EPFL

Innovation for construction & the environment

Also part of :

E4S
Enterprise for Society

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Schweizerischer Ingenieur- und Architektenverein
Société suisse des ingénieurs et des architectes
Società svizzera degli ingegneri e degli architetti
Swiss society of engineers and architects

Dr. Dimitrios Terzis

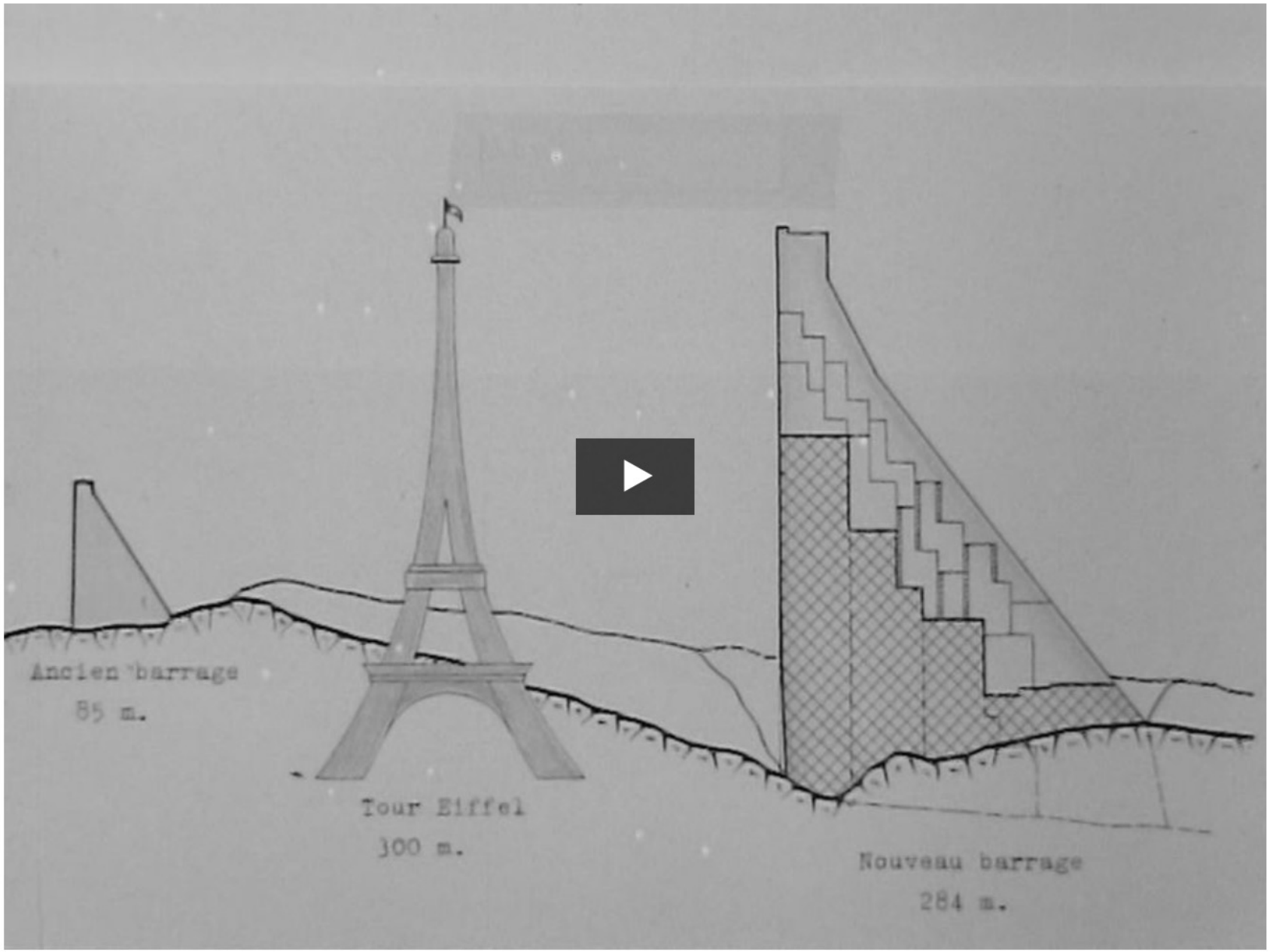
25/11/2025


ESPERIA

Last week's class

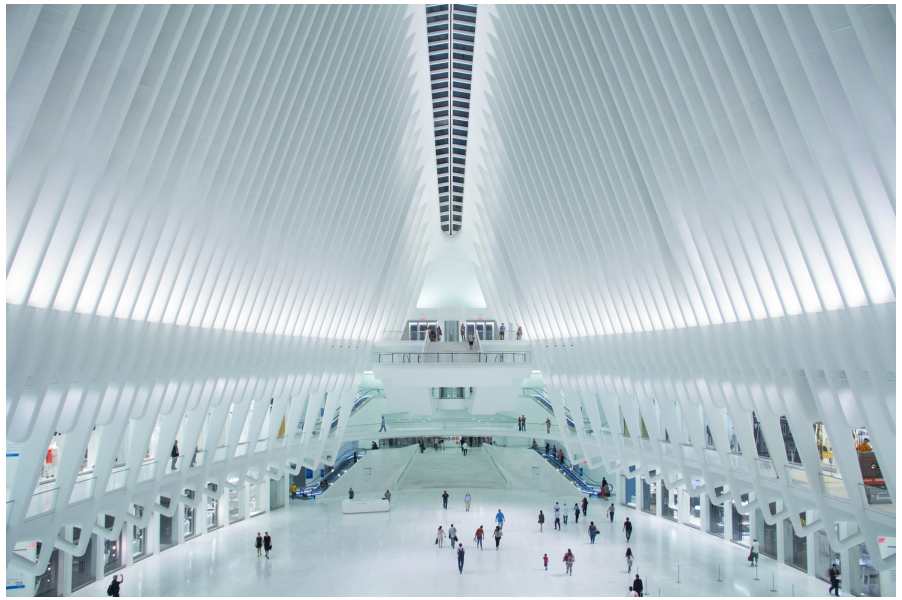
- Structural Health Monitoring (SHM)
- Digital Twins & semantics
- Cyberphysical systems
- An example from the EPFL Innovation ecosystem

Muveran
Sion
Conthey
Ardon
Vex
Chamoson
OVRONNAZ
Veysonnaz
Rhône
Leytron
E62
Nendaz
Hérémence
Saint-Martin
Becs de Bosson
Anniviers
Hirsihorn
GRIMENTZ
SAINT-LUC
VAUD
VALAIS
Evionnaz
Saillon
Riddes
Dent de Nendaz
Dorénaz
Saxon
Sasseneire
Fully
Vernayaz
ZINAL
Pierre Avoi
Salvan
Evolène
Martigny
La Crevasse
VERBIER
Barrage de la Grande Dixence
Mont Fort
GIETTE
Martigny-Combe
Sembrancher
Val de Bagnes
LES HAUDÈRES
SARREYER
Aiguilles Rouges d'Arolla
FERPÈCLE
GOUILLE
Dent Blanche
La Breya
Orsières
AROLLA
CHANDONNE (LIDDES)
BOCHERESSE MAUVOISIN



La sécurité du barrage de la Grande Dixence / Le Régional / 5 min. / le 14 octobre 1960

On SHM of metallic structures



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On Digital twins

The network Services Our promises The Company Search | Customer portal

The digital twin

The "Digital twin" programme is one of the major campaigns launched in-house by the Engineering & Projects (I & P) and Innovation Divisions. The aim is to optimise project design, service portfolio content and production functions.

A technological innovation with multiple applications to enter service by 2024

Like the ghost in video games, a digital twin is the virtual reproduction of a system as it really exists and not as it would be in an ideal world. NASA was the first to apply this principle to its industrial requirements for the Apollo mission. The technique is also widely used in the aerospace industry. SNCF Réseau is aiming to have it in service by 2024.

> **"The (rail) sector has taken inspiration from the aeronautics industry, a precursor in the field, particularly with the digital twins used for reactors to factor in the whole of their lifecycle operating history."**
>
> Pierre Cresci, Cabinet Oliver Wyman

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On Digital twins & Cyberphysical systems

The construction industry is among the least digitized.

McKinsey Global Institute industry digitization index; 2015 or latest available data

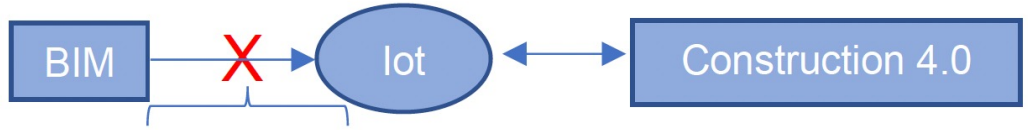
Relatively low digitization — Relatively high digitization

● Digital leaders within relatively undigitized sectors

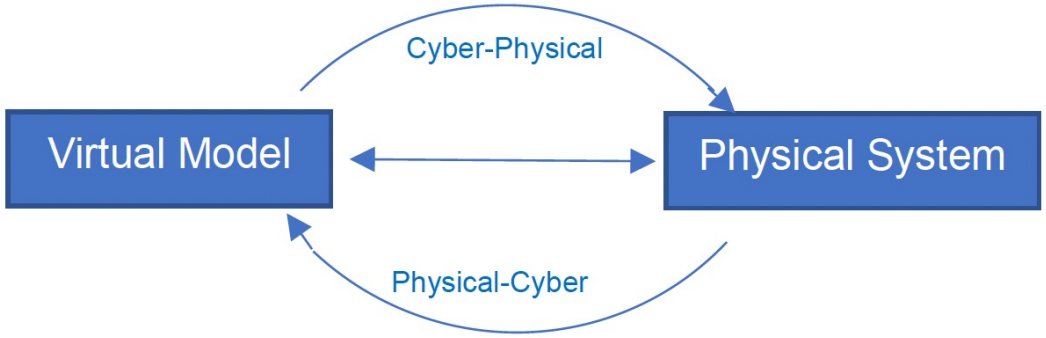
Sector	Assets: Overall digitization[1]	Assets: Digital spending	Usage: Digital asset stock	Usage: Transactions	Usage: Interactions	Usage: Business processes	Usage: Market making	Labor: Digital spending on workers	Labor: Digital spending deepening	Labor: Digital capital	Labor: Digitization of work
ICT[2]											
Media											
Professional services											
Finance and insurance											
Wholesale trade											
Advanced manufacturing											
Oil and gas											
Utilities											
Chemicals and pharmaceuticals											
Basic goods manufacturing											
Mining											
Real estate	●										
Transportation and warehousing	●										
Education	●										
Retail trade	●										
Entertainment and recreation											
Personal and local services											
Government	●										
Healthcare											
Hospitality	●										
Construction											
Agriculture and hunting											

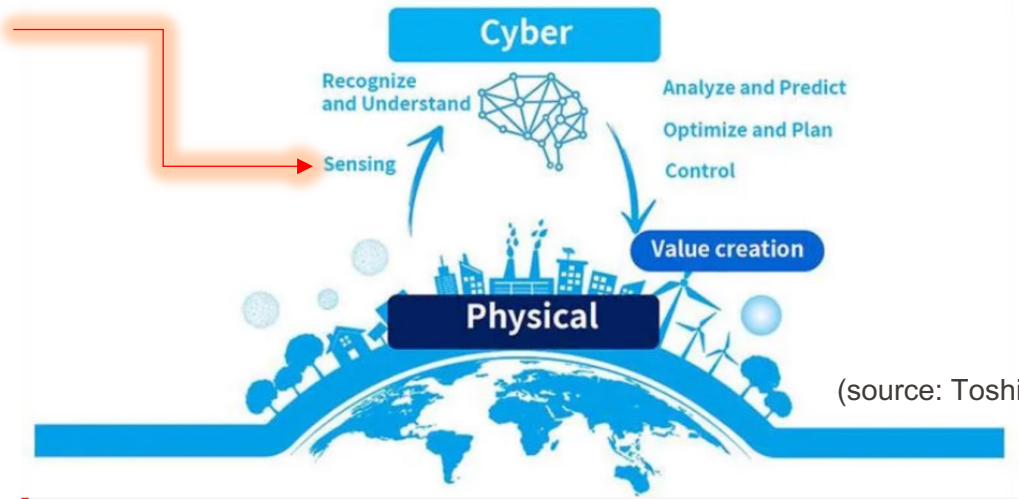
[1]Based on a set of metrics to assess digitization of assets (8 metrics), usage (11 metrics), and labor (8 metrics).
[2]Information and communications technology.

Source: AppBrain; Bluewolf; Computer Economics; eMarketer; Gartner; IDC Research; LiveChat; US Bureau of Economic Analysis; US Bureau of Labor Statistics; US Census Bureau; McKinsey Global Institute analysis



- Lack of sensor networks and control systems
- Incompatible legacy formats and standards



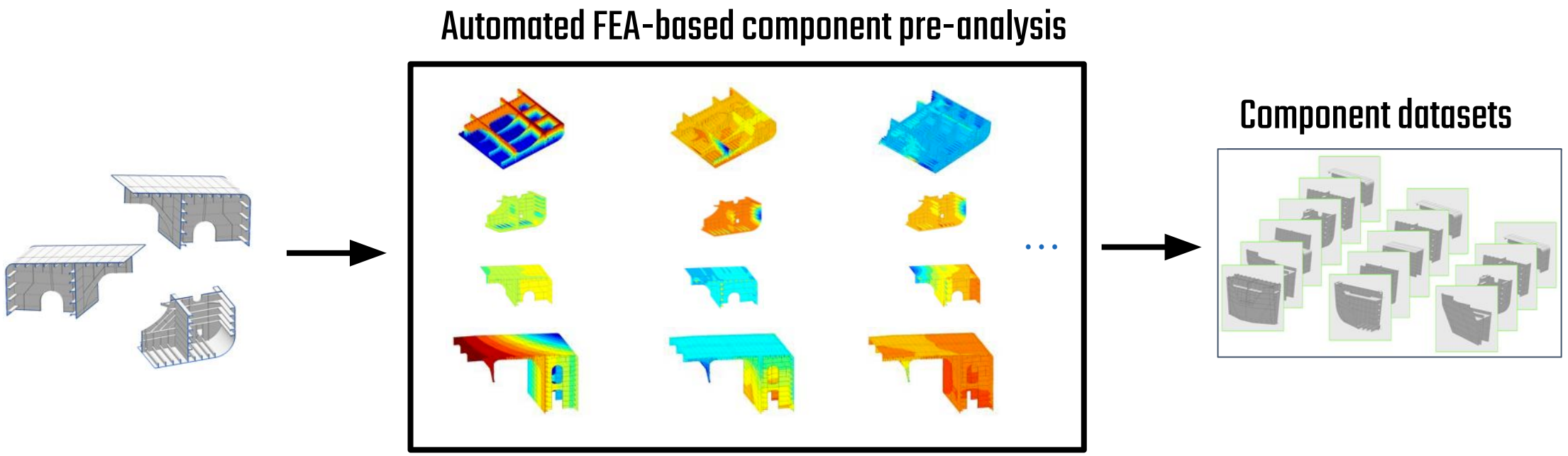


(source: Toshiba)

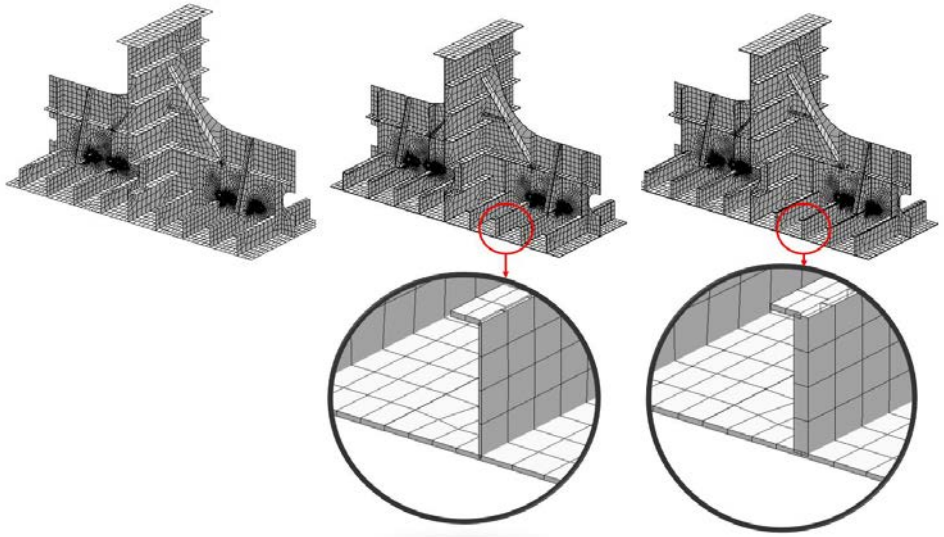
Component Pre-analysis

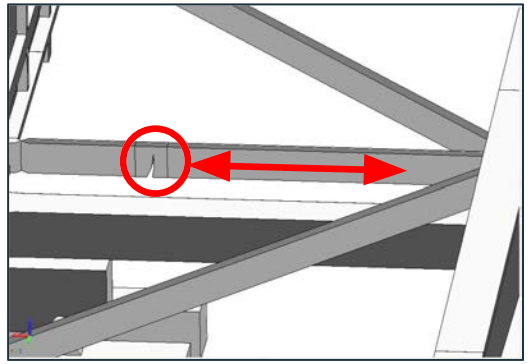
- Automated FEA + postprocessing of components (individual and groups) to construct accurate reduced model of component physics and interactions

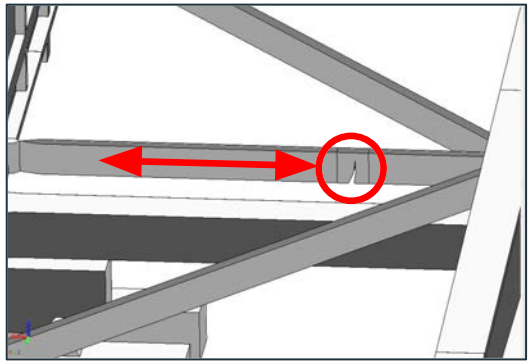
- **Performed upfront (during Digital Twin setup)**, datasets **stored** and **reused** over the asset's lifetime

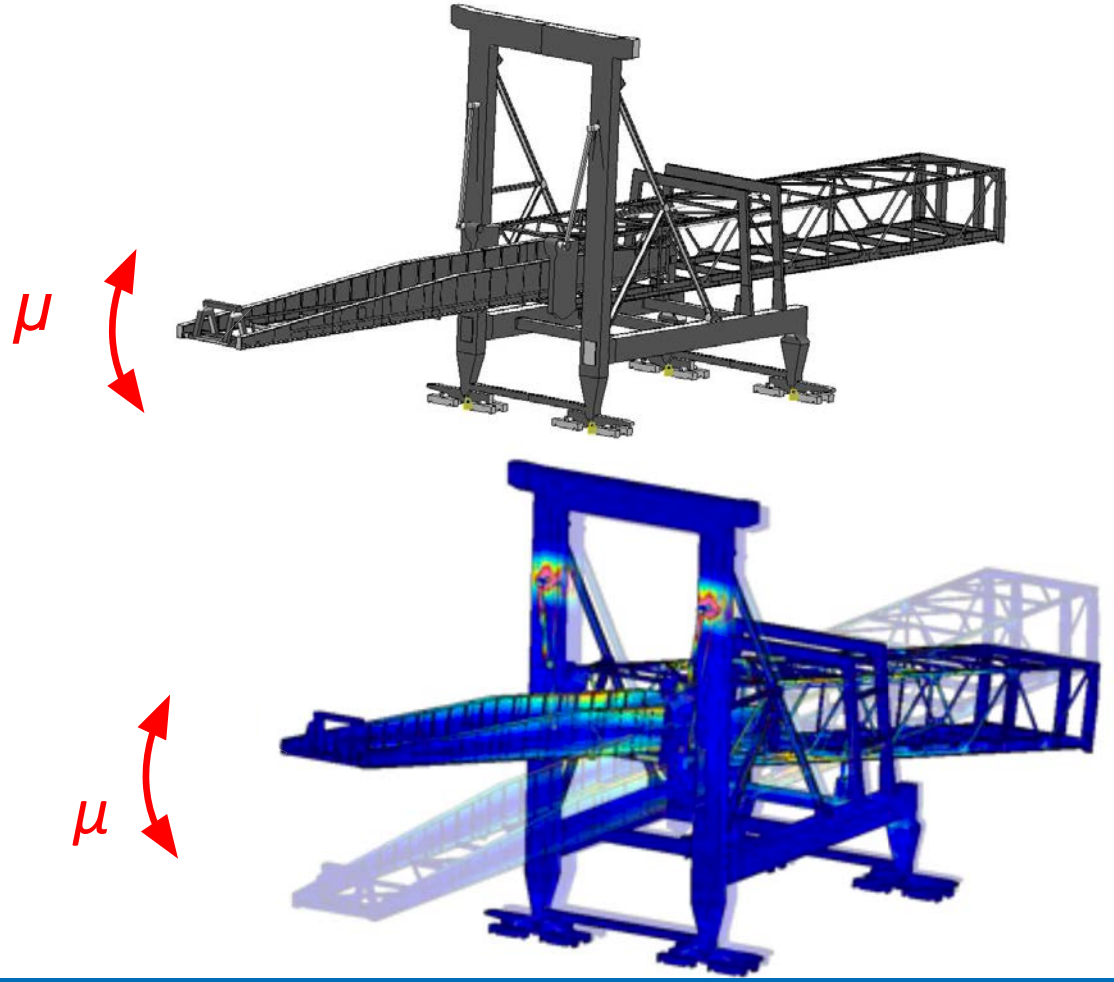


Components are Parametrized









Akselos RB-FEA technology at a glance

1000X FASTER

Provides major speedup compared to FEA for linear PDEs, e.g. **>1000x** for large-scale problems

1000X LARGER MODELS

Easily solve models with **>100m** FEA DOFs. This enables true condition-based models of entire assets (Digital Twins).

PARAMETRIC

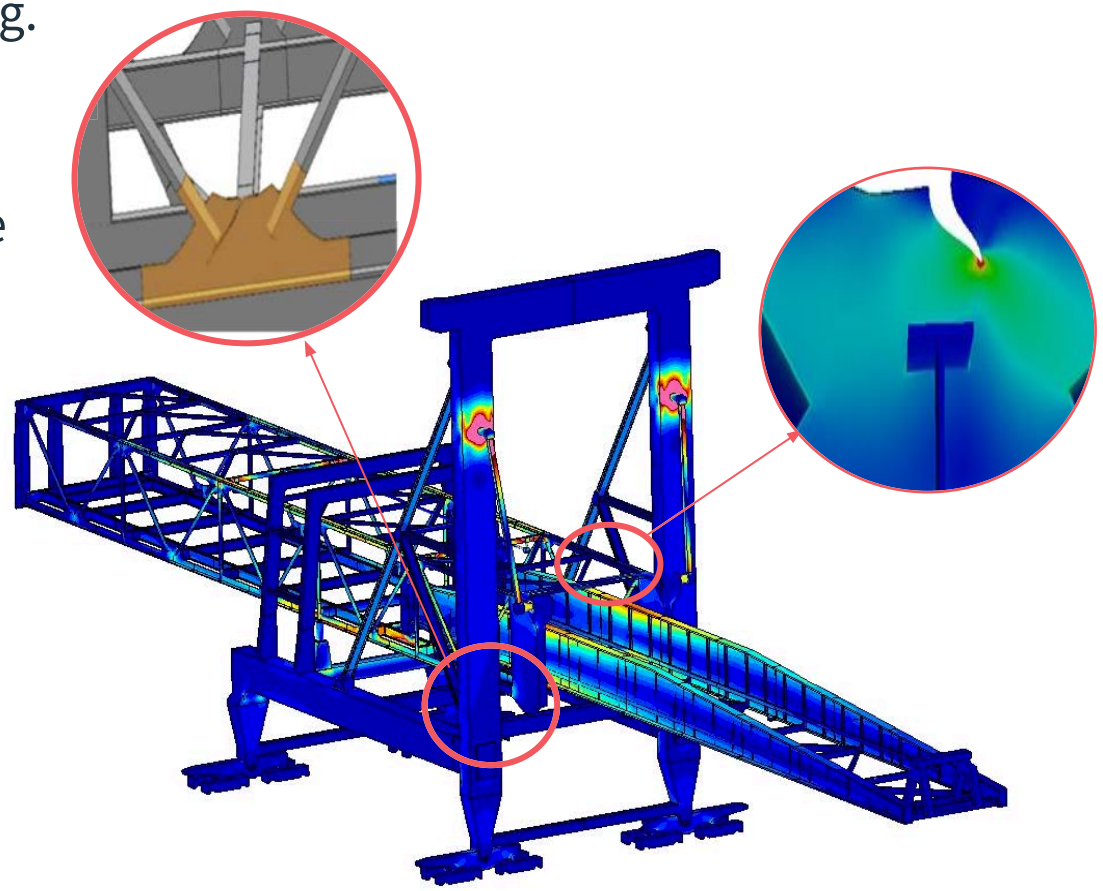
Modify models by changing parameters. Efficiently handles systems with many parameters, e.g. **>1000**

COMPONENT-BASED MODELING

Modular designs, easily add/remove/replace components

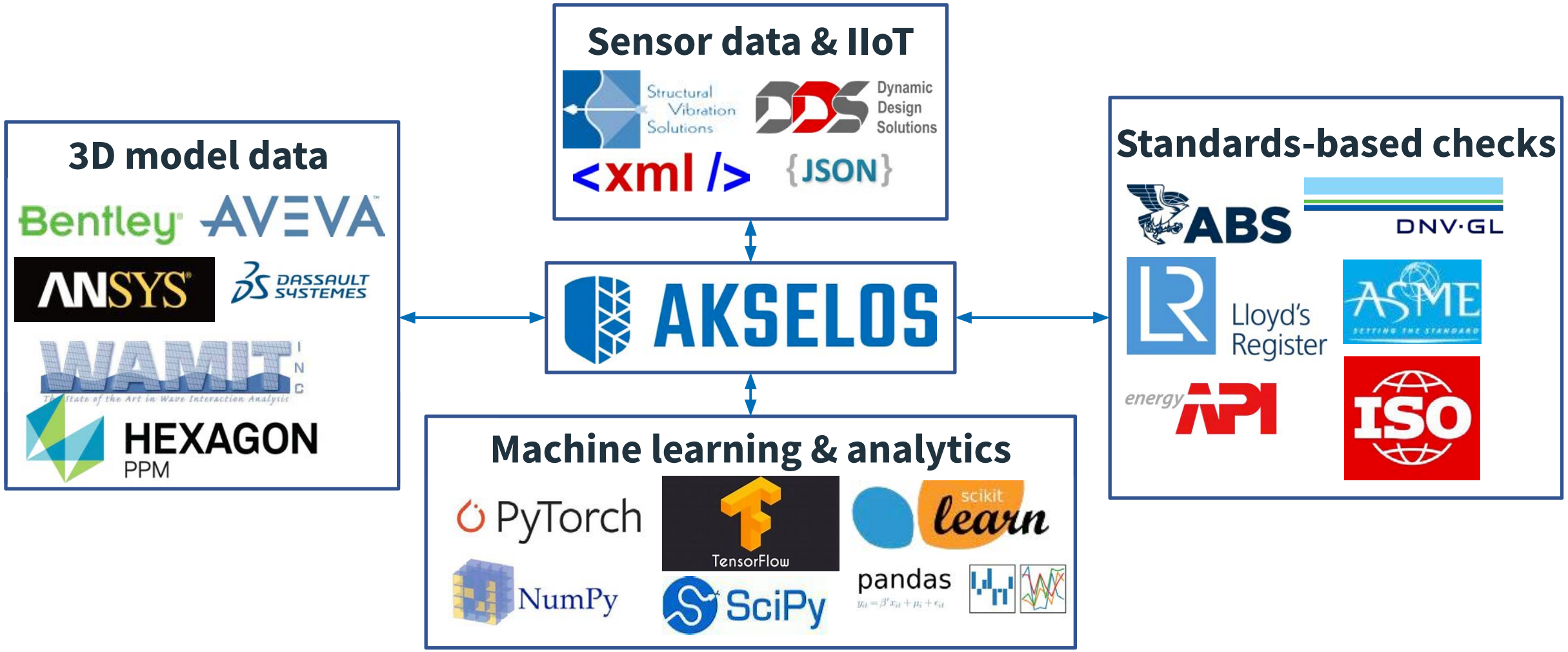
CLOUD-BASED PLATFORM

Provide all users with powerful computational platform via secure client-server architecture



Integrates with the Digital Transformation Ecosystem

Open API (Python-based), open data formats, import/export data and models



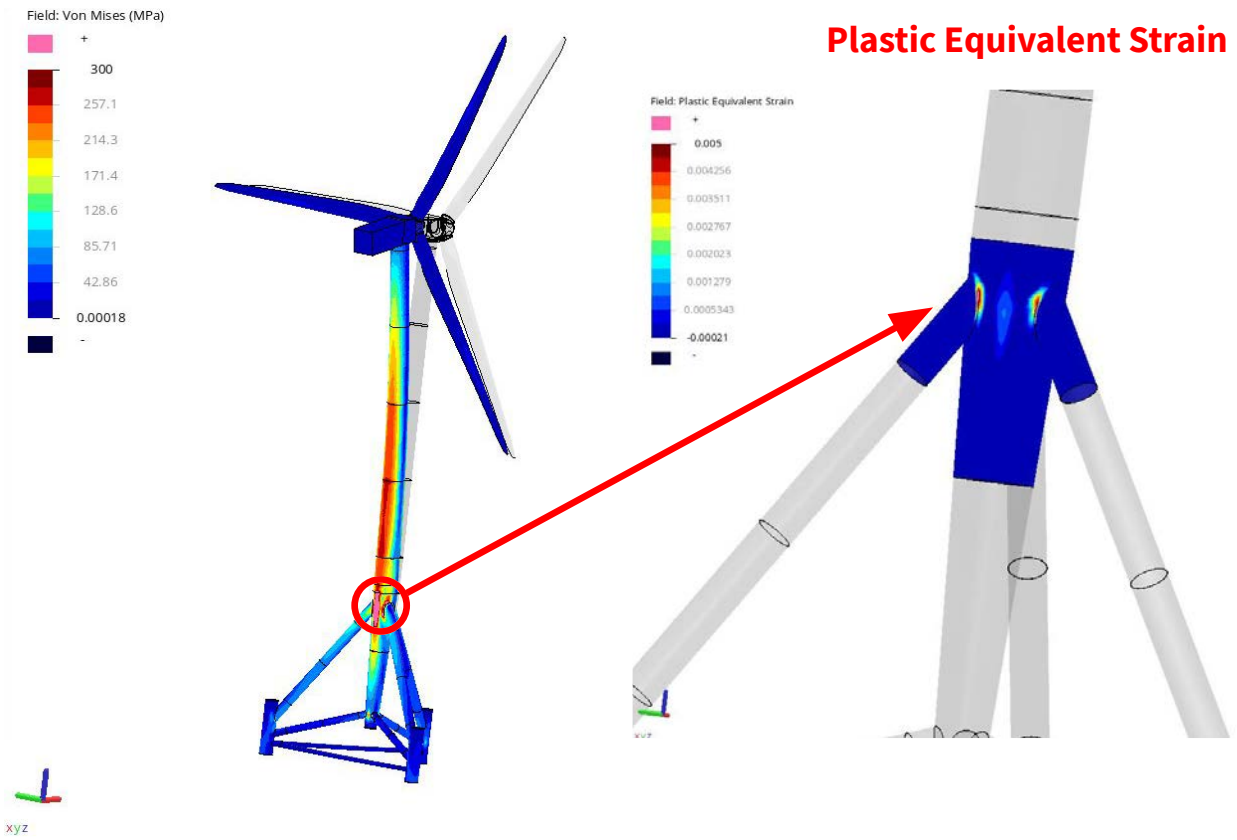
Incorporating Nonlinear Analysis

RB method applies to linear problems, but many engineering problems involve nonlinearities:

Core idea: Split domain into "linear" and "nonlinear" regions

Key points:

- Arbitrary nonlinearities in FEA region (e.g. contact, plasticity, finite strain)
- Accelerate the linear region, fast for "localized nonlinearities"
- Formulation is fully conforming, numerically robust



Development of Non-Destructive Testing Strategies in structural Health Monitoring

Guest Lecturer
Dr. Alexis Kalogeropoulos
CEO of Bridgology SA

Contact
Tel: +41 79 297 40 54
ak@bridgology.com

Non Destructive Testing - NDT

Waves carry information using the superposition principle

Non Destructive Testing - NDT

Most of NDT techniques are based
on the emission and the reception of waves

For **EVERY** wave:

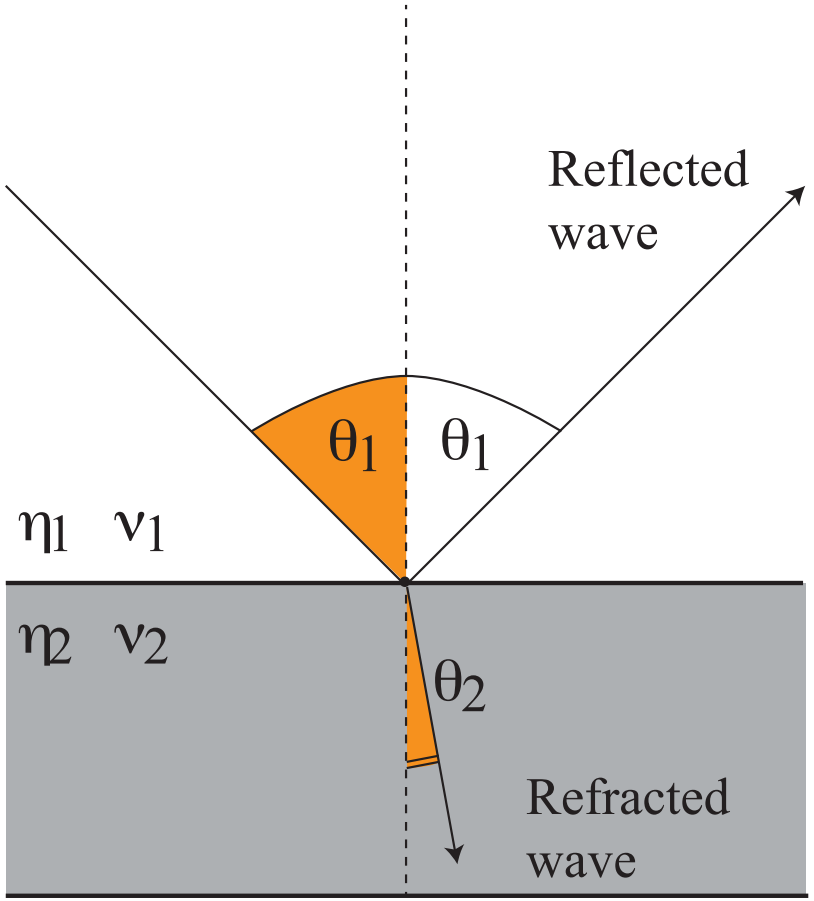
Waves travel and are attenuated in a way that is specific to each material.

A reflexion/transmission couple is produced at each boundary between materials.

Non Destructive Testing - NDT

Willebrord van Roijen Snell
1580-1626

René Descartes
1596-1650



Non Destructive Testing - NDT

Speed

Attenuation

Non Destructive Testing - NDT

We use digital signal processing strategies
to measure the properties of the materials

OUT = IN*Filter

Ground Penetrating Radar - GPR

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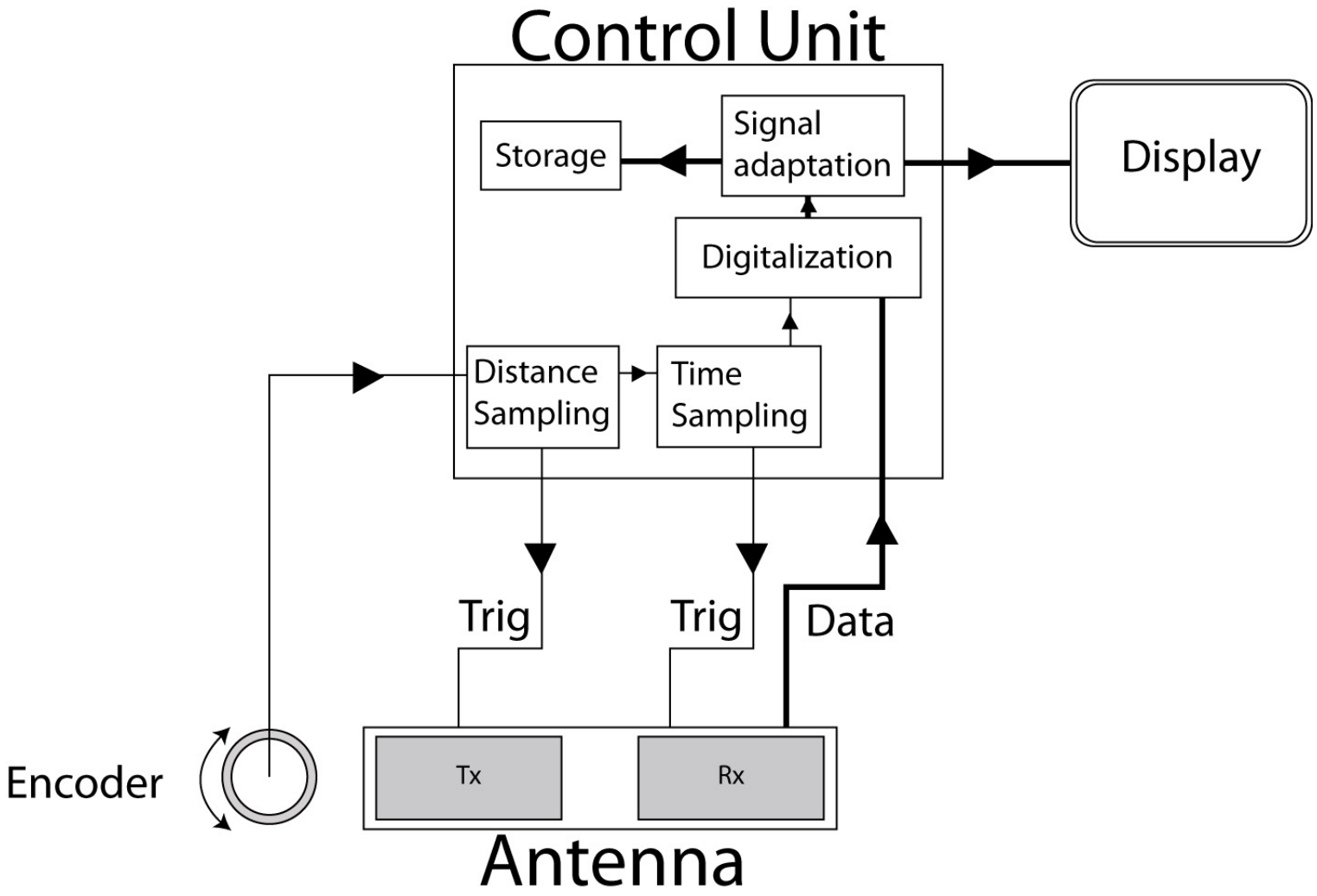
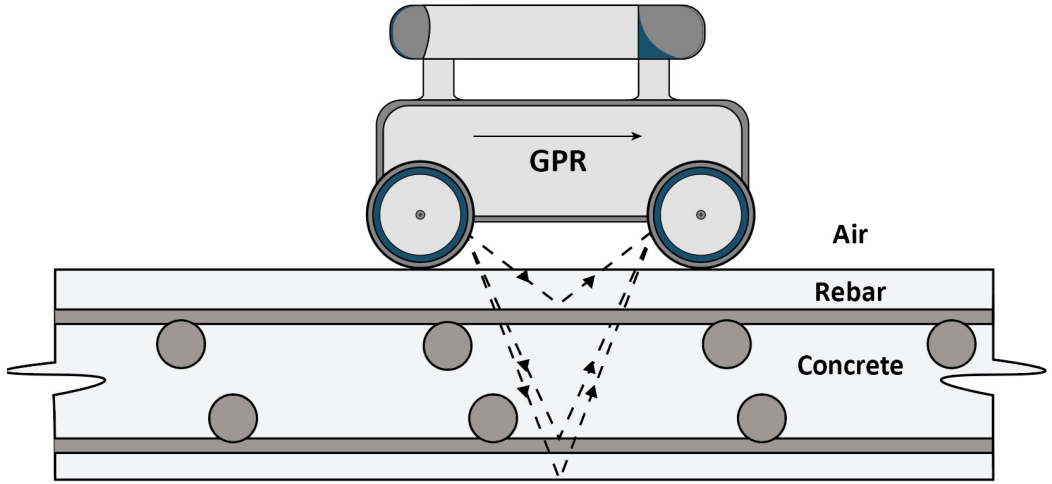
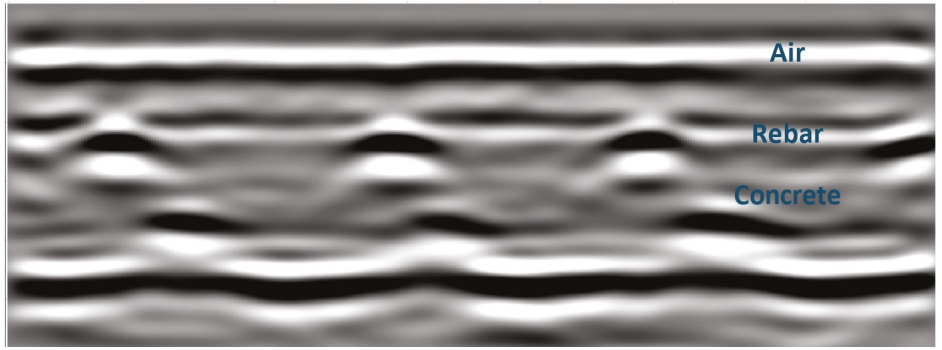
Ground Penetrating Radar - GPR



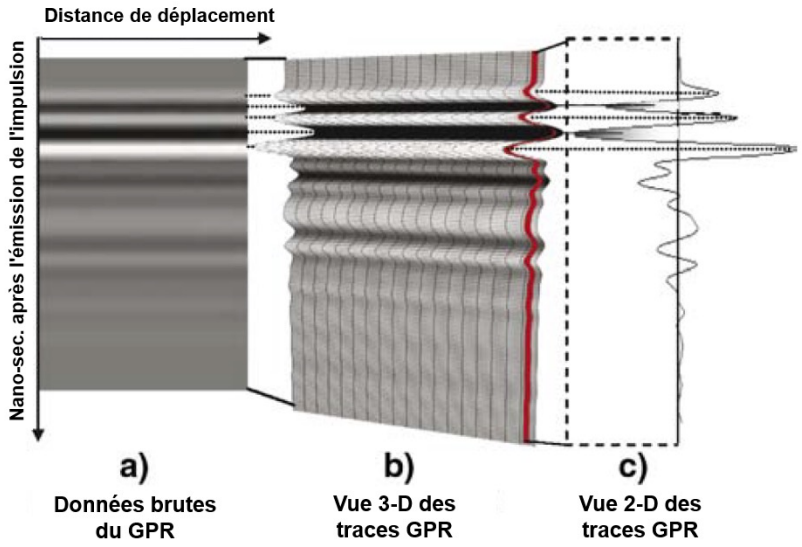
Ground Penetrating Radar - GPR



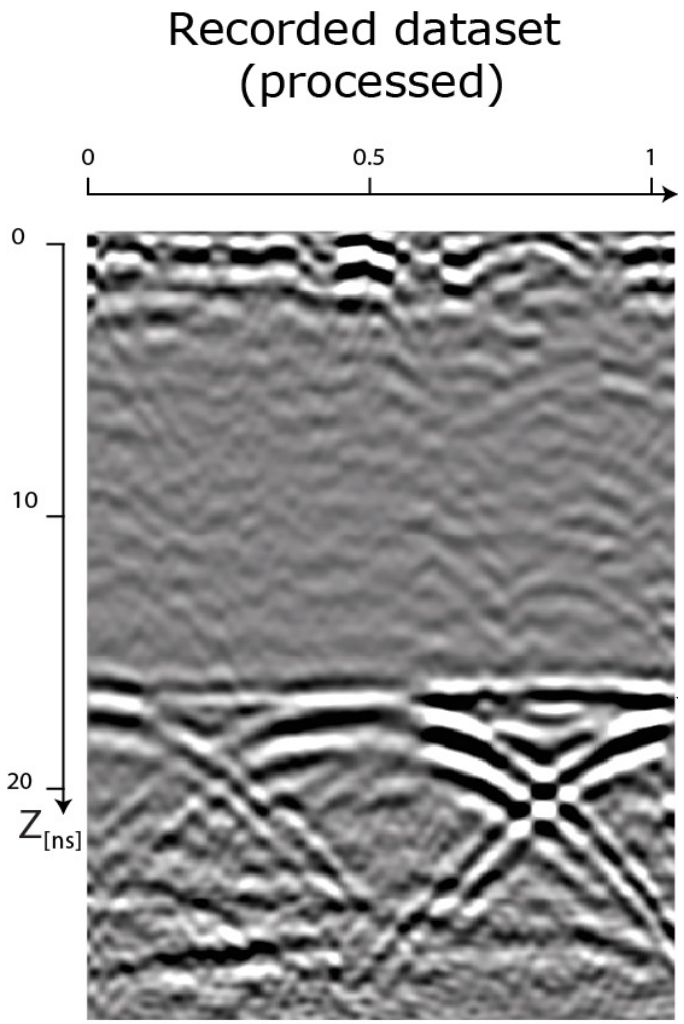
Data: Radargram



Ground Penetrating Radar - GPR



Source : LESTER.J, BERNOLD L.E. (2007) - Innovative process to characterize buried utilities using GPR. Automation in Construction 16, pp 546–555.



A radargram is the sum of all recorded traces

It must be processed using Digital Signal Processing

IT MUST BE INTERPRETED

Artefacts might be present

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Ground Penetrating Radar - GPR

COGNITIVE BIASES

We have a strong tendency to want to find what we are looking for. ***Validation Bias***

Measurements must always be placed in a context, since alone, they do not contain information.

A discussion between the civil engineer and the geophysicist must take place

Theory

James Clerk Maxwell
(13 june 1831- 5 novembre 1879)

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

$$\nabla \cdot \boldsymbol{D} = \rho$$

$$\nabla \cdot \boldsymbol{B} = 0$$

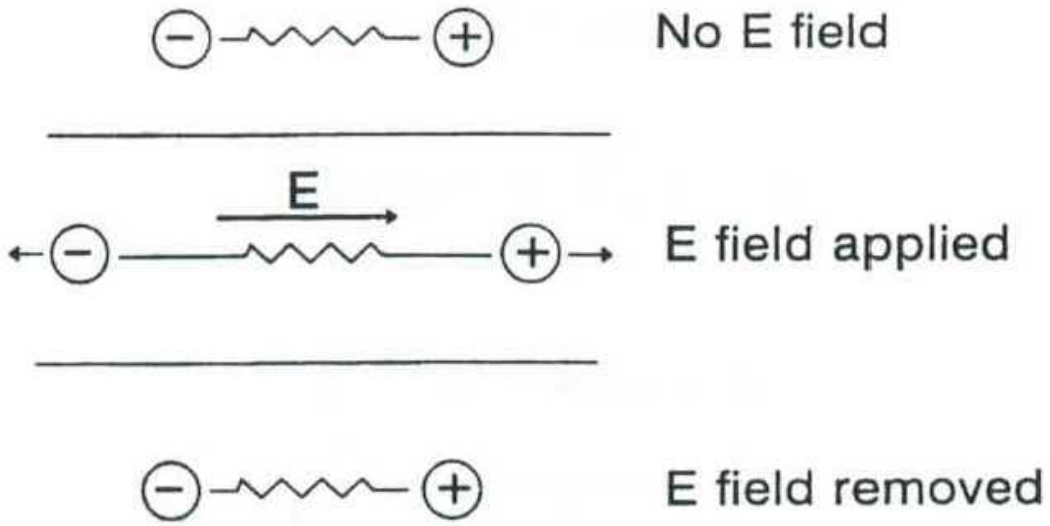
Les lois de
l'éléctromagnetisme
présentées en 1865

Theory

Displacement currents :

Storage of Energy

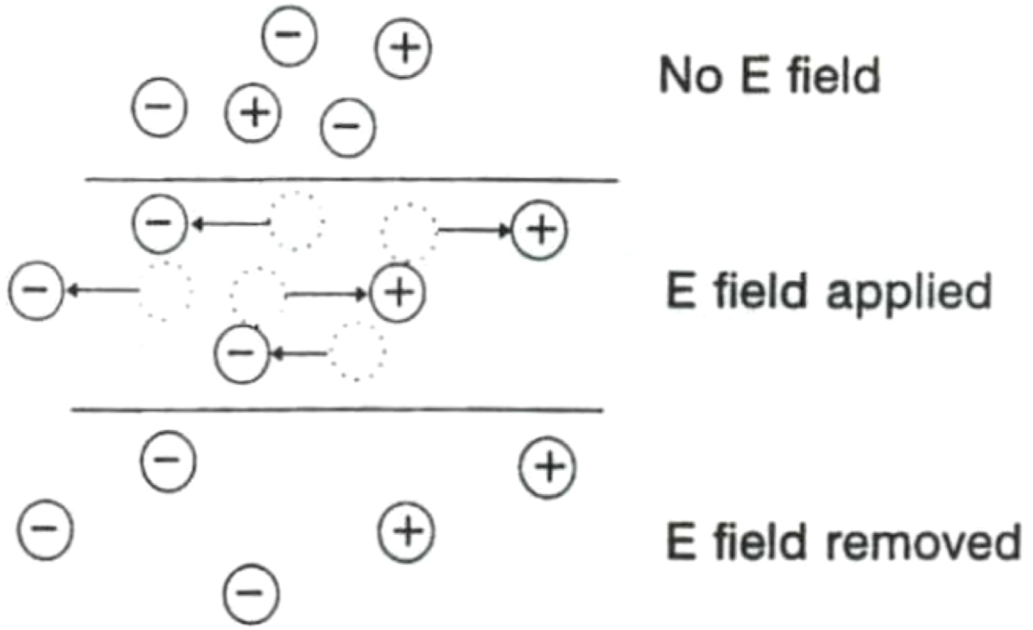
$$\mathbf{J} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$



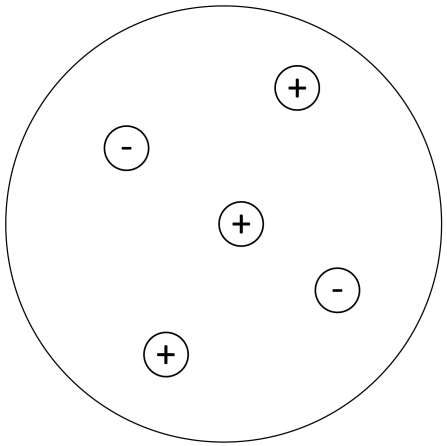
Theory

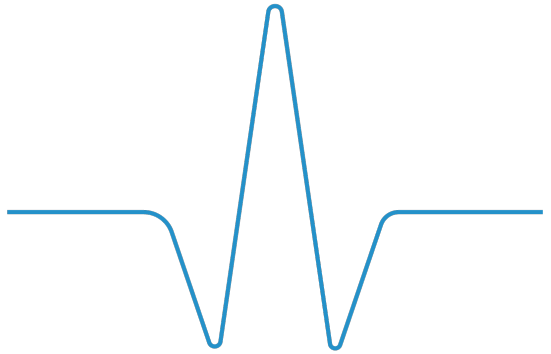
Conduction Currents:

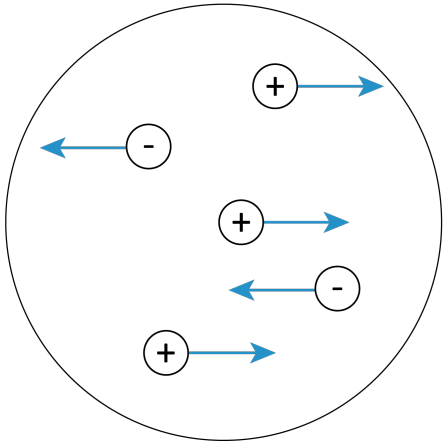
Energy dissipation $\mathbf{J} = \sigma \mathbf{E}$

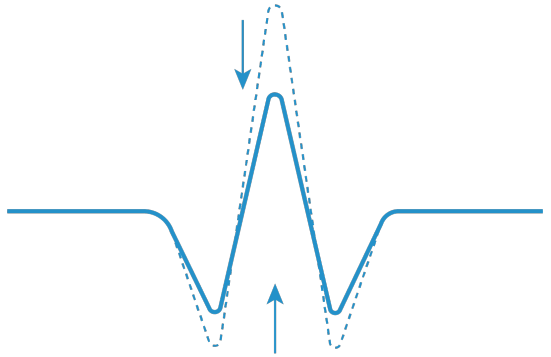


Theory

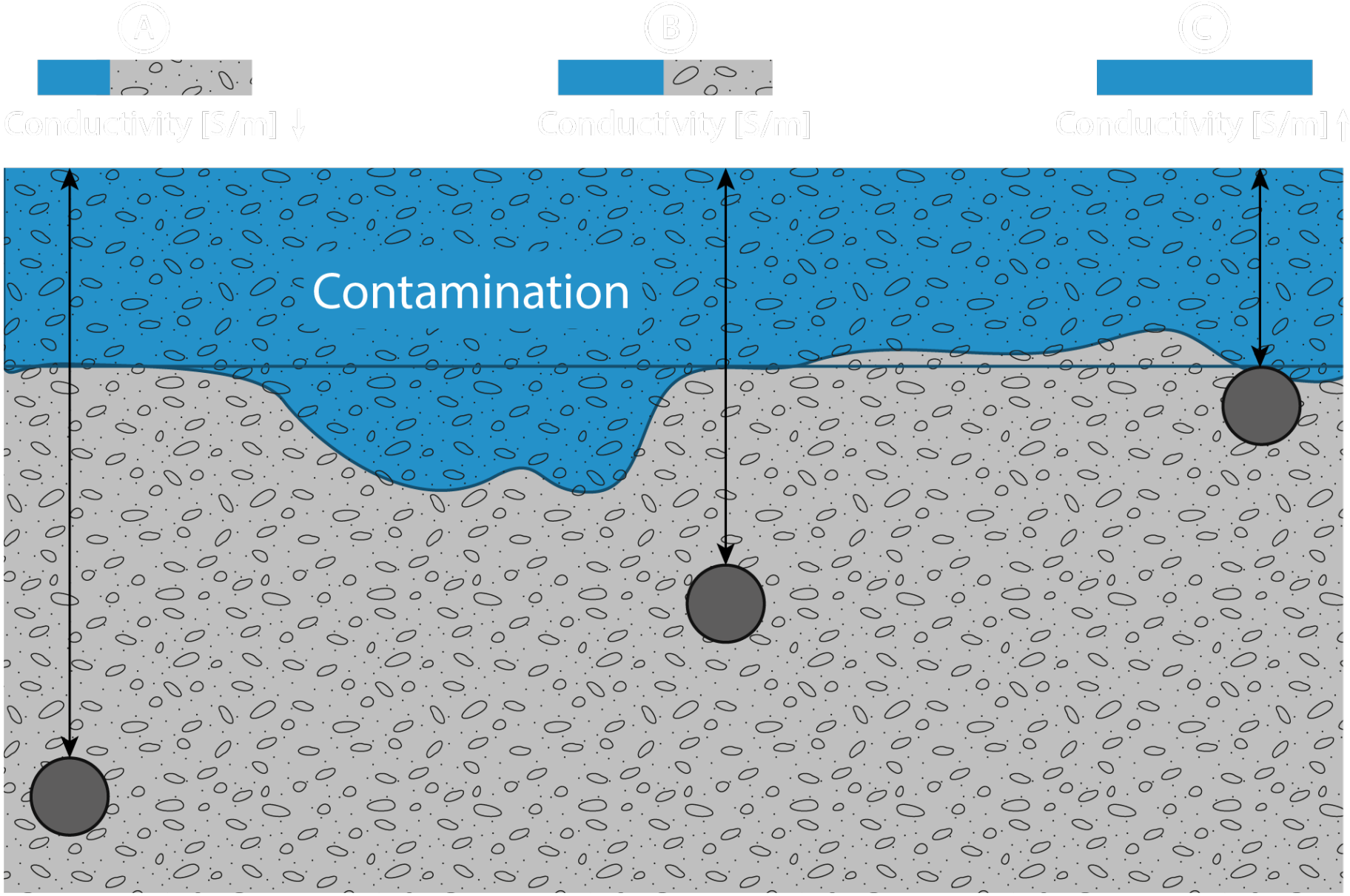




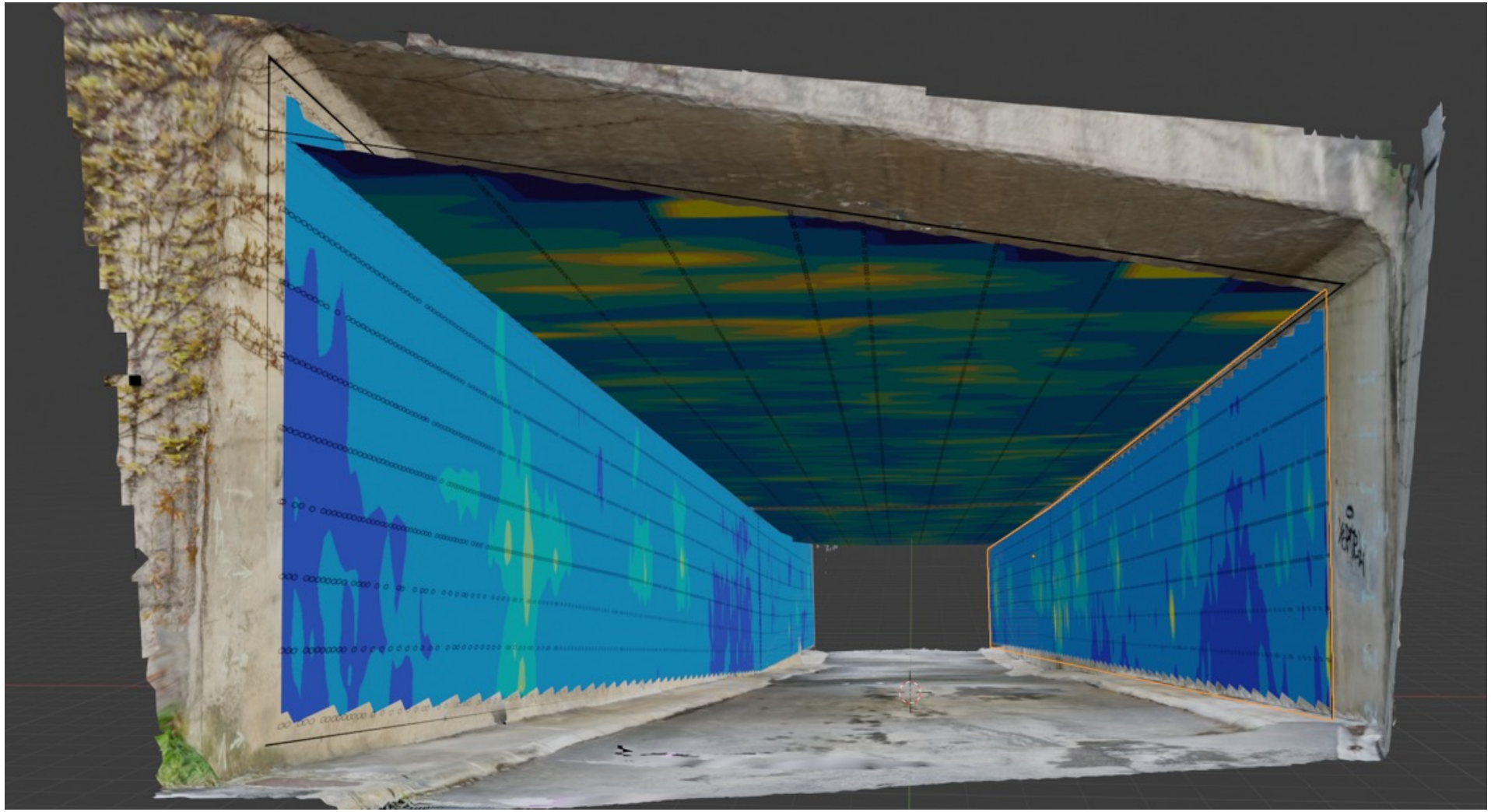




Theory


A
B
C
Conductivity [S/m] ↓
Conductivity [S/m]
Conductivity [S/m] ↑
Contamination

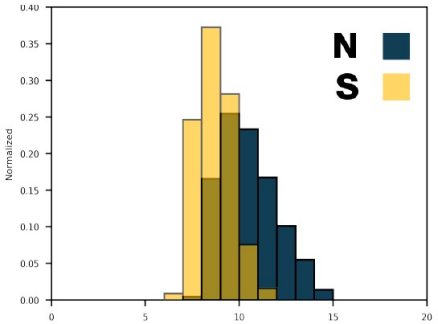
Results and Examples



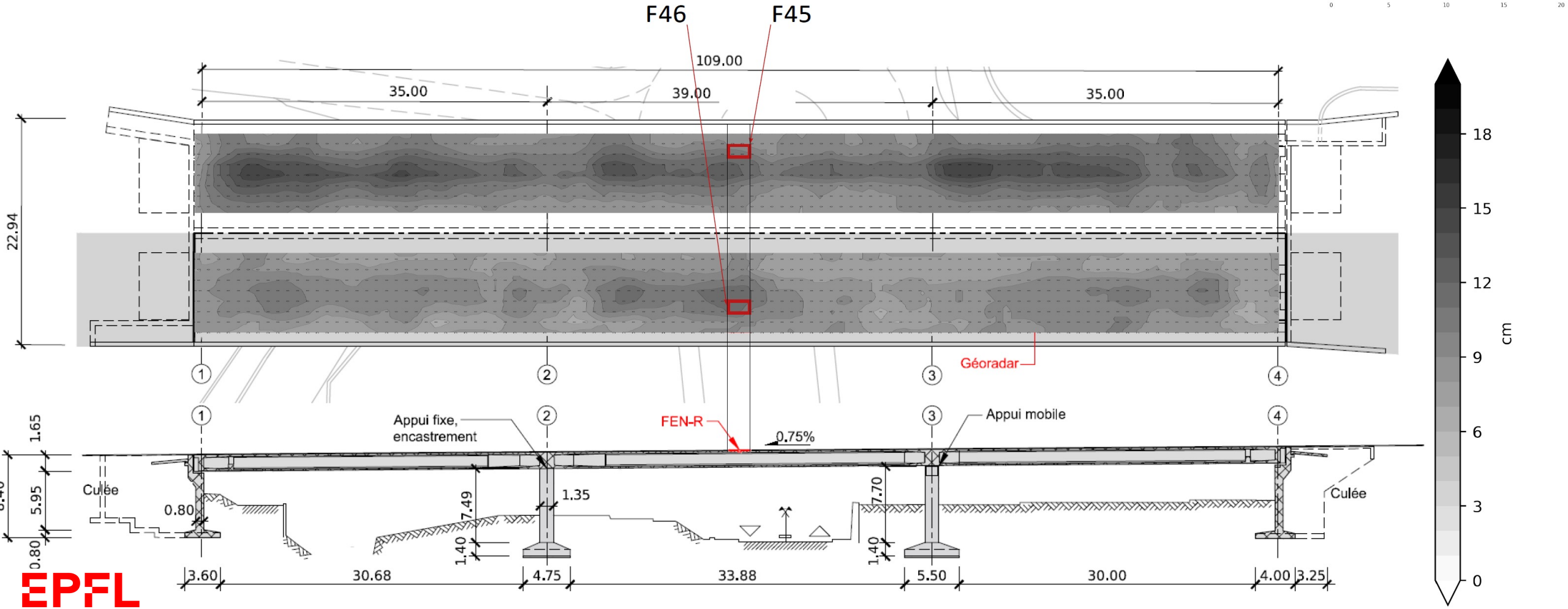
Structure mapping – Motorway Bridge

BDGY

Asphalt cover thickness



The thicknesses follow a normal distribution. The Nothern bridge has slightly higher asphalt thickness than de Southern bridge: 10.3 cm vs. 8.6 cm. Both decks have large concrete curbs without surfacing directly exposed to chlorides.



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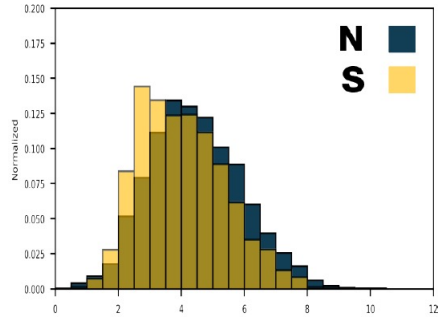
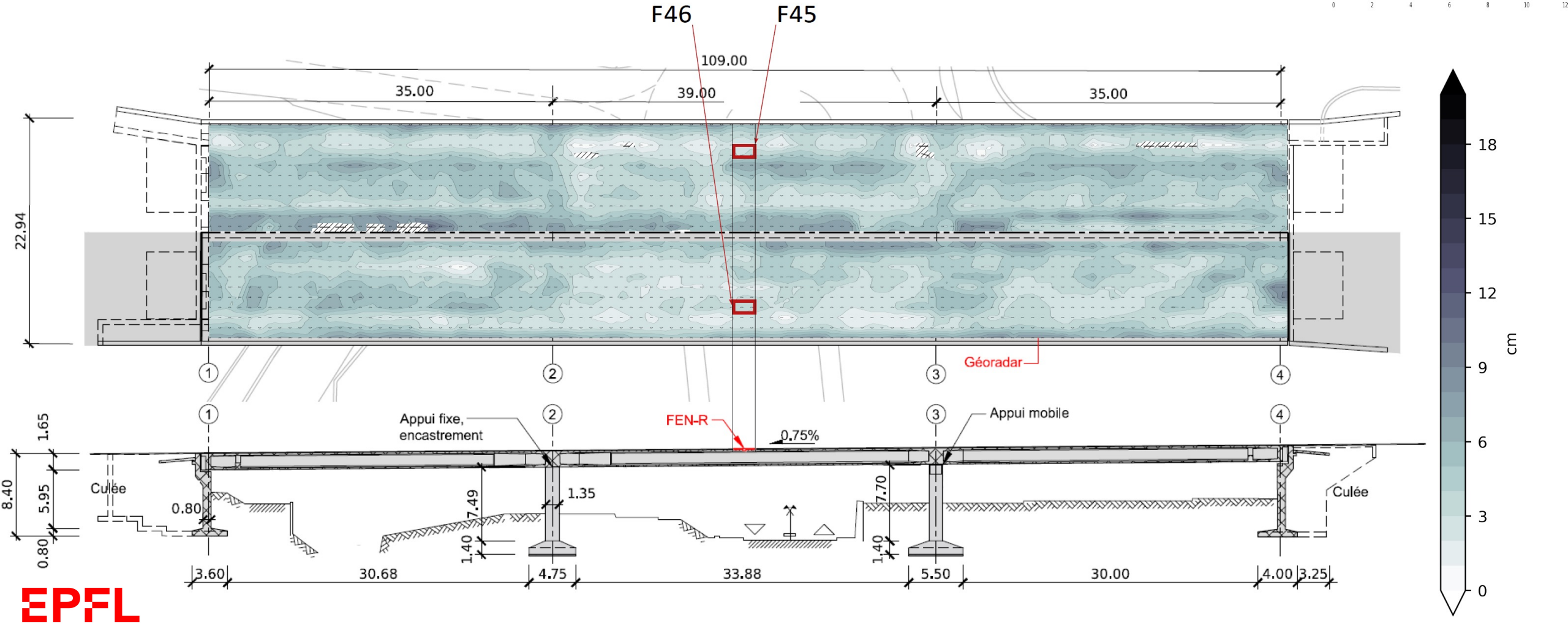
Structure mapping – Motorway Bridge

BDGY

Concrete cover thickness

The measurements follow a normal distribution on both bridges. Both decks have significant under-thickness at the edges of the structure. This suggests that the reinforcement in the exposed areas is more vulnerable.





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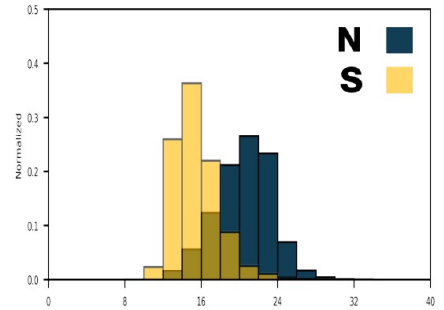
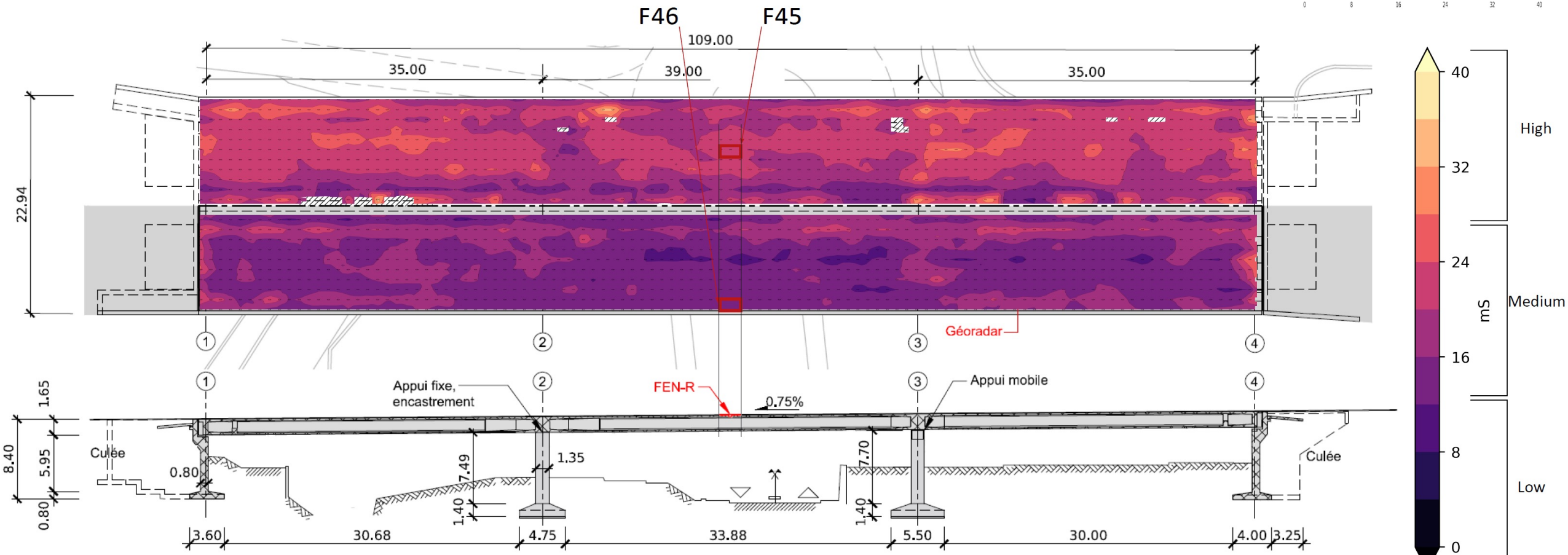
Structure mapping – Motorway Bridge

CONTAMINATION

Overall contamination is average.
However, in detail, the North deck is heavily contaminated compared to the South deck.





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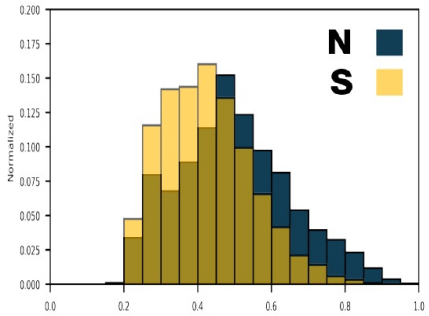
BDGY

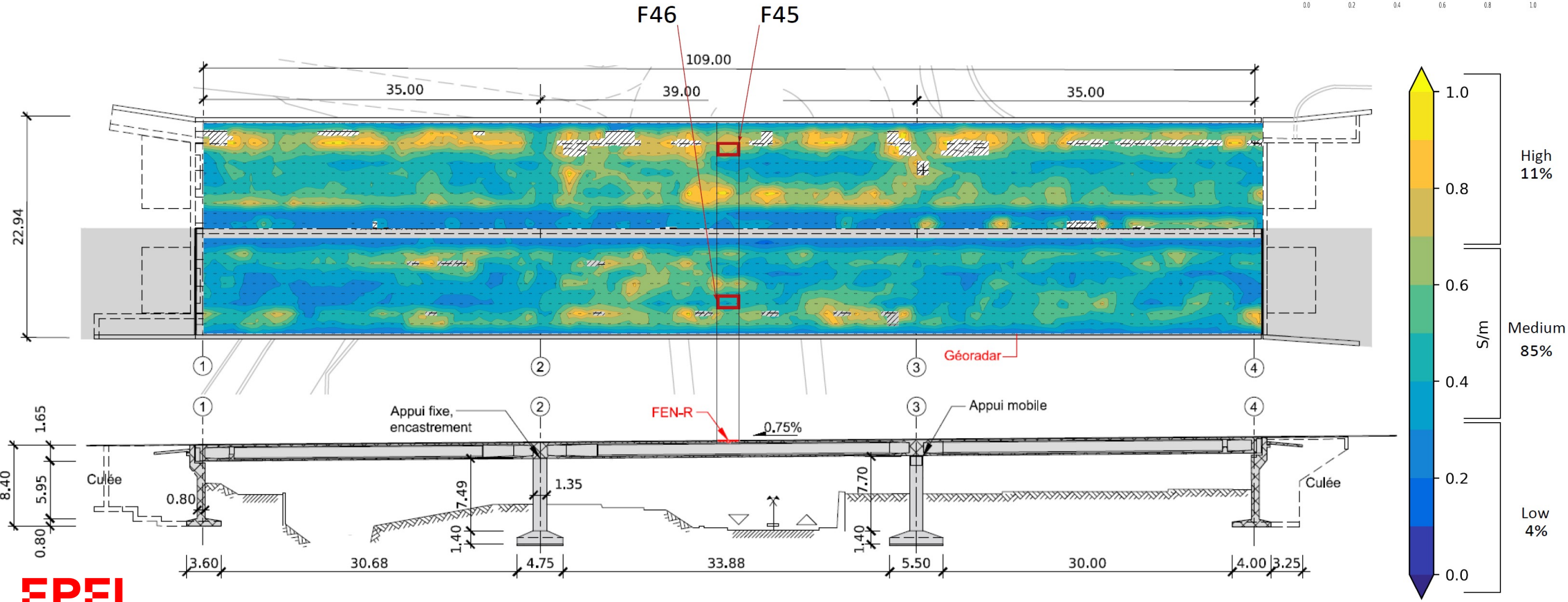
Structure mapping – Motorway Bridge

BDGY

Corrosion Risk

The overall risk of corrosion is medium. However, our analysis reveals areas with a high risk of corrosion, mainly at the edges of both decks where the cover concrete is low. The generally higher values from the Nothern deck are due to the presence of a noise reduction wall at the Nothern border.





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Structure mapping – Motorway Bridge

ADDITIONAL VERIFICATION AND CONFIRMATION OF CONTAMINATION

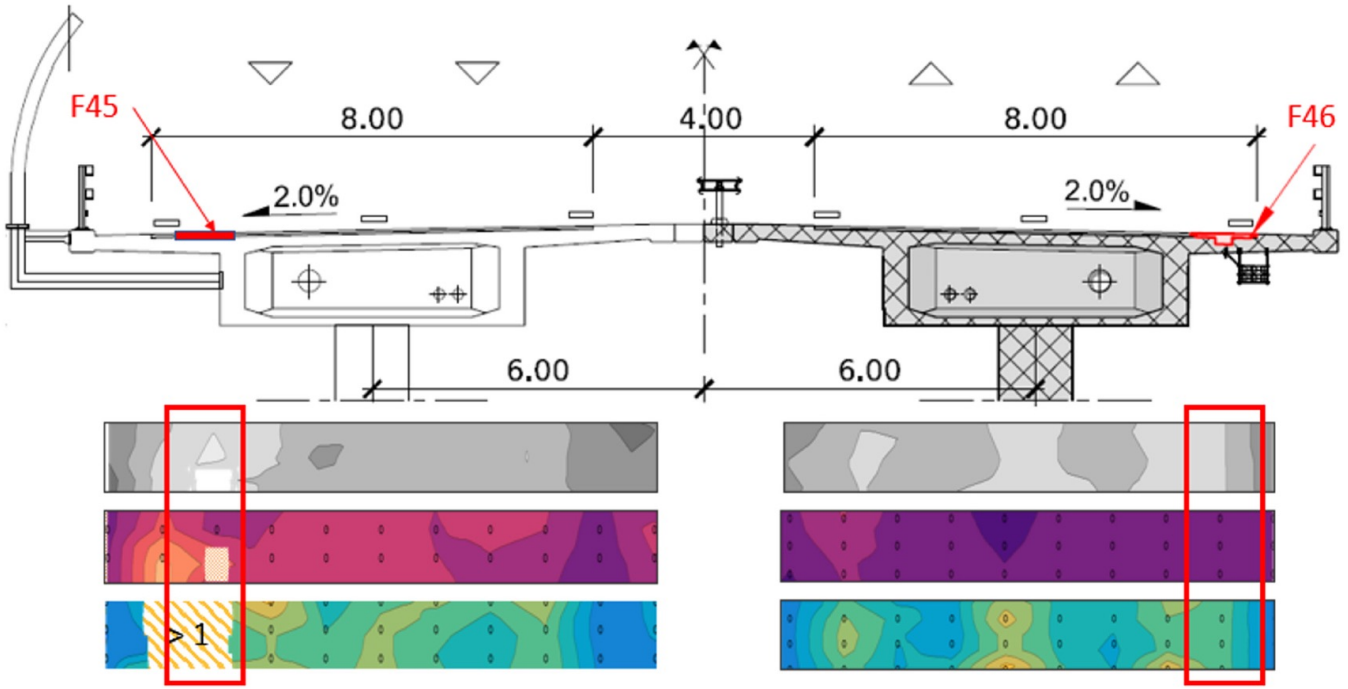
The structure having transverse prestressing, probing had been planned.

The first F46 probe was carried out in a low-contamination area.

Following signs of strand corrosion as well as high contamination values on the north deck, we recommended the opening of a second, initially it was an optional survey.

The F45 survey on the other deck confirmed the assumptions.

It was concluded that the exposed edges served as points of entry and accumulation of chlorides in the transverse prestressing ducts.

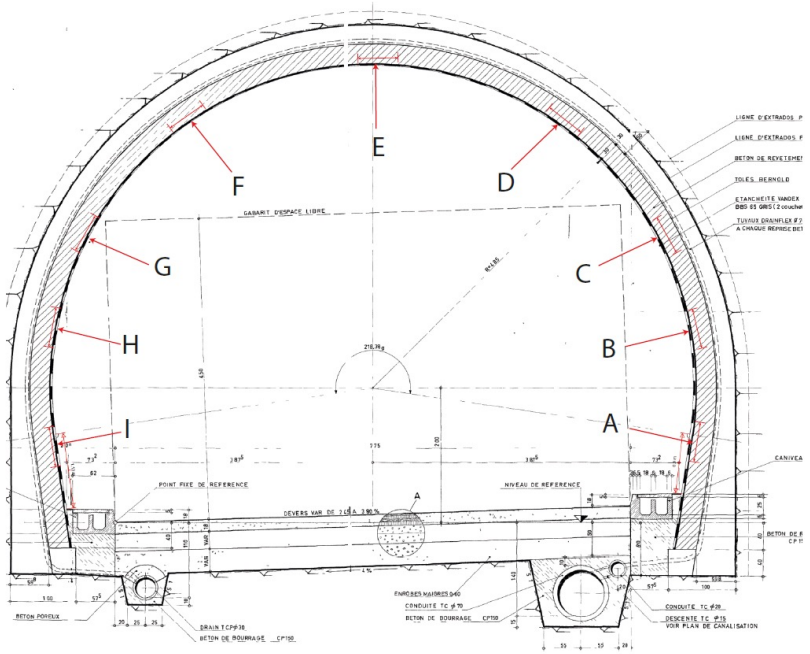


Evaluation	Caracteristics	Evaluation
	Carbonatation	
10 [mm]	Concrete Cover	32 [mm]
2.34[%]	[Cl-]	0.06[%]
	Rebar condition	
	Strand condition	
	Waterproofing	
	ASR Top	
	ASR Bottom	
	Microstructure	
50 MPa	Resistance	44.2 MPa

Structure mapping – Tunnel

Methodology

A series of 9 longitudinal profiles of 135 [m] at the nacelle. The traffic interruption lasted 2 x 6 hours. The measurement density was determined to maximise the area inspected and form a realistic compromise between the measurement time and the accuracy of the final result.



Objectives

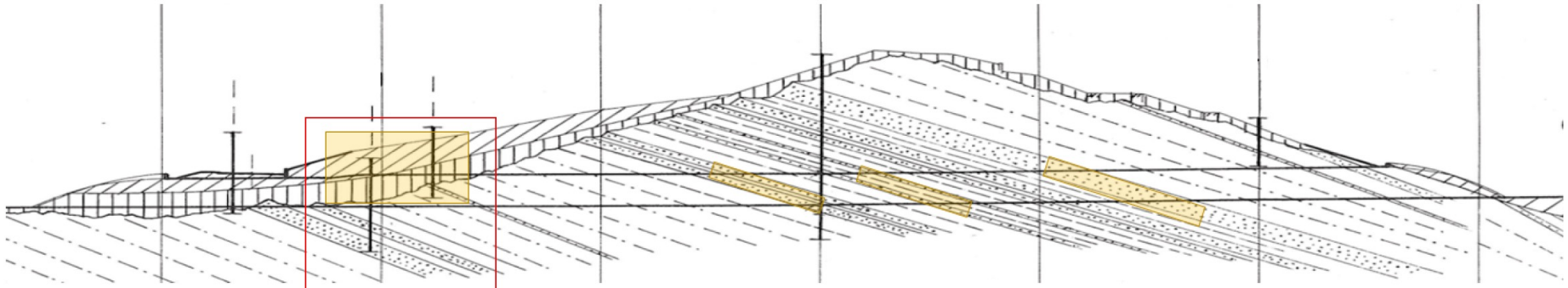
The first part of the study consisted of measuring the facing thicknesses of the structure in preparation for the renovation work.

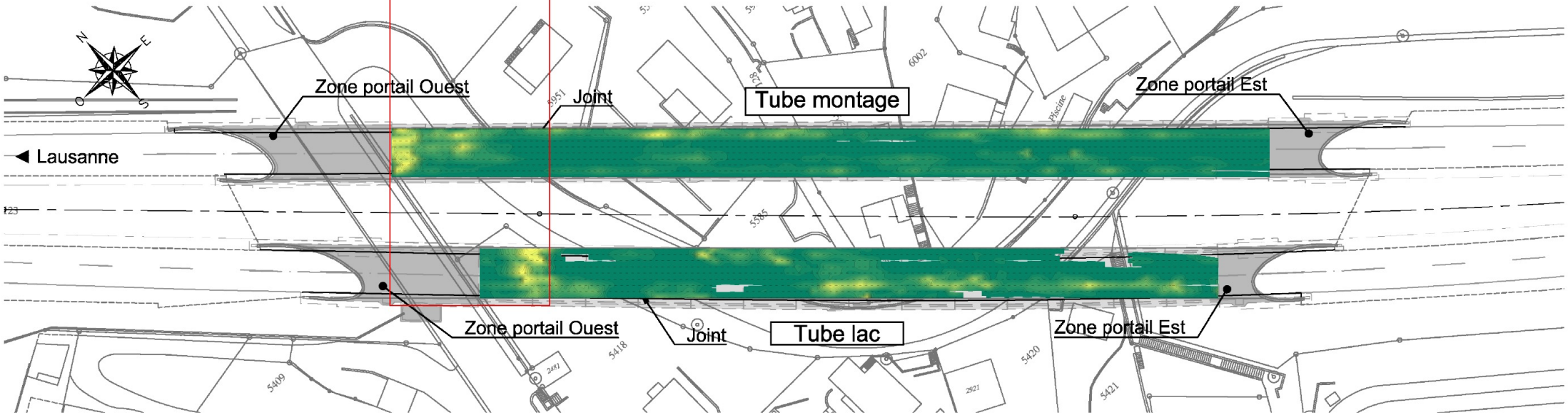
As the structure showed signs of degradation due to water circulation. The objective of the study was to determine the points of accumulation and weakness of the cladding.

Structure mapping – Tunnel

Observations

Link between the risk of detachment and the change in geological layers.
A particularly degraded area is observed at the western portal.



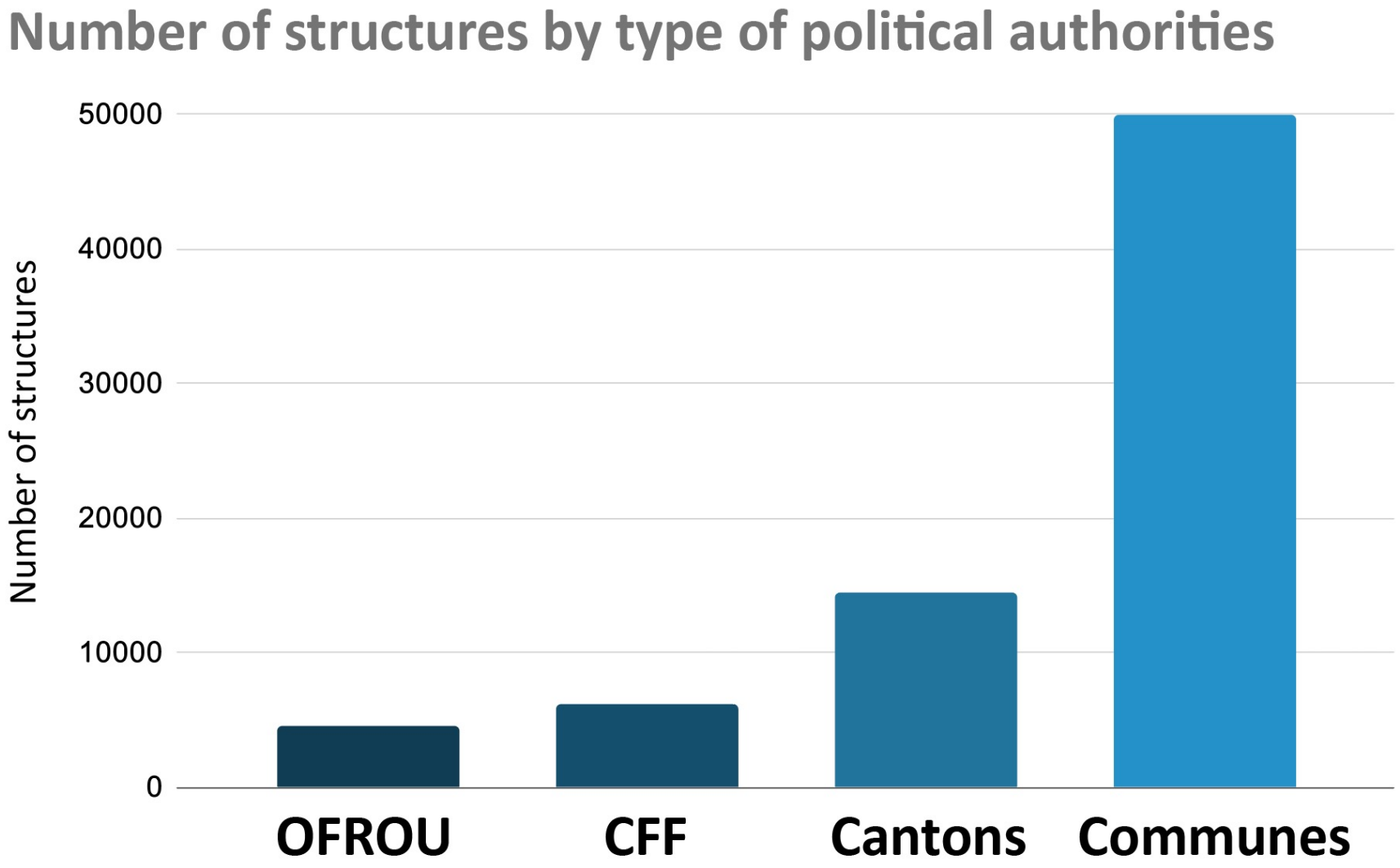


Structure mapping – Tunnel

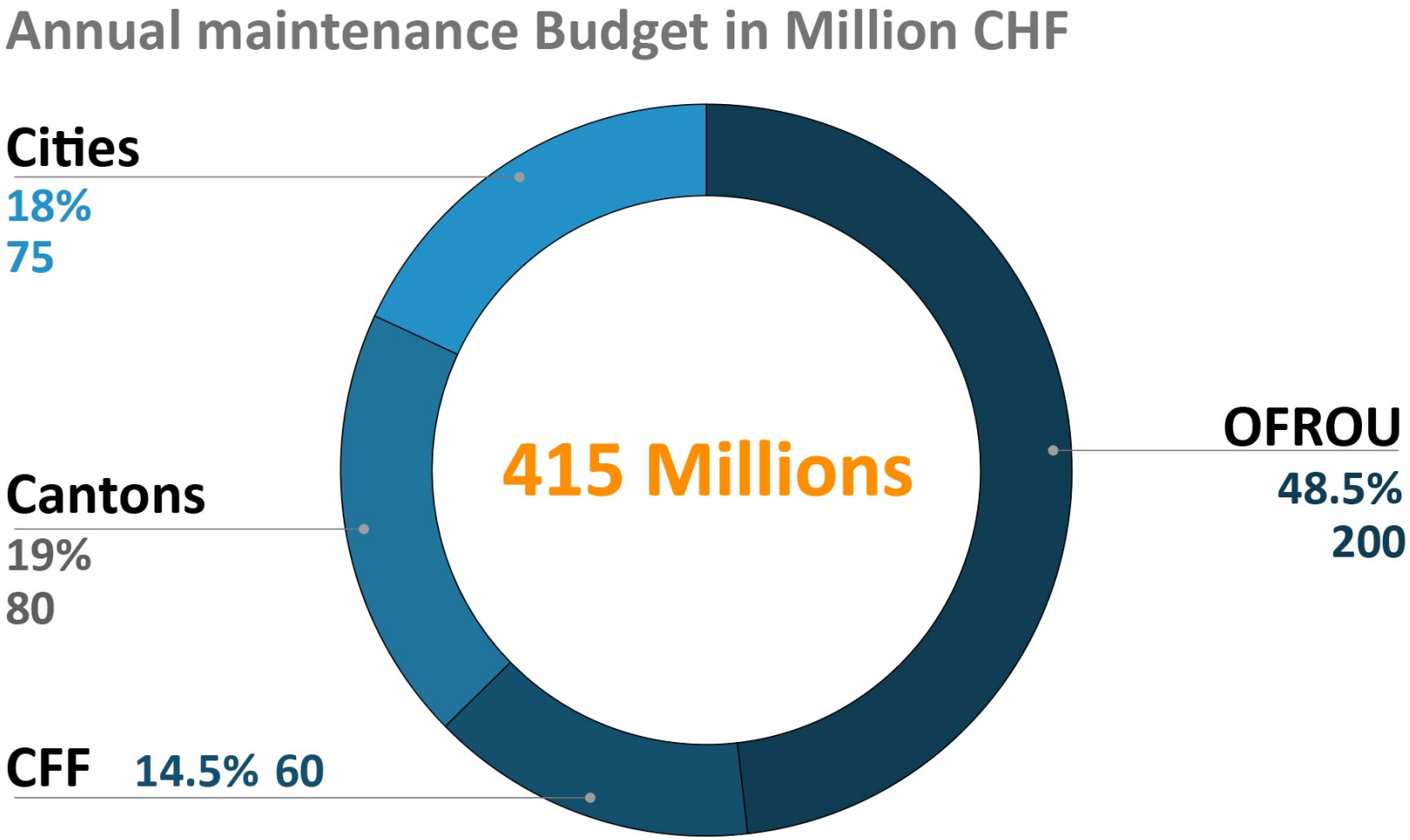
Observations

An area of soft ground is located between two roads, this area being at the apex of the infiltration observations.
It could act as an entry point and reservoir, accelerating degradation.

Future and perspectives



Future and perspectives



Future and perspectives