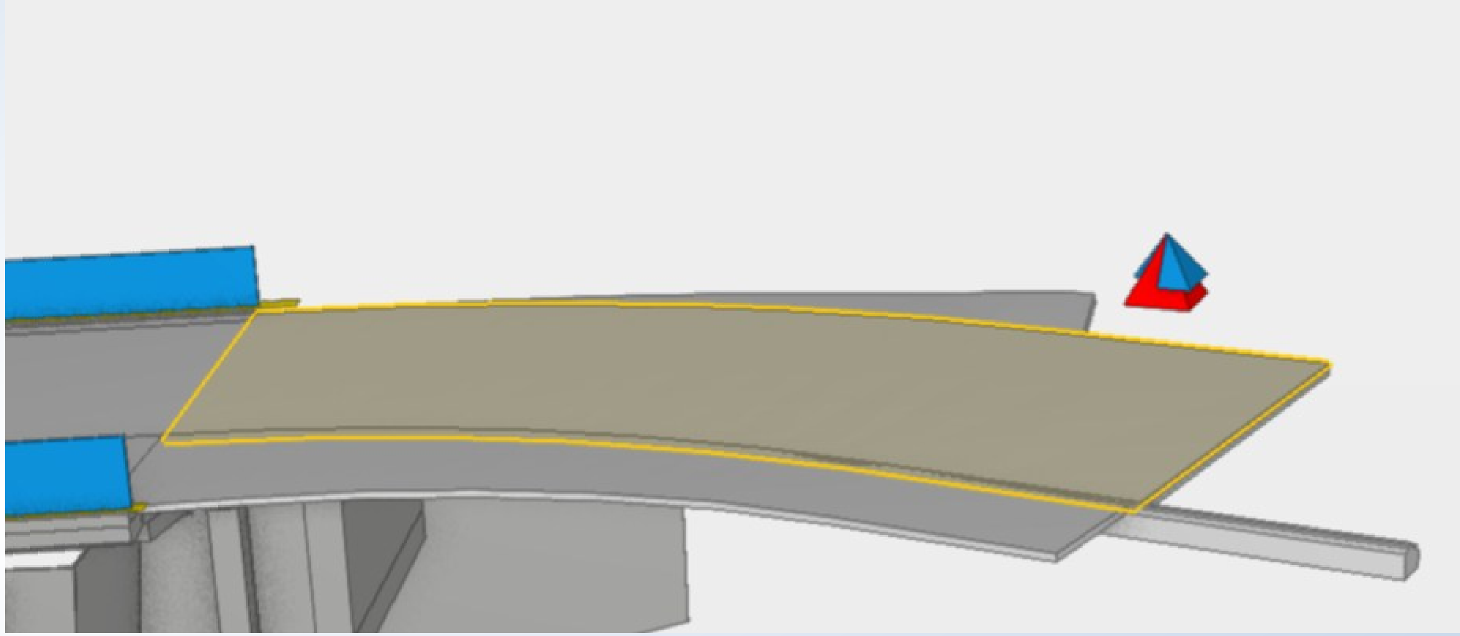
Methodology

- Predefined views



Methodology

- Geometry controls
  - Using GPS point list (pyramid points)
  - Deviations are reported immediately in the model

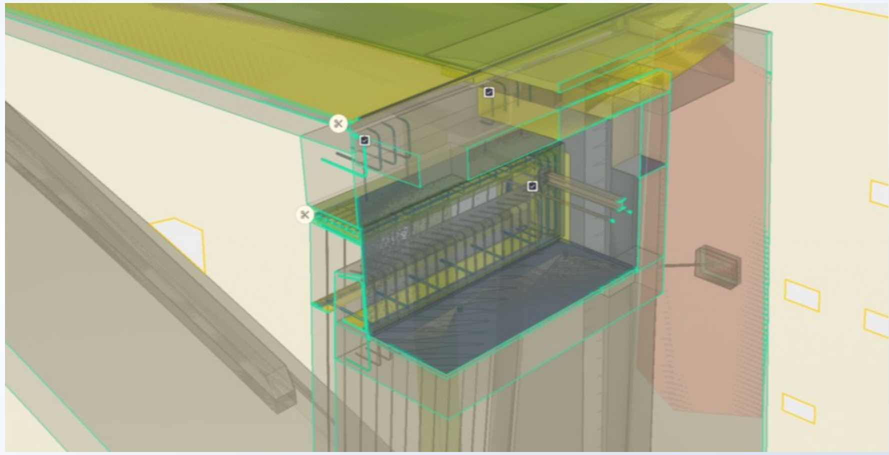


Methodology

- Automatically generated information:
  - Reinforcement list
  - Bill of quantities
- Submodels for information exchange (e.g. formwork)
- Construction program included as a property
- Inspection and control plan
  - All elements defined as “pending” until finished

Maillartbrücke Aarburg

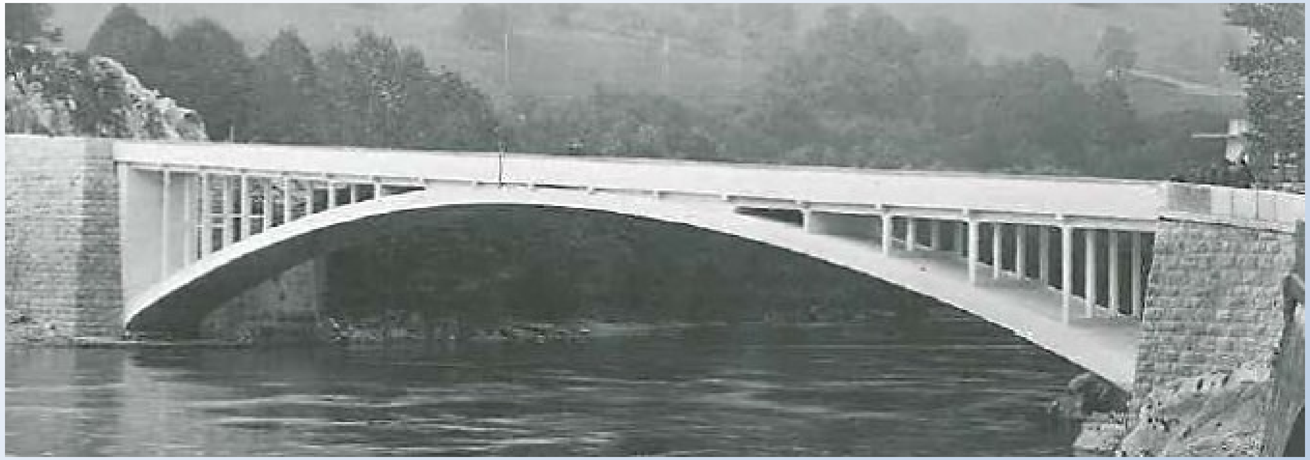
- Rehabilitation of bridge deck
- Strengthening by UHPFRC
- First BIM project for rehabilitation incl. BIM-to-Field
- BIM model compatible with bridge asset management database BMS
- New drainage system in curb
- Assessment 2021
- Execution 2022



History

- Suspension bridge 1837
- Maillart bridge 1912
- Replacement of deck 1969
- Rehabilitation 1996

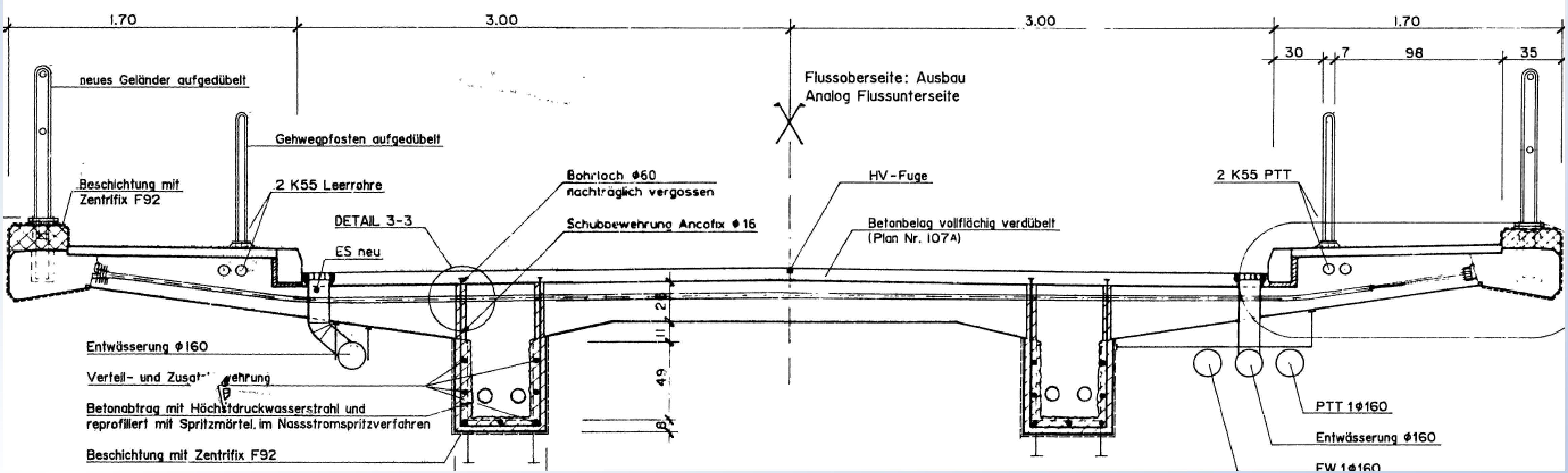
1996



1912

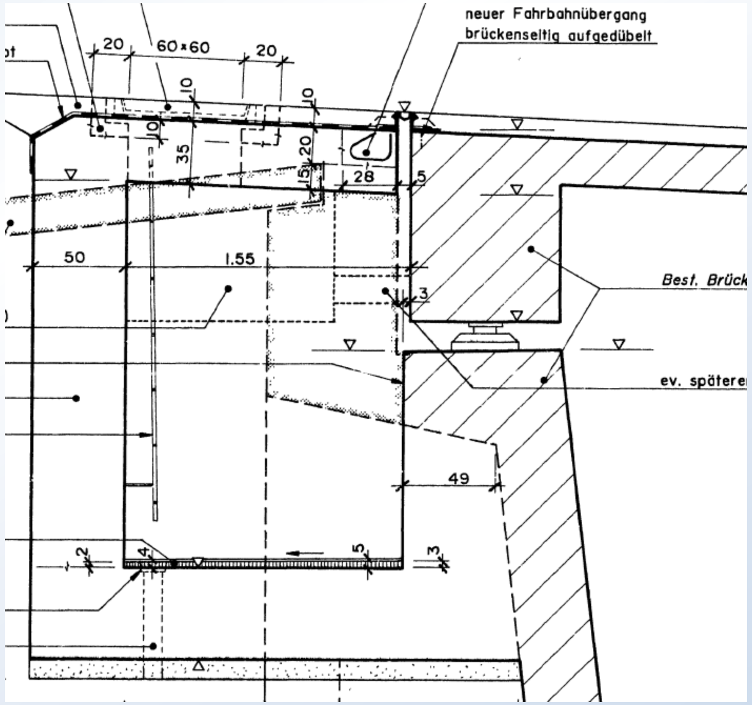
Initial Situation

- Missing waterproofing, transversal prestressing, chlorides
- Lack of structural resistance on sidewalks (pedestrians only)



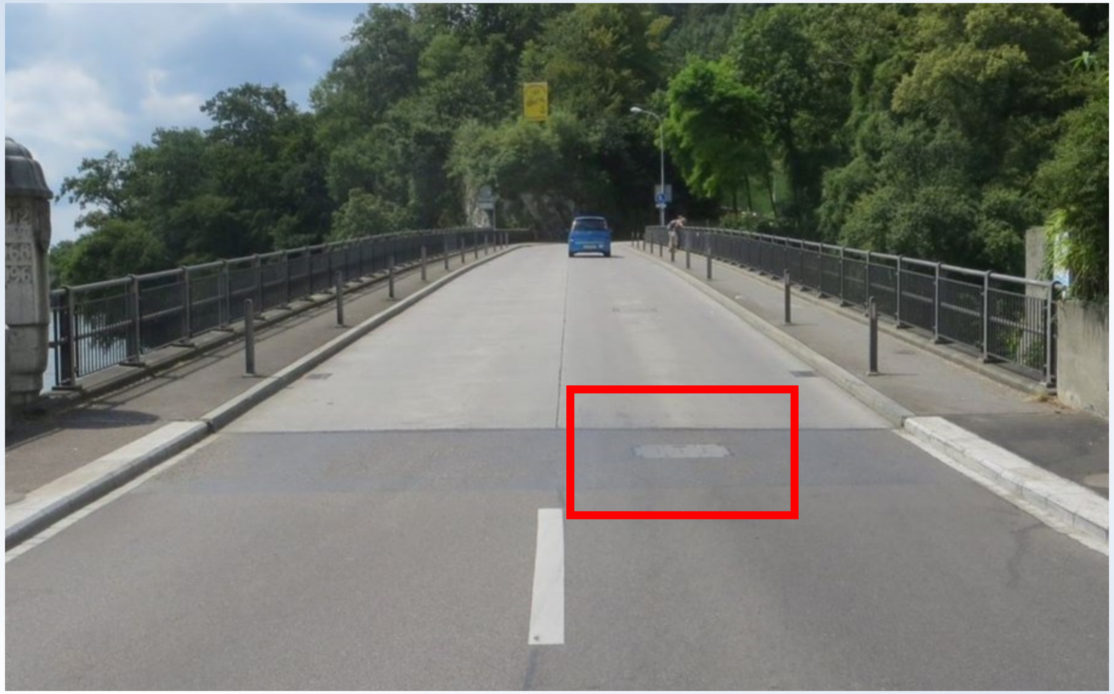
Condition State

- Leaking expansion joints
- Corrosion in abutment chambers



Access to Abutments

- From the road
- Disturbing traffic



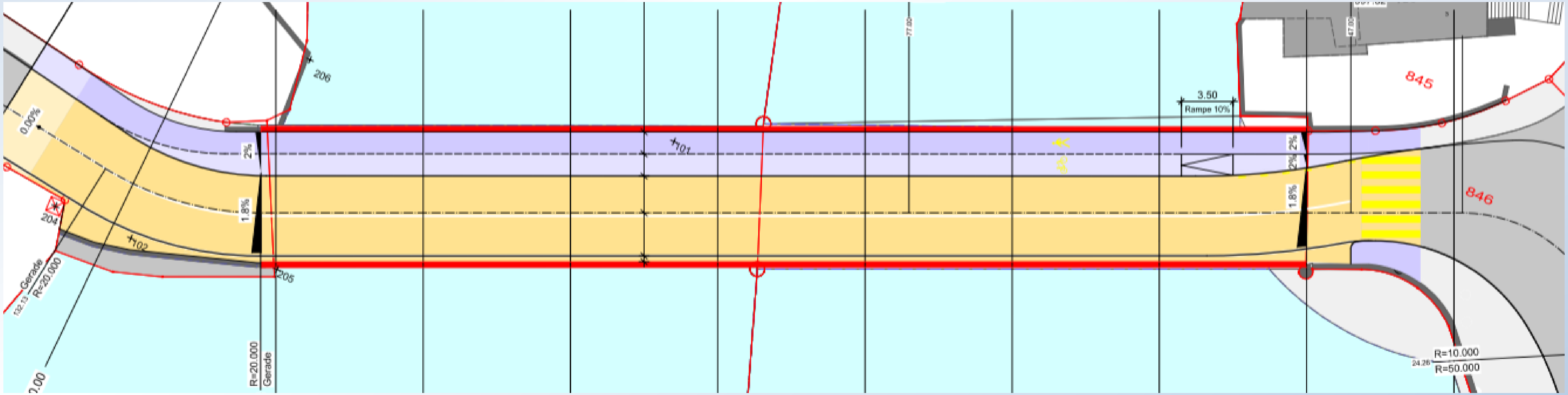
Special Conditions

Equi Bridges
Engineering & Management

- High amount of heavy traffic
- Narrow roadway, difficult to cross

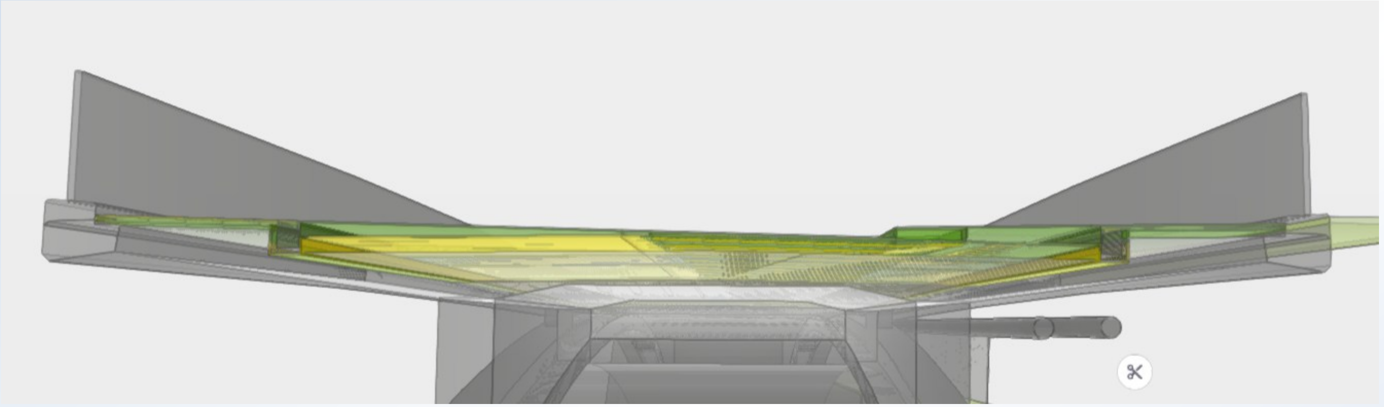
Project Scope

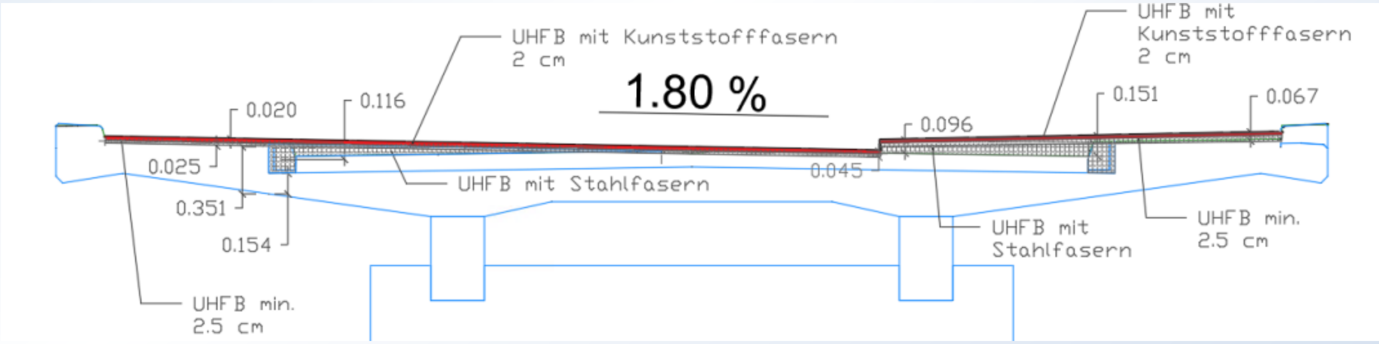
- Waterproofing and strengthening of the deck
- Reconstruction of bridge ends
- Combined cycle and pedestrian lane

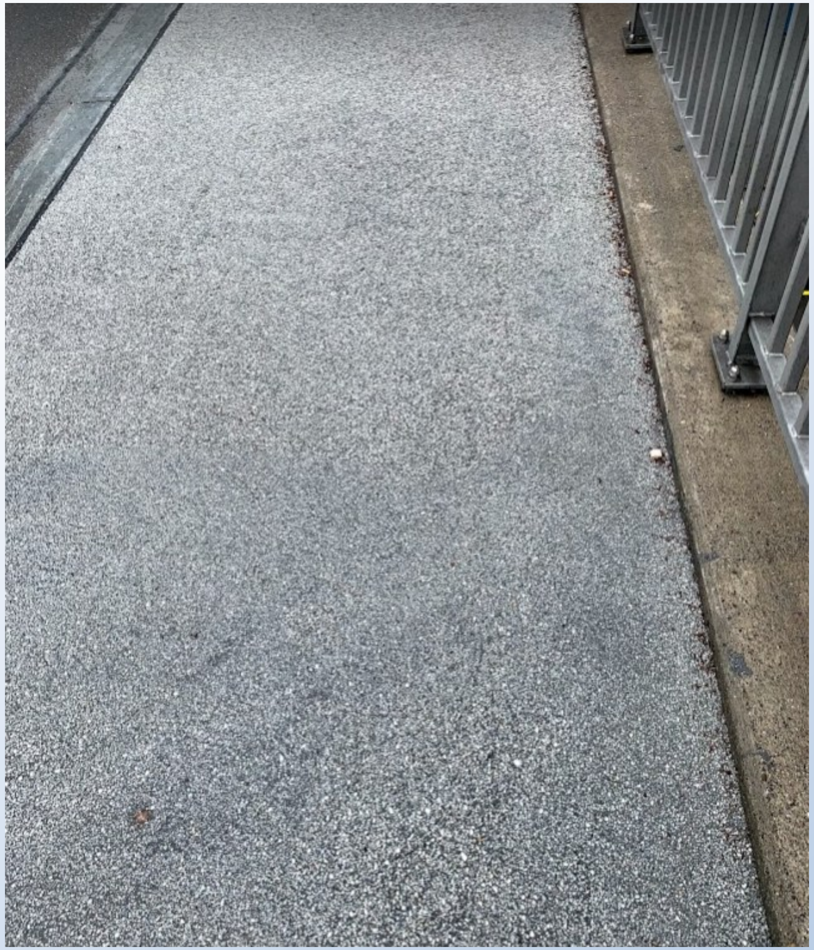


Deck Rehabilitation

- Waterproofing and strengthening by UHPC layer

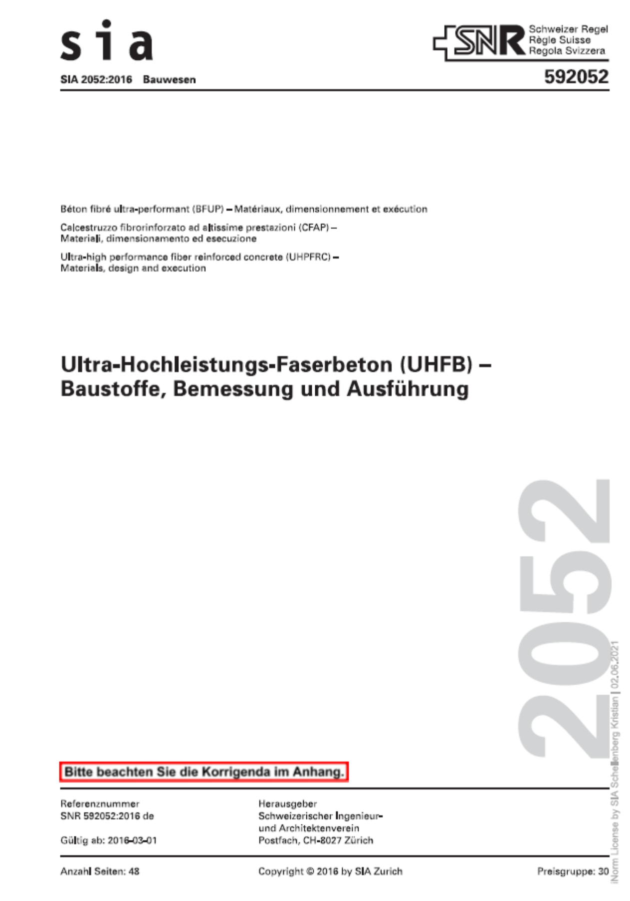






UHPC

- Cement: matrix with ~3% fibres
- Strength: 200 MPa (compressive) and 15 MPa (tensile)
- Material: durable (high density, low porosity)
- Water: can be used as a waterproofing layer


sia

SIA 2052:2016 Bauwesen

SNR Schweizer Regel
Règle Suisse
Regola Svizzera

592052

Béton fibré ultra-performant (BFUP) – Matériaux, dimensionnement et exécution

Calcestruzzo fibrorinforzato ad altissime prestazioni (CFAP) – Materiali, dimensionamento ed esecuzione

Ultra-high performance fiber reinforced concrete (UHPFRC) – Materials, design and execution

Ultra-Hochleistungs-Faserbeton (UHFB) – Baustoffe, Bemessung und Ausführung

2052

Bitte beachten Sie die Korrigenda im Anhang.

Referenznummer
SNR 592052:2016 de

Gültig ab: 2016-03-01

Herausgeber
Schweizerischer Ingenieur- und Architektenverein
Postfach, CH-8027 Zürich

Anzahl Seiten: 48

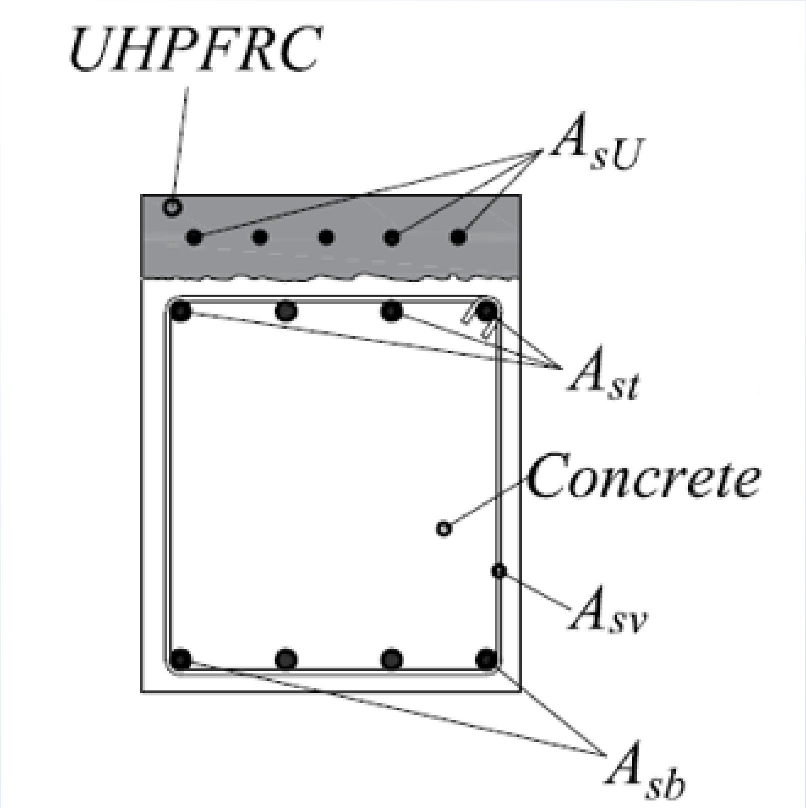
Copyright © 2016 by SIA Zurich

Preisgruppe: 30

iNorm License by SIA Schellenberg Kristian | 02.06.2021

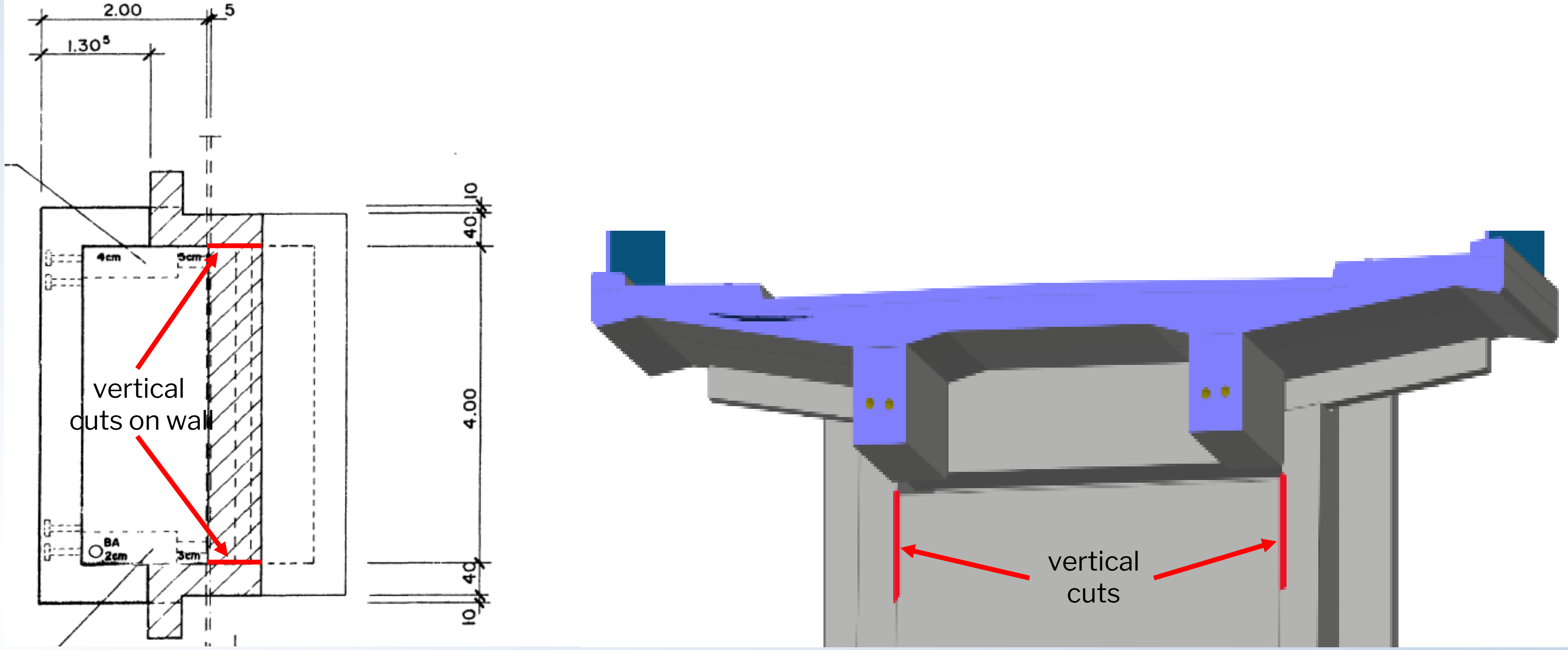
UHPC Properties

- Application
  - Removal of ~2 cm of existing concrete surface
  - Moistening of the surface
  - Placement of reinforcement
  - Pouring of UHPC



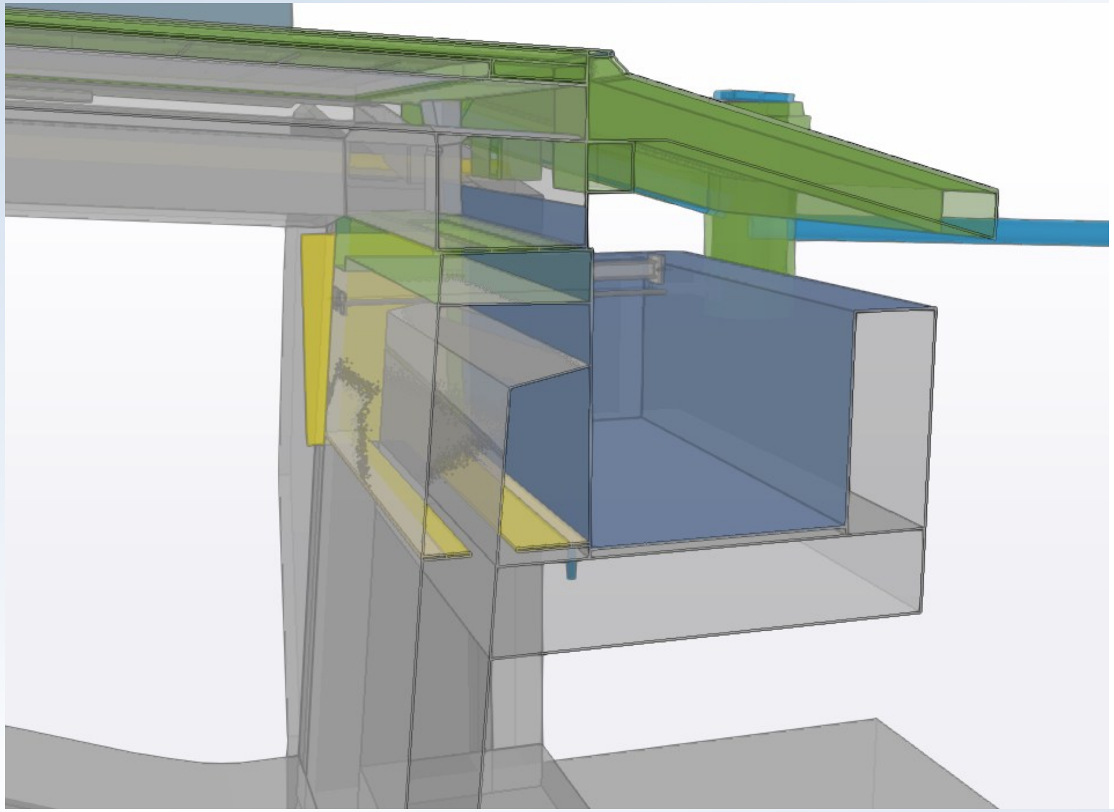
Adjustments of Abutment

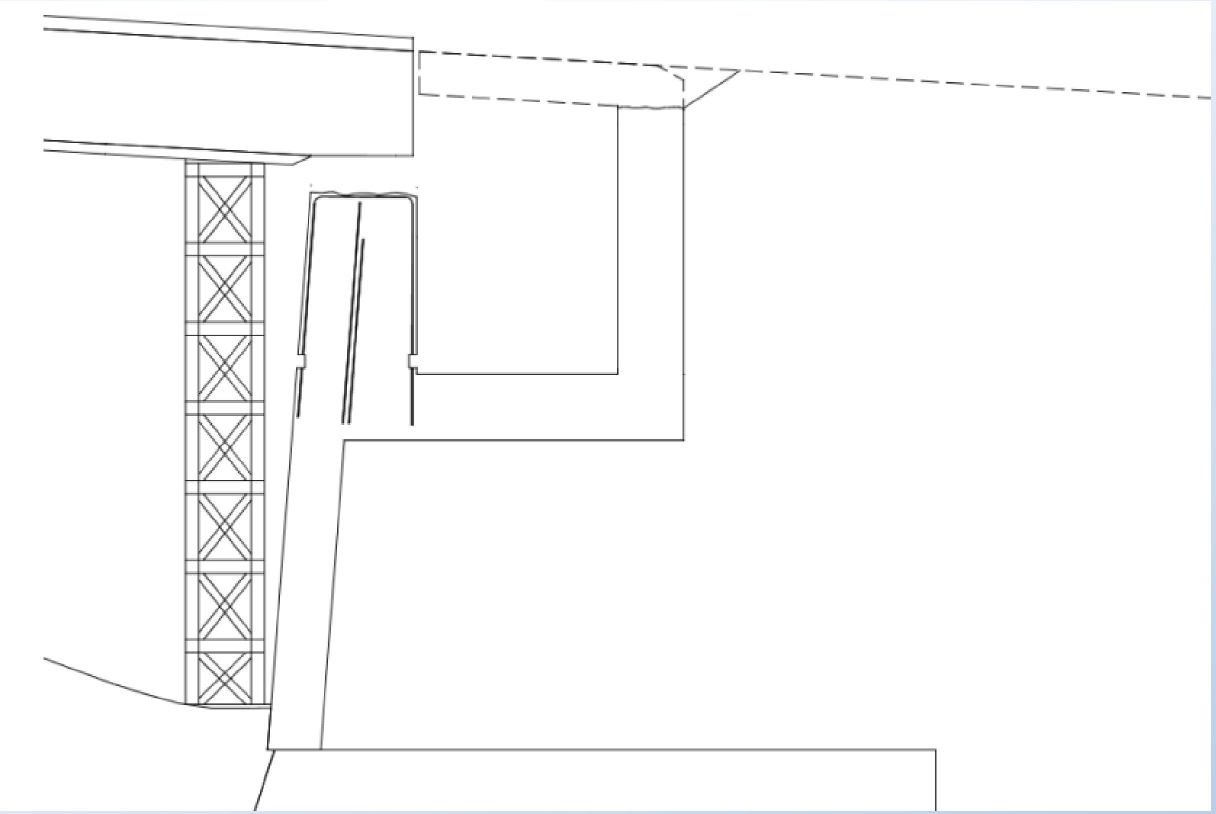
- Elimination of expansion joints and inspection chambers
- Connection of the deck to the abutment wall



Adjustments of Abutment

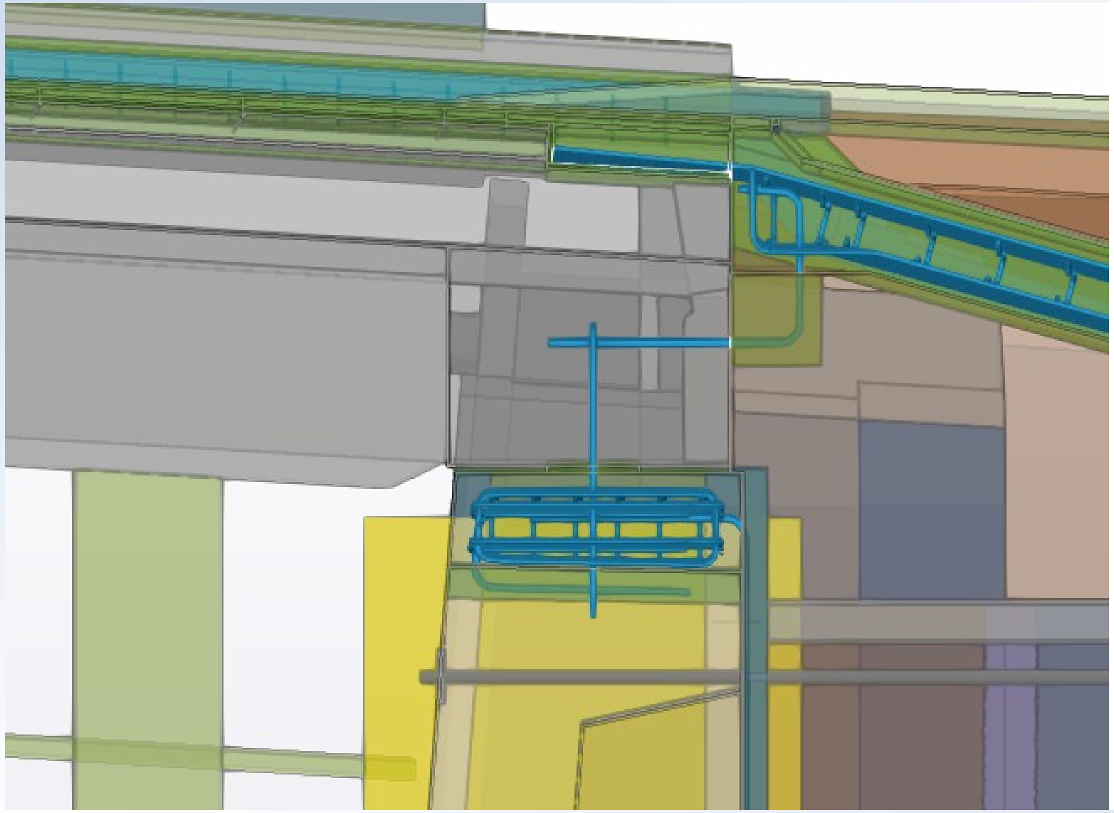
- Removal of expansion joints and inspection chambers

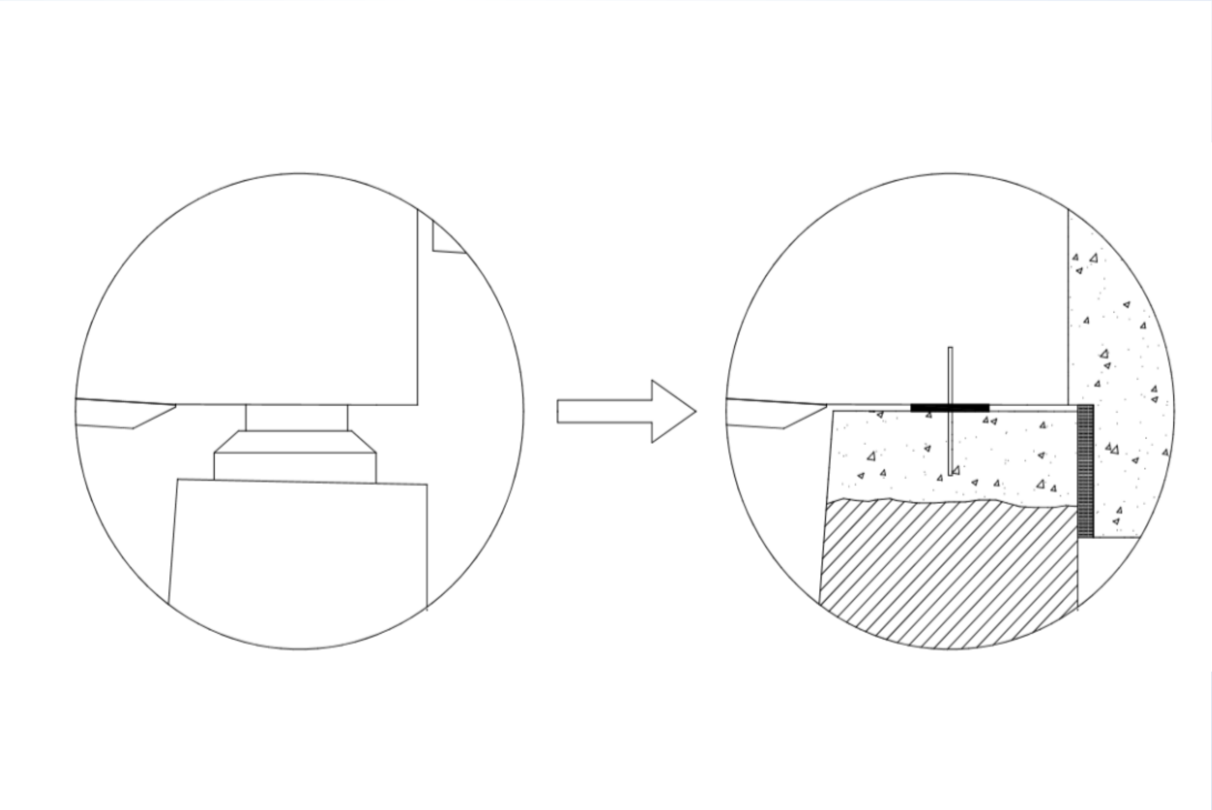




Adjustments of Abutment

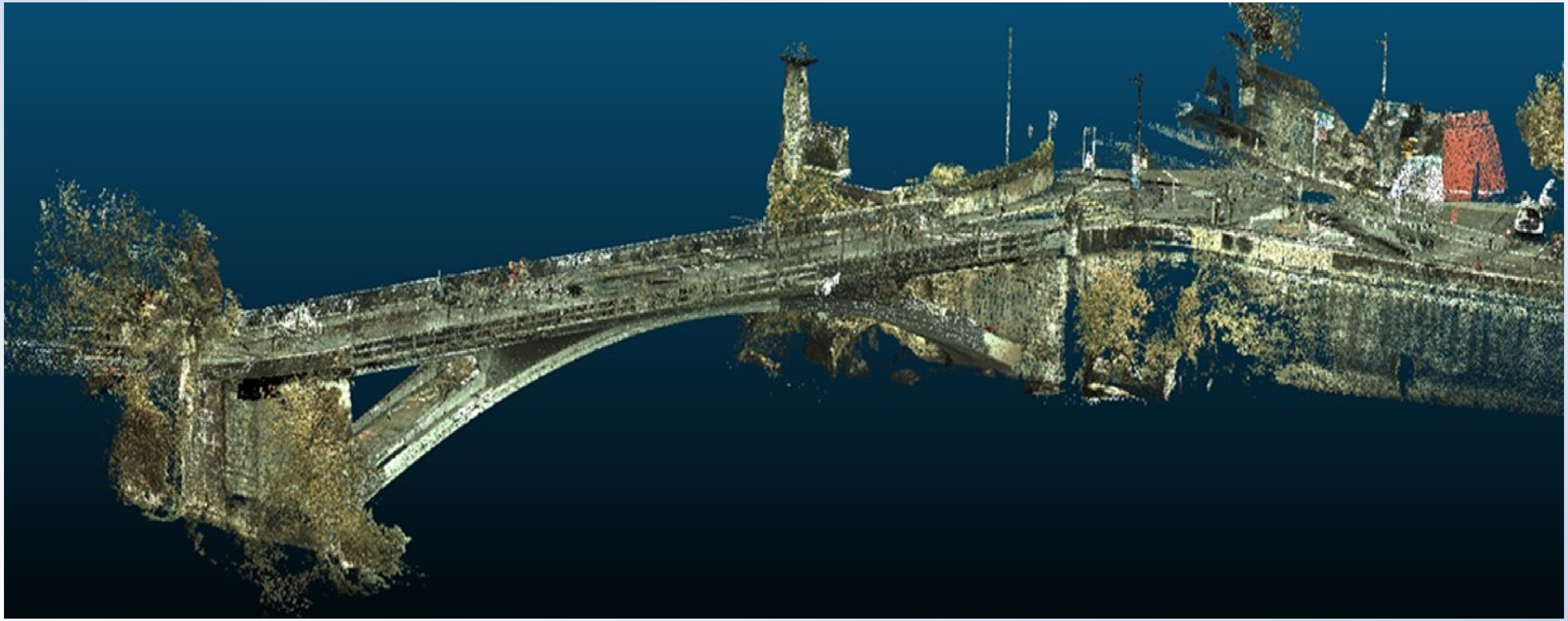
- Elimination of bearings





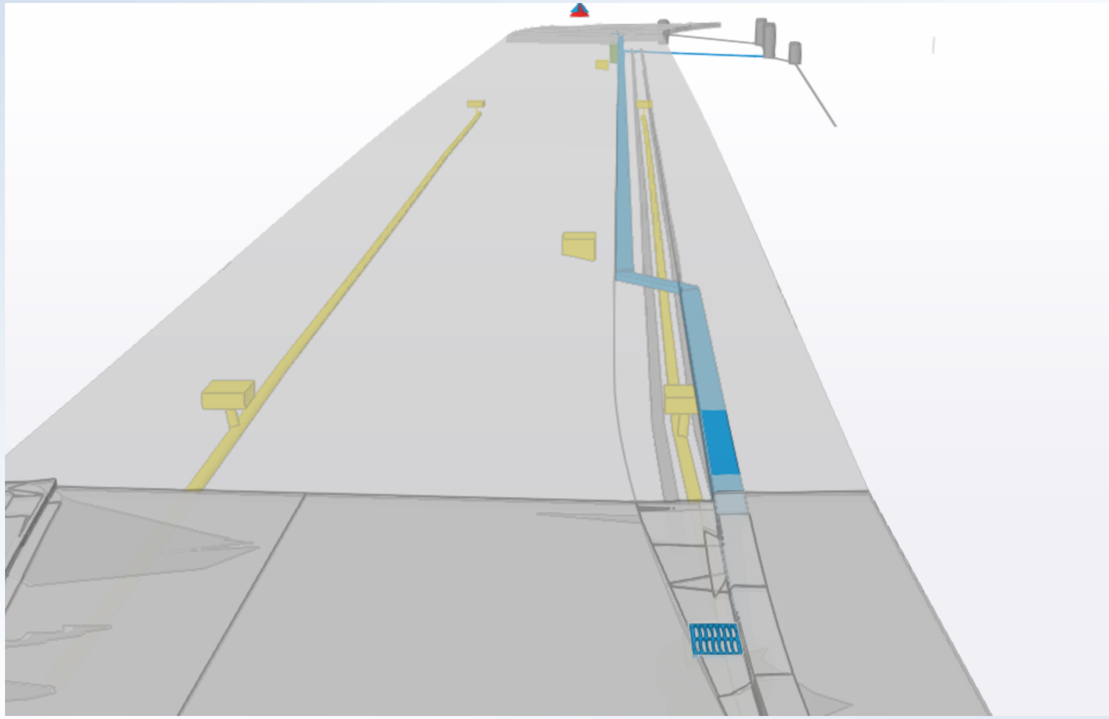
Laser Scanning

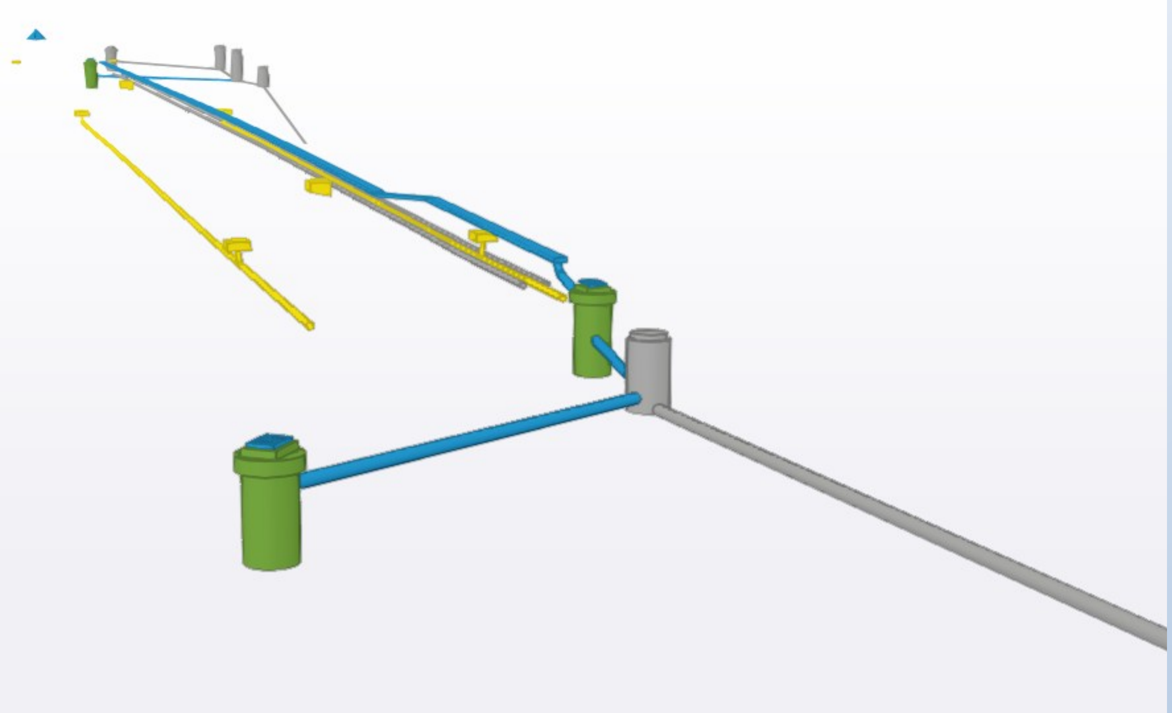
- Point cloud of laser scan



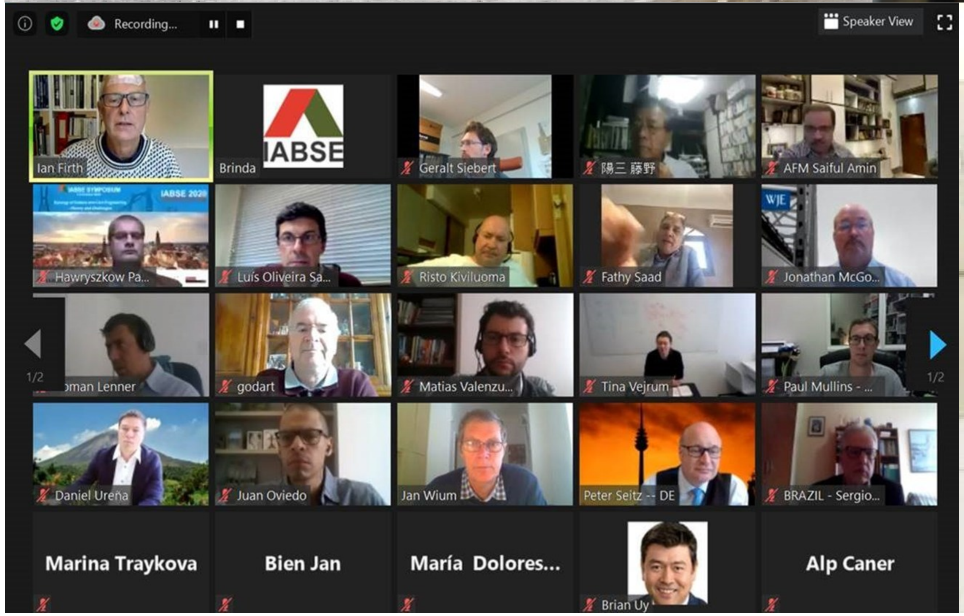
Drainage Model

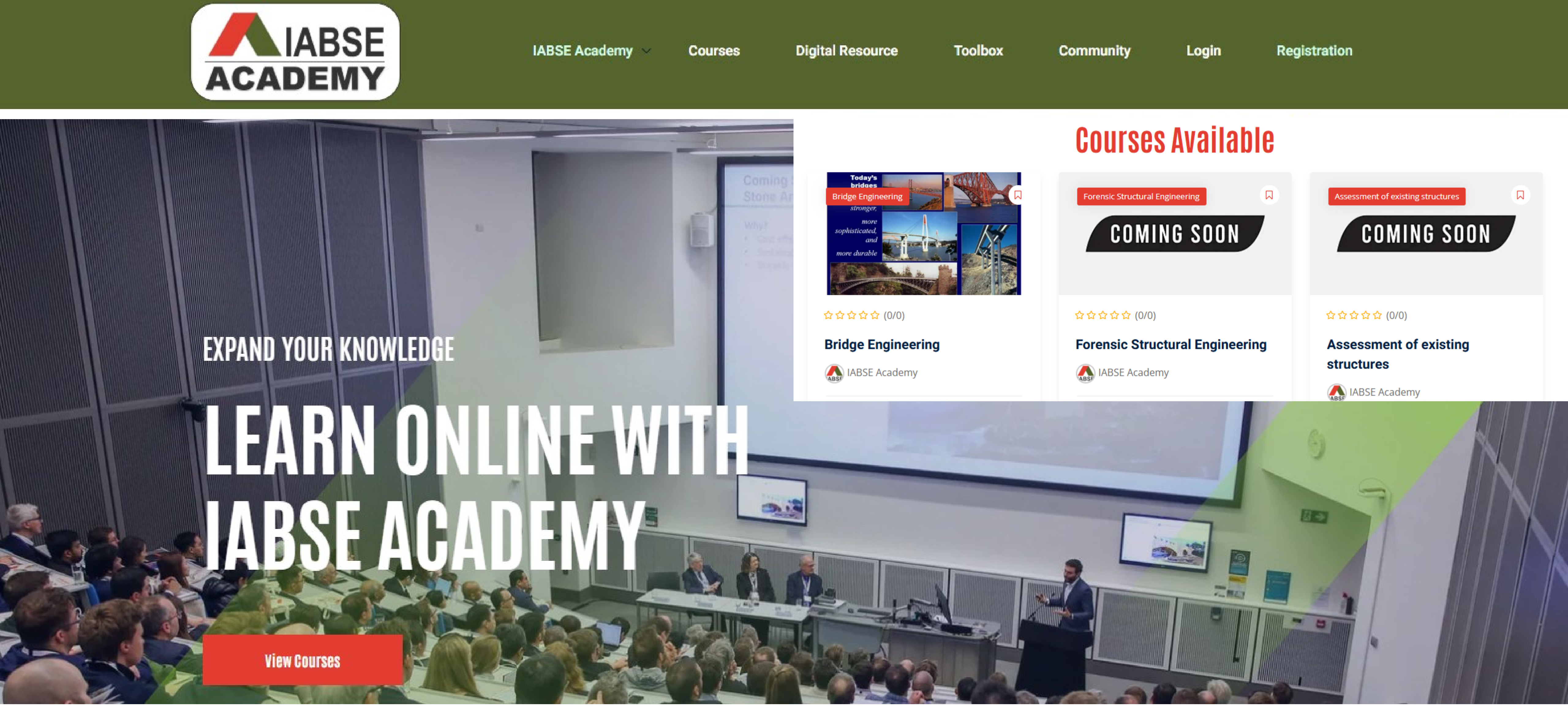
- Including the initial state, construction, and end state





IABSE: NATIONAL GROUPS, TASK GROUPS





IABSE
International Association for Bridge and Structural Engineering

Levels

Basic Level

Assessment of Existing Structures	Forensic Structural Engineering
Mandatory lessons (~28 hrs)	Mandatory lessons (~12 hrs)

Thesis

Free-choice lessons (at least 10 hrs)

Advanced Level

Assessment of Existing Structures	Forensic Structural Engineering
Mandatory lessons (~12 hrs)	Mandatory lessons (~8 hrs)

Thesis

Free-choice lessons (at least 5 hrs)


Equi Bridges
Engineering & Management
Gracias
ESCUELA DE
INGENIERÍA EN CONSTRUCCIÓN
PONTIFICIA
UNIVERSIDAD
CATÓLICA DE
VALPARAÍSO
IABSE
International Association for Bridge and Structural Engineering