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SAMHÄLLE. TEKNIK. INNOVATION.

Inspektion av betongkonstruktioner på distans

TEKN. DR. COSMIN POPESCU, INVATOR AB (WWW.INVATOR.SE)

ANDREAS WERNERSSON, AFRY

PROF. BJÖRN TÄLJSTEN, INVATOR AB

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Background

- Project financed by Energiforsk
- Project team
  - INVATOR AB (Dr. Cosmin Popescu & Prof. Björn Täljsten)
  - AFRY (Andreas Wernersson)
- Problem: A major challenge in the inspection work of concrete structures in NPP is the size of the structures, which means that it is difficult to carry out inspections at close range.
- Aim: map existing technologies, commercial as well as technologies at low TRL (technology readiness level) available in the relevant literature.

Background


DTWIN
LEVEL 1
Reality capture
Image collection
Image segmentation
Point cloud registration
Object identification
1
2
n
LEVEL 2
Static twin
Non-destructive testing
Material properties
Damage detection
IFC for BIM modelling
LEVEL 3
Dynamic twin
Wireless monitoring
IoT
Simulations
Data analytics
0.85
235
8.2


https://eprijournal.com/flying-inspectors-at-nuclear-plants/

Background

Routine inspection is needed to:

- Assess current structural condition
- Anticipate future problems
- Identify needed maintenance

Visual inspection (most versatile), but:

- Highly dependent on the inspector's experience
- Problematic knowledge transfer
- Time-consuming data collection
- Subjective information

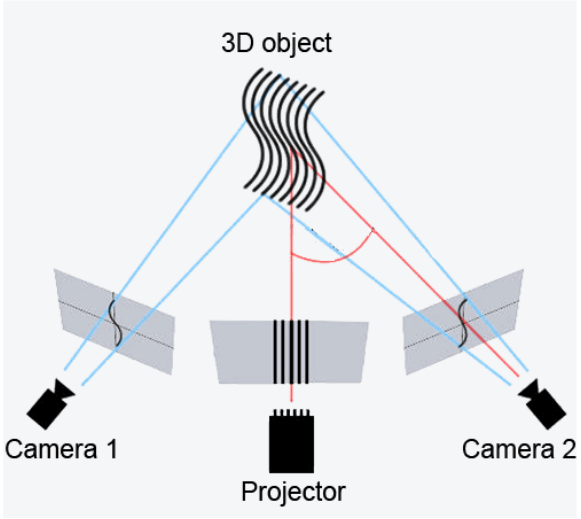
Methods for detecting surface damages

- Damage detection is the first step in a condition assessment process
- Detection methods employs different techniques:
  - visual inspection and routine observation
  - more complex non-destructive examinations.
- Focus of the project is on state-of-the-art and state-of-the-practice technology solutions to perform inspections at a distance as well as inspections of hard-to-reach structures in nuclear facilities

Imaging techniques

3D IMAGING TECHNIQUES	
ACTIVE	**PASSIVE**
• Structured light • Laser scanning • Spectral imaging	• Stereo-vision • Fixed-view approach • Multiple-view approach

Active 3D imaging – active sensors



Structured light

- It employs structured light without depending on external light source.
- The light source can be chosen between visible light, laser or infrared.
- Structured light 3D scanning devices use projected light and a camera system to shoot light onto the surface of an object.
- Mostly used indoor because of sunlight interference

Structured light

- Matterport's scanning solution uses RGB-D cameras in combination with an infrared camera
- The camera's range is about 4.5m.
- Alternative solution to visual inspection using Intel RealSense D435 depth cameras to detect external defects
- Cameras were mounted on a robot, allowing for inspection of inaccessible areas such as crawl spaces or other spaces difficult for a person to access safely. (Roudsari, S., et al. (2020).

Drone mounted - Zenmuse L1 - Lidar + RGB Surveying Solution

Laser scanning

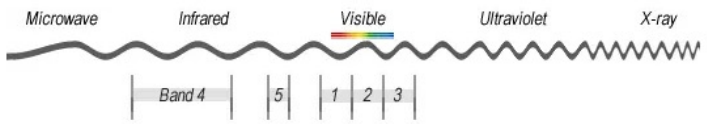
- Also known as LiDAR (light detection and ranging)
- Used to digitally recreate the as-built condition
- There are different types of laser scanners:
  - Based on triangulation principle (less known to be used in inspection of large structures)
  - Phase shift-based laser scanner;
  - Time of flight-based laser scanner.
- Three different scanning systems depending on the range of scales: airborne, terrestrial & micro-laser

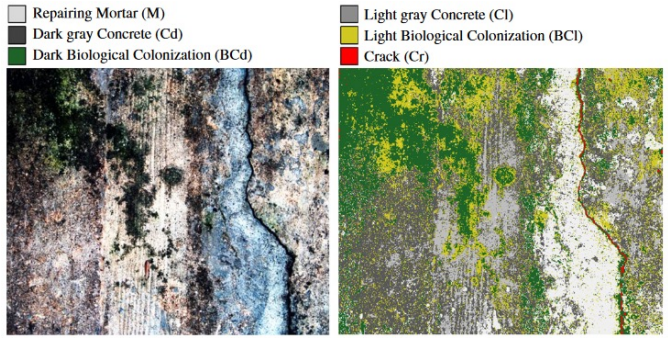
3D model of Juovajokk bridge obtained by terrestrial-laser scanning (Popescu et al., 2020)

Terrestrial laser scanning

Good results in capturing with high accuracy the geometrical characteristics.

Algorithms created to detect changes between different scanning





UV-VIS 250-500 nm UV-VIS 900-2500 nm Integrated Airborne System

Headwall's hyperspectral sensor integrated with lidar-enabled drones.

Spectral imaging

non-destructive method that provides data of reflectance information over a certain wavelength range in the electromagnetic spectrum

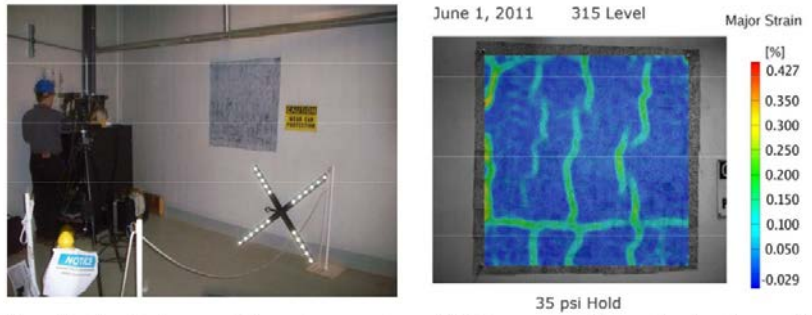
Concrete structures: to classify surface images of exposed concrete buildings where biological colonization, exposed aggregates, repairing mortars and cracks were previously detected on a visual inspection

Hyperspectral Imaging can be paired with LIDAR in order to obtain a 3D model to highlight the spectral properties of the concrete surface inspected.

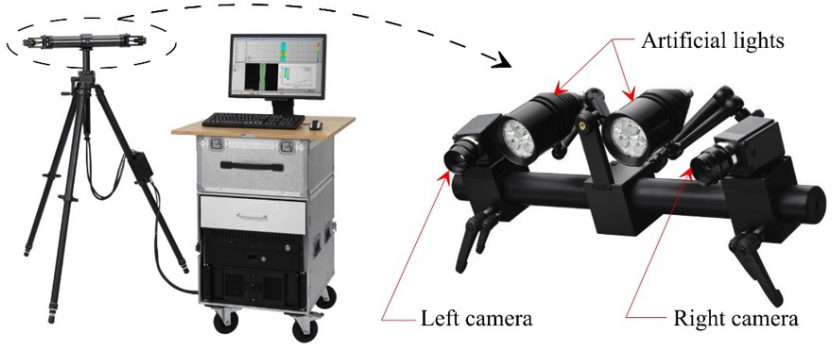
Passive 3D imaging

Stereo vision

- The technique simulates human visual depth perception
- The cameras have two lenses spaced at 60 mm apart (similar to humans' eyes) which enables them to capture slightly different images
- Post-processed in order to generate the depth map
- Works in short range, about 2 m, which makes it feasible only when is mounted on a drone.
- A commercial example is the ZED 2K Stereo Camera from Sterolabs



DIC application during a containment pressure test: (a) DIC cameras and inspection location; and (b) principal strain at 0.24 MPa showing strain concentrations – a sign of hairline cracks on the concrete surface



3D-DIC system and ARAMIS system (GOM mbH)

Fixed-view approach

A series of images are recorded using digital cameras, and coordinates of points (targets), patterns, and features in the images are subsequently identified using image processing techniques.

Single camera (2D measurements) and two synchronised cameras (3D measurements).

Depending on the type of optical targets the photogrammetry can be categorized into point-tracking (PT), **digital image correlation** (DIC) and target-less approaches

DSLR camera

DJI Mavic Pro

3DR SiteScan

Intel Falcon 8+ Octacopter

3D model of Juovajokk bridge obtained by photogrammetry

(Popescu et al., 2020)

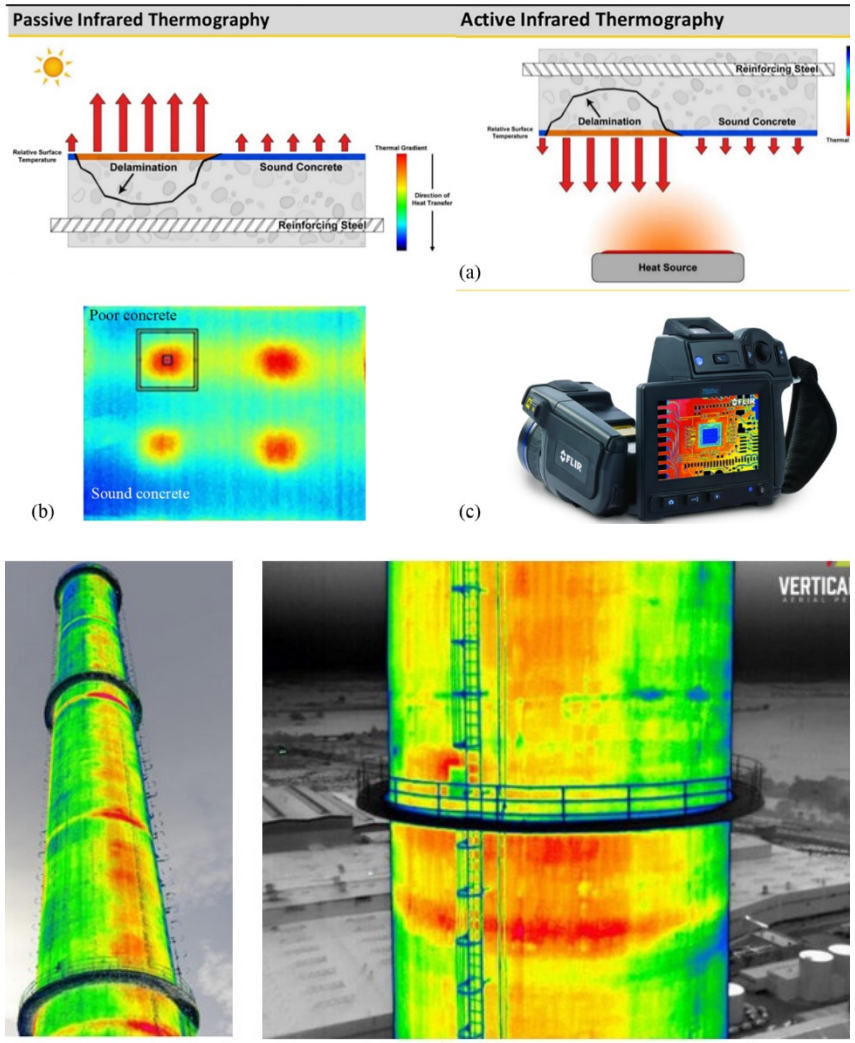
Multiple-view approach

Passive multiple view 3D imaging is also called photogrammetry

The measurement can be performed by a single camera taking multiple images around the object (60-80% overlap).

Practical application of the technique has been demonstrated on numerous applications.

Other methods

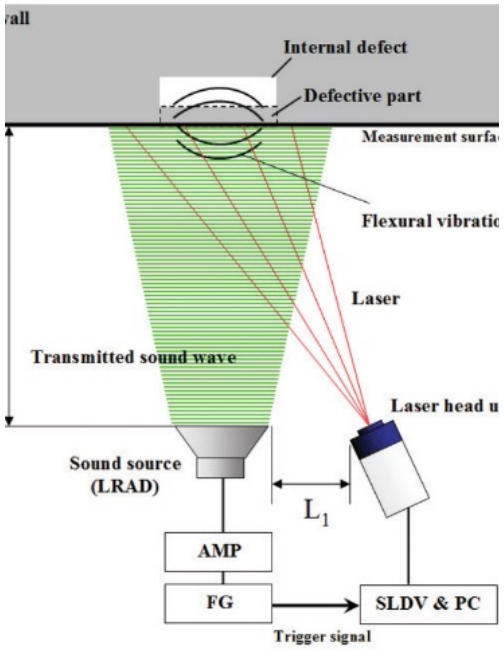


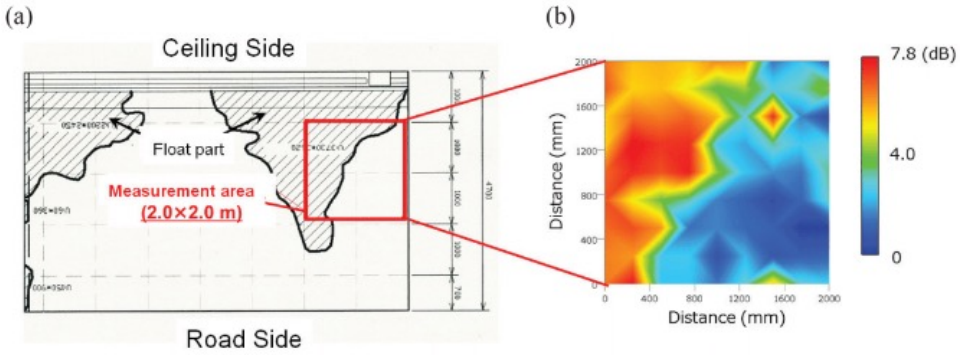
chimney model captured by workshell WIRIS thermal cameras for drones

Thermography

The infrared thermography is an inspection method used to locate near surface defects in concrete

Renshaw, Lhota et al. (2015) reported a study evaluating the feasibility of thermographic inspection of pipes, tanks, and containment liners from nuclear power plants.

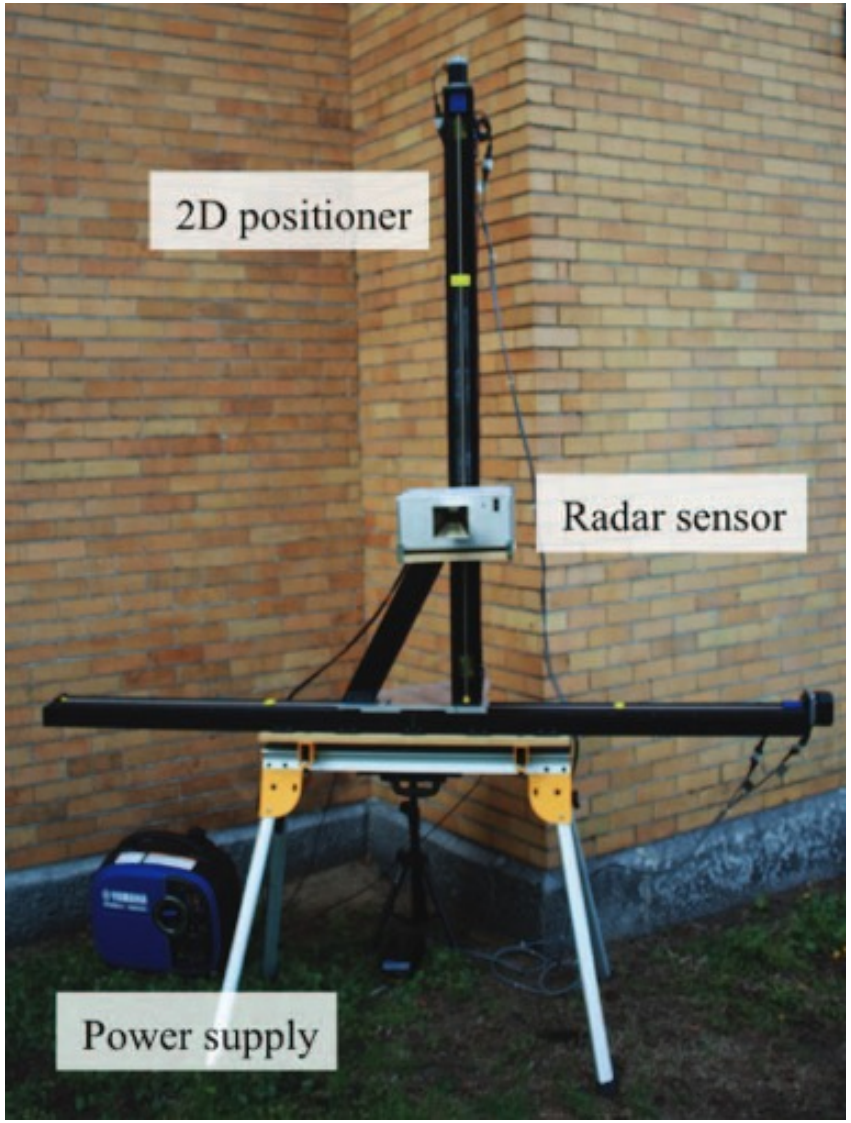




Experimental results: (a) hammering test; and (b) acoustic investigation method (Tsuneyoshi Sugimoto 2014)

Acoustic inspection

- Uses air-borne sound waves to excite the concrete surface.
- The sound waves are generated by a high-powered sound source.
- The vibration velocity on the concrete surface is optically detected by a scanning laser Doppler vibrometer.
- The upper part on the defect behaves similar to a vibrating plate with its own distinctive resonance frequency of flexural vibration.
- Measurements can be performed for distances exceeding 30 m



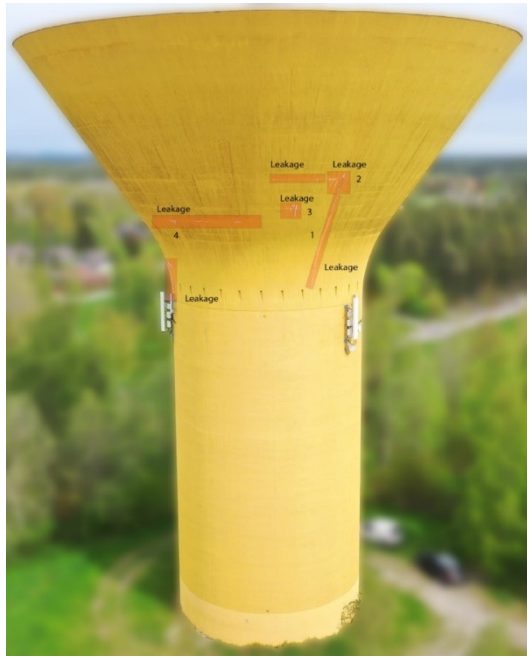
Portable radar system (Yu, Twumasi et al. 2017)

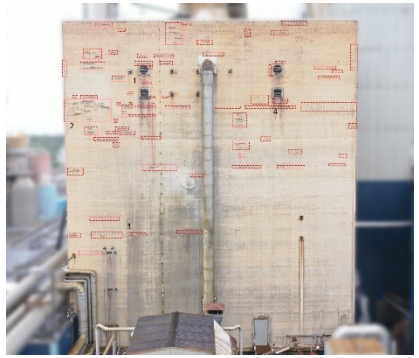
Synthetic Aperture Radar Imaging

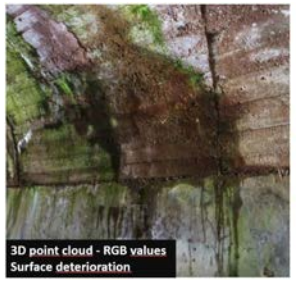
Surface as well as subsurface condition of concrete is obtained by a radar sensor able to emit electromagnetic waves penetrating dielectric materials.

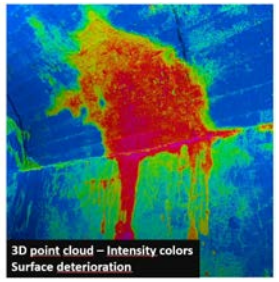
Synthetic aperture radar (SAR) is able to produce images with good resolution from distance.

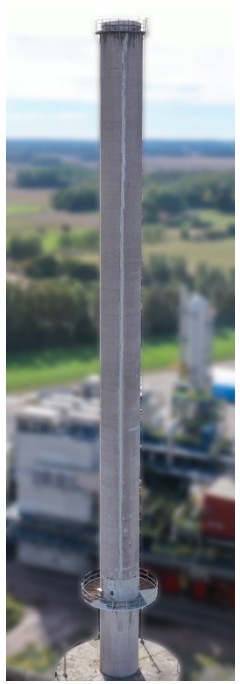
the ground-penetrating radar can perform remote sensing within close range (less than 1m) while SAR imaging technique can extend the range up to 15 m











Automatic damage detection

- Cell-based deformation algorithm
- Principal curvature
- Gradient derived from coordinated data sets
- Analyzing intensity values
- Analyzing RGB values

Implementation in Nuclear industry

Concrete makes up most of the mass in a nuclear power plant and has a passive but important role in many functions such as acting as a barriers, foundations or tunnels for safety related systems. As the general age of the world's reactors are increasing more and more focus are put on the ageing of concrete and reinforcement.

Inspections are regulated by law "*Byggnadsdelar, system, komponenter och anordningar av betydelse för säkerheten vid en anläggning ska fortlöpande kontrolleras och underhållas på ett sådant sätt att de uppfyller de säkerhetskrav som ställs.*"

Frequency for inspections not regulated but a maximum interval of 5 years is commonly considered satisfactory. Inspections are sometimes a bit tricky to perform due to for example big distances, location underwater or radiation restrictions.

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Enablers – conventional methods

Crane trucks

Rental, environmental impact

Scaffolding

Costly, personnel risk

Plattforms

Only on certain buildings

Enablers – new technology

Telescope cameras

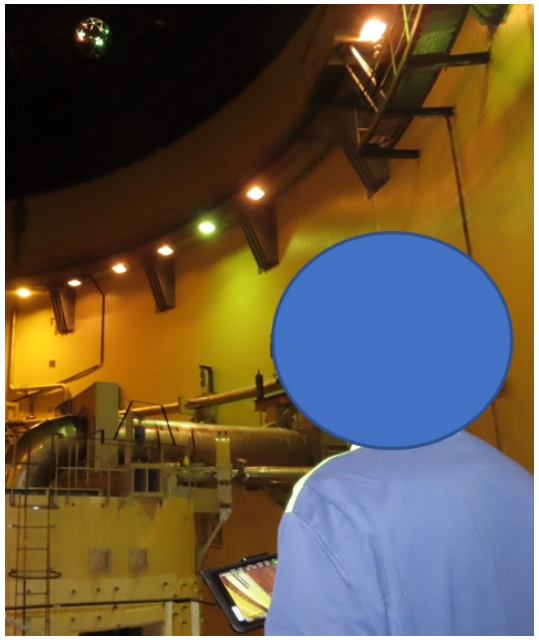
Radiation exposure reduction

ROV's

No need for draining systems

Drones

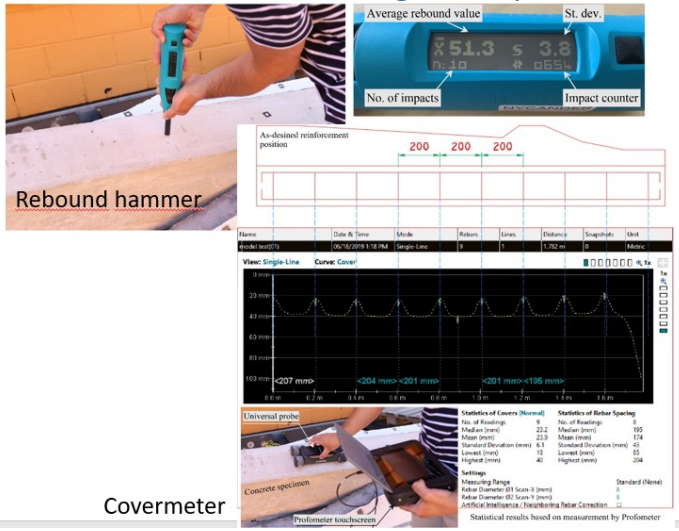
No need for scaffolding



Non-destructive testing - NDT

Static twin

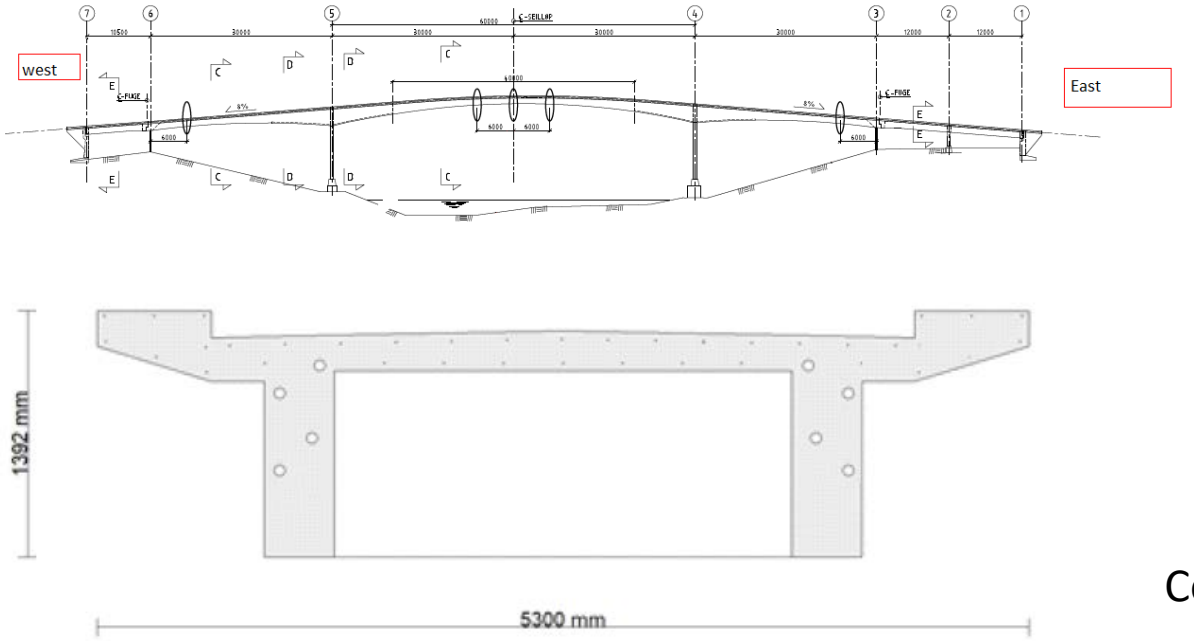
- Basic non-destructive testing techniques



- Enrich the digital model previously created with in-depth data regarding the material properties, inner geometry, and, if any, **internal damages**.
- Basic NDTs to estimate material properties, detect surface reinforcement, crack investigation

Advanced non-destructive testing

For complicated objects, such as cavities in ducts of prestressing reinforcement, different techniques must be combined. In addition, both handling and evaluation require experience



- Advanced non-destructive testing techniques

Detect steel tendons in pre/post tensioned RC bridges

Damage detection along cables (grouting defects, corrosion, etc.)

Covermeter + GPR + Shearwave Tomography + Impact Echo

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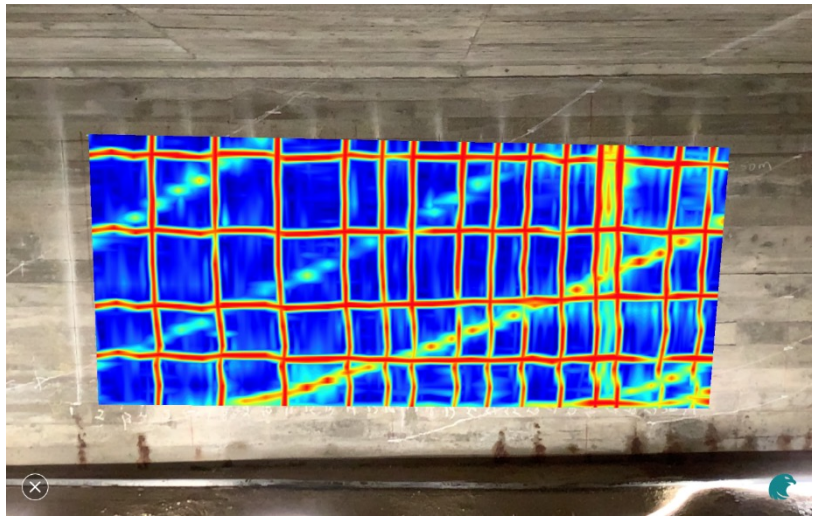
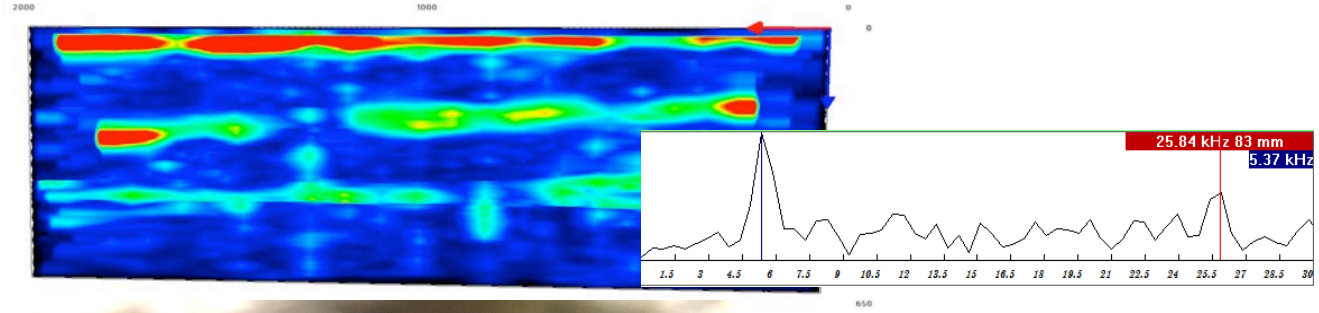
Advanced non-destructive testing

Covermeter + GPR + Shearwave Tomography + Impact Echo



Position of surface reinforcement and prestressed cables



Corrosion detection of the presrtressed tendons using Shear wave tomography + Impact echo & Verified using Endoscope

Conclusion

- Imaging methods only providing near-surface information – in-depth inspection is missing.
- Photogrammetry + laser scanning aided by drones are the most promising
- Drones-enabled inspections are not enough and can only be used as a complement to traditional inspections
- Physical functions (e.g., hammering, measuring, and testing) equivalent to a hands-on inspection cannot be replaced by drones
- Flexibility in the time performing the data collection is crucial. Unfavorable lighting conditions is likely to create difficulties in generating the 3D models
- future developments could include automated damage detection using machine learning techniques to improve the objectivity of the results (less human dependent)
- In-depth information is crucial to obtain a complete picture of the status (use of advanced non-destructive methods)

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