IM-SAFE.EU

Harmonised Transport Infrastructure Monitoring in Europe for Optimal Maintenance and Safety

IM-SAFE (ref. 958171)

www.IM-safe-project.eu

https://www.linkedin.com/company/im-safe-project/

https://cordis.europa.eu/project/id/958171

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MORNING SESSION

Moderated by P. Darò (SACERTIS Ingegneria S.r.l., Turin, Italy)

Surveying technologies

Contributors:

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Damage indicators & vulnerable elements

Contributors:

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Performance indicators for bridges and tunnels

Contributors:

A. Strauss [4], K. Bergmeister [4] and L. Ptacek [4]

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Surveying technologies

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Speaker:

A. Sánchez Rodríguez (University of Vigo, Vigo, Spain)

Dr. Ana Sánchez Rodríguez

- University of Vigo Department of Materials Engineering, Applied Mechanics and Construction
- IM-SAFE WP Leader (Diagnostics based on Inspection, Monitoring and Testing)
- Resilience of transport infrastructure to extreme events
- Expertise on inspecting and monitoring the structural condition of bridges, merging information from different sensors
- Responsible for experimental campaigns in large in-service bridges

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SURVEYING TECHNOLOGIES

a. **09:15-09:20 |** Introduction. General concepts

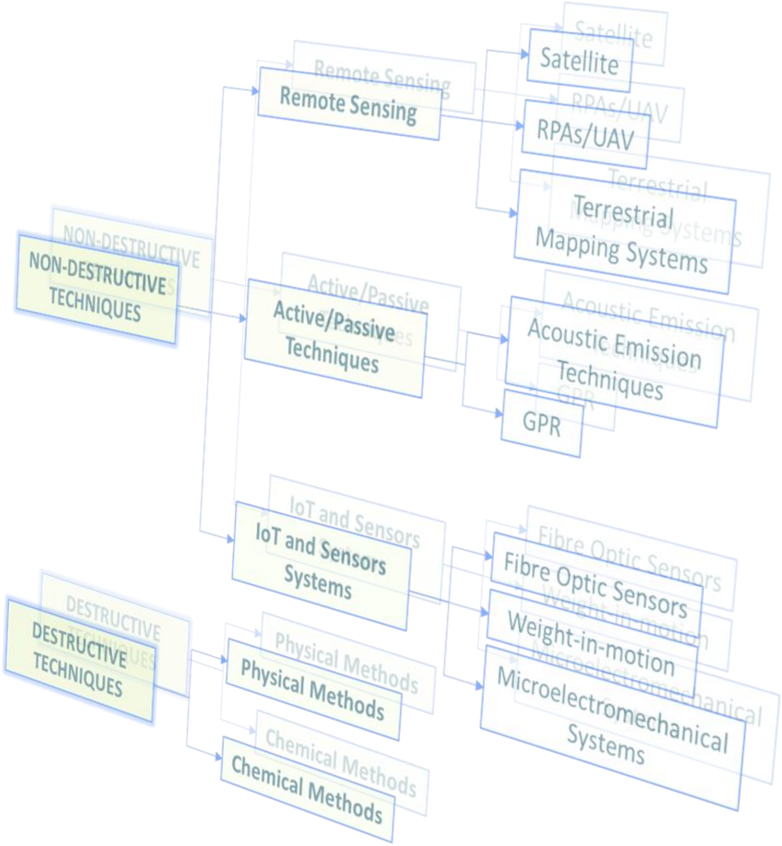
b. **09:20-09:40 |** State-of-the-practice of the most relevant surveying technologies for bridges and tunnels

c. **09:40-09:50 |** Fitness-for-purpose of surveying technologies

09:50-10:15 **Q&A**

Introduction

- Surveying technologies in the context of IM-SAFE
- General concepts
- Technologies considered in the project



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Surveying Technology

Investigation (or **Survey**)

IM-SAFE definition	Procedure related to a collecting quantitative information about network, object, component or element, performed in order to determine or identify change of its status of the items in population.[1, 2] [1] Note: Surveying activities may involve document search, inspection, testing and/or monitoring. [2] Note: Alternatively, *investigation* may be referred to as *survey*.

ISO 13822:2010	*CEN/TS 17440:2020*	*prEN1990-2*
Investigation is collection and evaluation of information through inspection, document search, load testing and other testing.[1]	Investigation is collection and evaluation of information through inspection, document search, measurements, material testing, load testing and other testing	Investigation is collection and evaluation of information through inspection, document search, measurements, material testing, load testing and other testing

[1] Note : ISO 13822:2010, *CEN/TS 17440* and *prEN1990-2:2020* use term “*investigation*”

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Surveying Technology

Surveying technology

IM-SAFE definition	*Technology applied to collect data during the survey process, which aims at gathering information about the shape and current condition for a network, structure, its components or elements and/or to about the relevant actions and hazards.*

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Testing, Monitoring and Inspection

Testing

IM-SAFE definition	*Test of the structure (or part of it) aimed at obtaining information about the current condition or performance of a structure or/and its components or elements.*
fib Model Code 2010:2013	
Procedure aimed at obtaining information about the current condition or performance of a structure or its components.	

Load testing of high-speed rail bridges (Galicia, Spain)

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Testing, Monitoring and Inspection

Monitoring

IM-SAFE definition	*Frequent or continuous, normally long-term, observation or measurement of structural conditions or actions or structural response*
ISO 2394:2015	*ISO 13822:2010*
Frequent or continuous, normally long-term, observation or measurement of structural conditions or actions or structural response.	Frequent or continuous, normally long-term, observation or measurement of structural conditions or actions.

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Testing, Monitoring and Inspection

Inspection

IM-SAFE definition	On-site examination within the scope of quality control and damage and/or condition assessment, aiming to assess the present condition of a structure.				
ISO Guide 73:2009	*ISO 13824:2009*	*EN 13306:2010*	*ISO 2394:2015*	*ISO 13822:2010*	*COST TU1402*
-	-	Examination for conformity by measuring, observing, or testing the relevant characteristics of an item.	On-site examination within the scope of quality control and condition assessment aiming to assess the present condition of a structure.	On-site non-destructive examination to establish the present condition of the structure.	On-site non-destructive examination aiming to assess the actual condition of the structure

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Permanent and Periodic monitoring

COST TU1402

Permanent monitoring

Continuous action over time by means of a permanent monitoring system on a structure towards the **collection of measurements for a long period of time**.

Periodic monitoring

Collection of measurements by means of a programmed criterium, usually a predefined threshold related to a parameter that is being measured which triggers the data recording.

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Destructive and Non-Destructive Testing

fib Model Code 2010:2013

Destructive Testing

Testing which may cause damage to the structure or marking of the surface finishes (e.g. pull-out tests, material sampling, load testing beyond the elastic range).

Non-Destructive Testing

Testing which does not cause damage to the structure by the test procedure (e.g. testing with cover meter, radar, acoustic emission, load testing in the elastic range).

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SURVEYING TECHNOLOGIES

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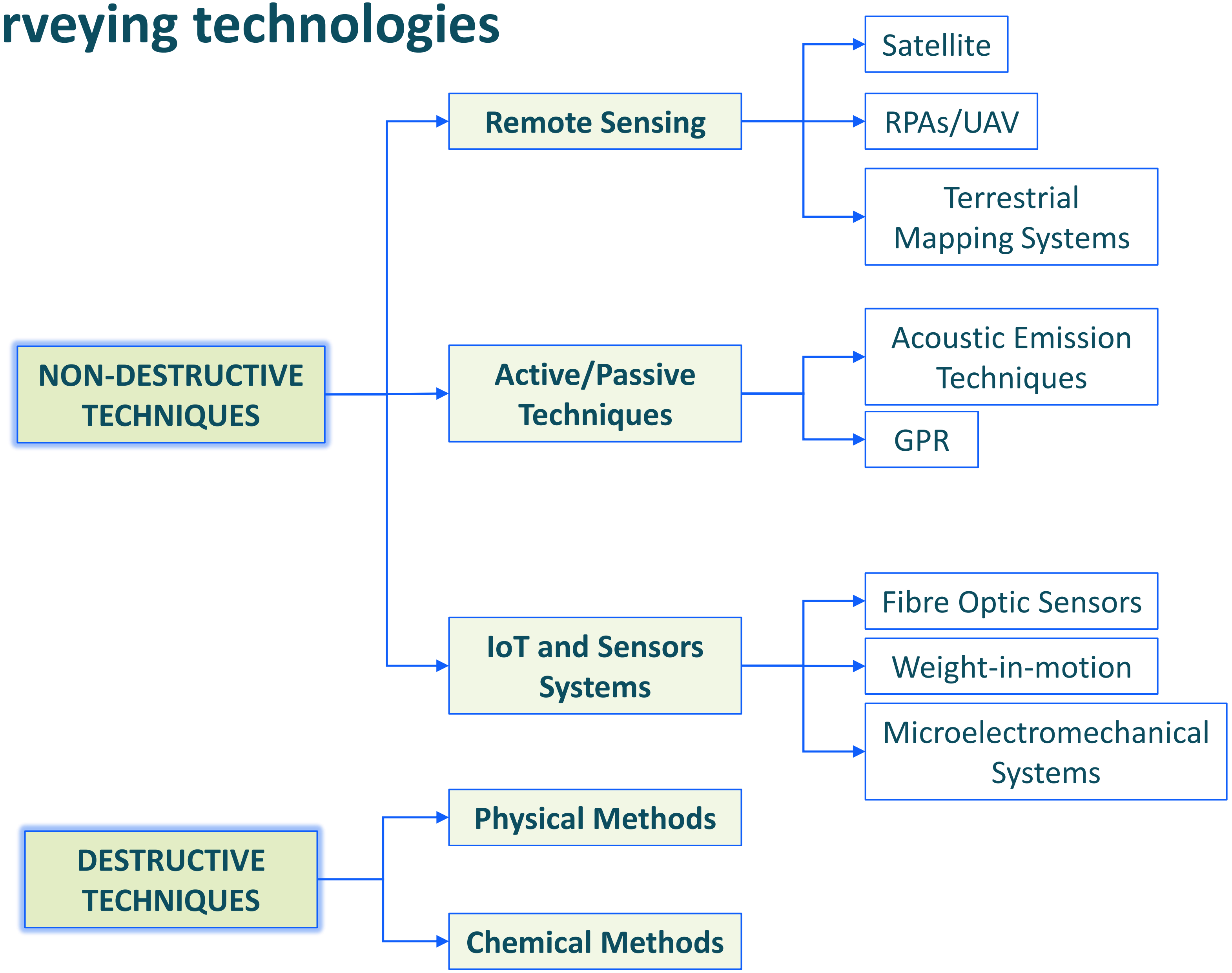
Surveying technologies



…Among others

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NON-DESTRUCTIVE TECHNOLOGIES

REMOTE SENSING

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b.

REMOTE SENSING

OBJECTIVE: Measuring and monitoring the environment without contact

TYPES

- **Satellite technologies**, including optical and radar monitoring
- Aerial und **UAV technologies**, including optical and NDT payloads
- **Terrestrial dedicated inspection platforms** and Mobile Mapping Systems including GNSS, IMU, cameras and LiDAR

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REMOTE SENSING

CHARACTERISTICS

SATELLITE

Different types of satellite depending on the measurement task.

- Data capture type: active or passive
- Resolution types:
  - Spatial resolution
  - Spectral resolution
  - Radiometric resolution
  - Temporal resolution
- Highly dependent on meteorological conditions

- Measurable damage processes:
  - Detect changes over time

RPAS/UAV

Their main contribution is to access difficult areas, lowering risks and costs.

These systems enable Aerial Robotics, which can take measurements and perform inspection tasks on bridges.

- Measurable damage processes:
  - Visual Inspection of Infrastructures
  - Visual inspection of Surface defects
  - Dependence on P/L sensors and Path Planning

TERRESTRIAL DEDICATED PLATFORMS

Focus on **Laser Scanning.**

Creates a representation of the environment in the shape of a 3D point cloud using laser beams.

- Performance:
  - Great range and data acquisition rate
  - Good precision

- Measurable damage processes:
  - Displacement/deformation
  - Rupture
  - Cracks and holes
  - Spalling

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NON-DESTRUCTIVE TECHNOLOGIES

ACTIVE AND PASIVE

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b.

ACTIVE AND PASIVE

OBJECTIVE: Detecting internal failures progressing in time and discontinuities at the measured interface

TYPES

- Acoustic Emission Techniques
- Guided Wave Techniques
- Ground Penetrating Radar
- Magnetic and Electrical Methods
- Radioactive and Nuclear Methods

GROUND PENETRATING RADAR:
a- Air-coupled (AC) system
b- AC Multi-antenna system
c- Ground-coupled (GC) system
d- Array multi-channel GC system

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ACTIVE AND PASIVE

CHARACTERISTICS

ACOUSTIC EMISSION TECHNIQUES

Challenging to get accurate results in loud service environments.

Possibility of continuous monitoring from 2-6 hours up to 24 days.

Performance requires an experienced operator and relatively complex, expensive software.

- Measurable damage processes:
  - Qualitative results: detection of cracks
  - Quantitative results: if combined with other methods (ultrasonic testing)

GROUND PENETRATING RADAR

Measuring the time arrival and amplitude (intensity of reflection) of the reflected waves.

Both static or dynamic measurements.

Sensitivity of measurements to environmental conditions.

- Measurable damage processes:
  - Cavities
  - Fractures
  - Moisture
  - Thicknesses
  - Corrosion
  - Cracking
  - Spalling
  - Delamination
  - …

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NON-DESTRUCTIVE TECHNOLOGIES

IoT AND SENSOR SYSTEMS

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IoT AND SENSOR SYSTEMS

OBJECTIVE: Monitoring of loads, deformations and accelerations on civil engineering structures to protect them from overstressing due to overloading

TYPES

- DOF Techniques
- Weight-in-Motion methods
- Fibre Optic Sensors
- Microelectromechanical Systems

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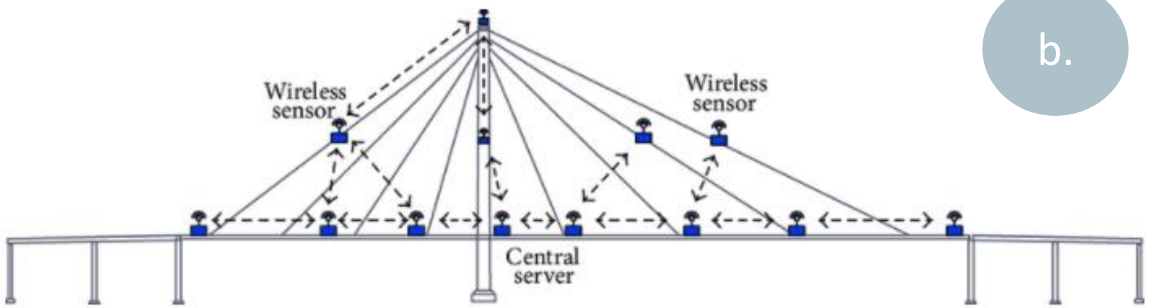
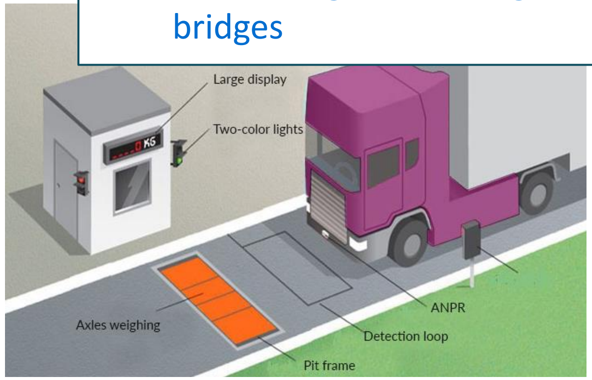


IoT AND SENSOR SYSTEMS

CHARACTERISTICS

WEIGHT-IN-MOTION SYSTEMS

- **Low Speed WIM** (LS-WIM) – weighting in dedicated area, outside of the traffic, usually on the platform.
- **High Speed WIM** (HS-WIM) – weighting in traffic with actual velocity.
- Continuous monitoring for at least 7 years when properly maintained/calibrated.
- Physico-mechanical properties quality and the stiffness of the surface (road) influence the results.
- Protection from overstress by overloaded vehicles
- Measurable processes:
  - Monitoring of existing traffic volume and loads on bridges



FIBRE OPTIC SENSORS

- Continuous measurement along the length of the monofilament
- Replacement of plenty of traditional sensors with one single optical fibre
- Longer lifetime than conventional resistance strain sensors
- Long-term signal stability under unfavourable conditions
- Possibility of placing several sensors on the same fibre
- Resistance to interference
- Low cost and highly sensitive
- Monitoring of civil engineering structures and facilities in the vicinity of the construction site

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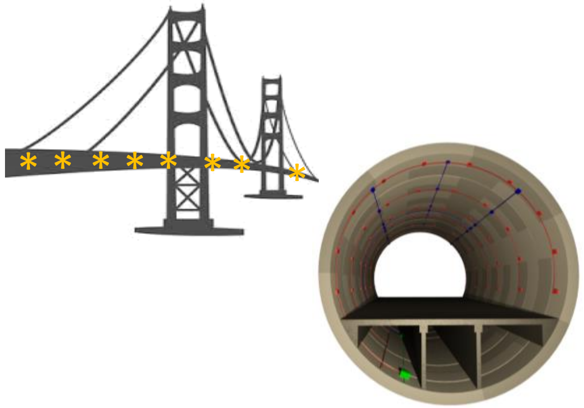
IoT AND SENSOR SYSTEMS - MEMS

b.

CHARACTERISTICS



- Widespread sensors network
- Low-cost technology
- Small-size sensors
- Easy transportation and installation
- Adjustable parametres (applicability at different fields and structures)

MEMS technology on Highways.

MEMS technology on a footbridge (monitoring of both deck and cables).

MEMS technology on Tunnels.

CLINOMETERS

- Evaluation of structure static behaviour.
- Clinometers are g-sensitive: pitch or roll measurements through a change in the projection of gravity along one or two normal axes.
- Detection of structure elements deformations
- Detection of relative displacements between different structural elements
- Damage/Degradation processes detection

ACCELEROMETERS

- Evaluation of structure dynamic behaviour.
- Acceleration measurements along one, two or three normal axes.
- Modal analysis (description of the main modes of vibration: natural frequencies, damping ratio, modal shapes, etc.).
- Assessment of structures vibrational levels
- Damage detection (change in structure modal parameters)
- Detection of anomalous vibrations

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DESTRUCTIVE AND SEMI-DESTRUCTIVE TECHNOLOGIES

PHYSICAL METHODS

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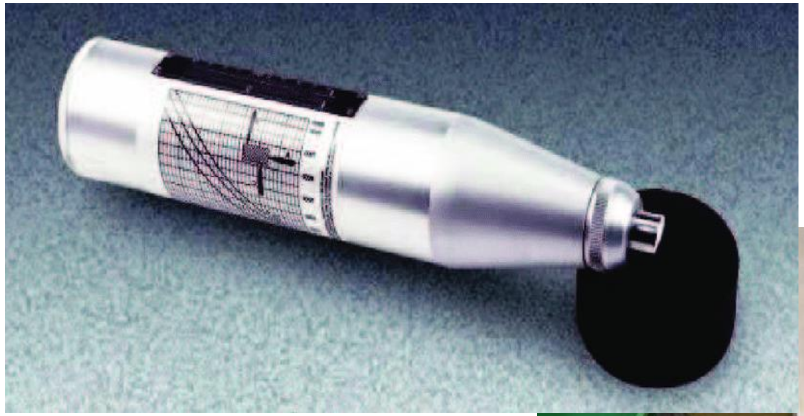
PHYSICAL METHODS

OBJECTIVE: General assessment of concrete quality and relative strength in different parts of a structure process control

TYPES

- Water absorbability test
- Schmidt rebound hammer test
- Windsor probe test
- Penetration test
- Ultrasonic Pulse Velocity method
- Boroscopy/Endoscopy
- Adhesion evaluation
- Strength evaluation
- …



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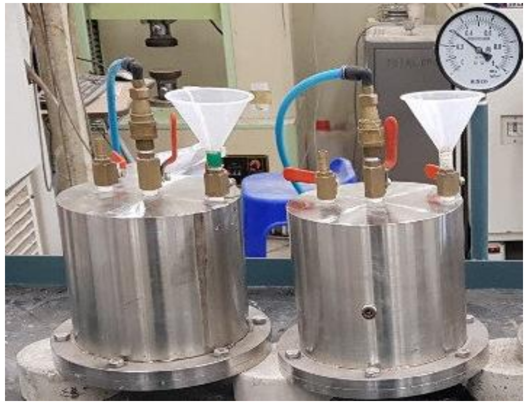
b.

PHYSICAL METHODS

CHARACTERISTICS

- Relatively quick testing
- Process control, for example in the preparation of anti-corrosion coatings
- Design studies of facilities subjected to dynamic loads
- Technical expertise regarding assessment of impact of vibrations
- Construction appraisal and diagnostics



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DESTRUCTIVE AND SEMI-DESTRUCTIVE TECHNOLOGIES

CHEMICAL METHODS

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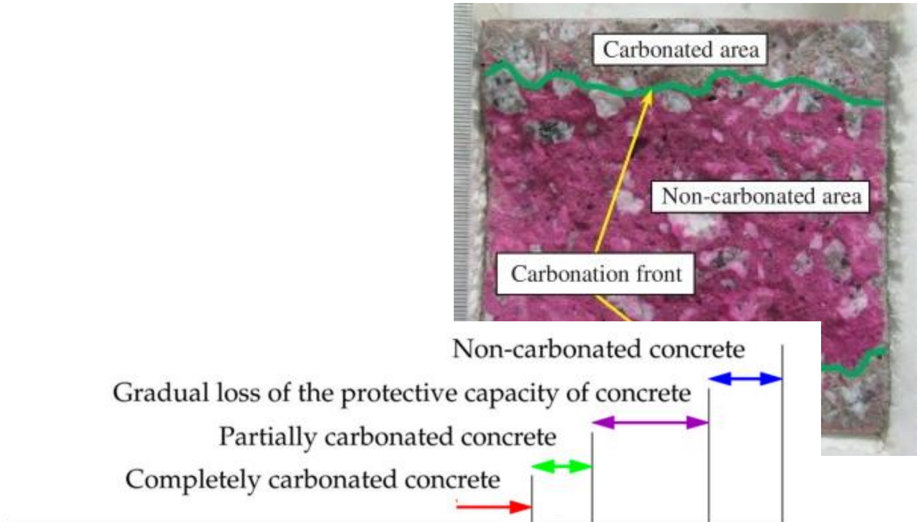
CHEMICAL METHODS

OBJECTIVE: Assessment of the natural ability of concrete to protect the reinforcement against corrosion, measurement of the carbonation process depth and testing concrete and protective coatings resistance to chloride penetration

TYPES

- **Qualitative analysis:**
  - Phenolphthalein test
  - Thymolphthalein test
  - Rainbow test
- **Quantitative analysis:**
  - Alkali content test
  - Chloride ions test
  - Concrete resistivity test
  - Half-cell potentials method
  - Galvanostatic pulse technique



pH value:	5	6	7	8	9	10	11	12	13
RAINBOW-TEST	5		7		9		11		13
Phenolphthalein Test	< 8.5			> 9.5					
Thymolphthalein Test	< 9.3					> 10.5			

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CHEMICAL METHODS

CHARACTERISTICS

- Can be performed in laboratory or on the construction site – directly in the investigated structure, on freshly prepared forgings
- Simplicity and speed of the measurement
- Easy feasible to repeat
- During the performance of tests when determining the current technical condition of the facility in connection with the planned renovation
- During renovation works to determine the size of the necessary forgings
- During the implementation of sclerometric measurements, as a measurement facilitating their correct interpretation

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SURVEYING TECHNOLOGIES

DATA COLLECTION

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b.

DATA COLLECTION

SURVEY PLANNING

- Identification of critical sections and attributes of interest
- Survey location or route to follow
- Temporal and spatial scope
- Instruments’ layout and installation
- Safety assessment and permissions

DESIGN CONSTRAINTS

- Technological limitations (e.g., instrument specifications)
- Adverse environmental conditions
- Obstacles, occlusions

SYSTEM PREPARATION

- Calibration
- Installation
- Initialisation and setup
- Post-installation verification (i.e., survey trial)

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SURVEYING TECHNOLOGIES

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b. **09:20-09:40 |** State-of-the-practice of the most relevant surveying technologies for bridges and tunnels

c. **09:40-09:50 |** Fitness-for-purpose of surveying technologies

09:50-10:15 **Q&A**

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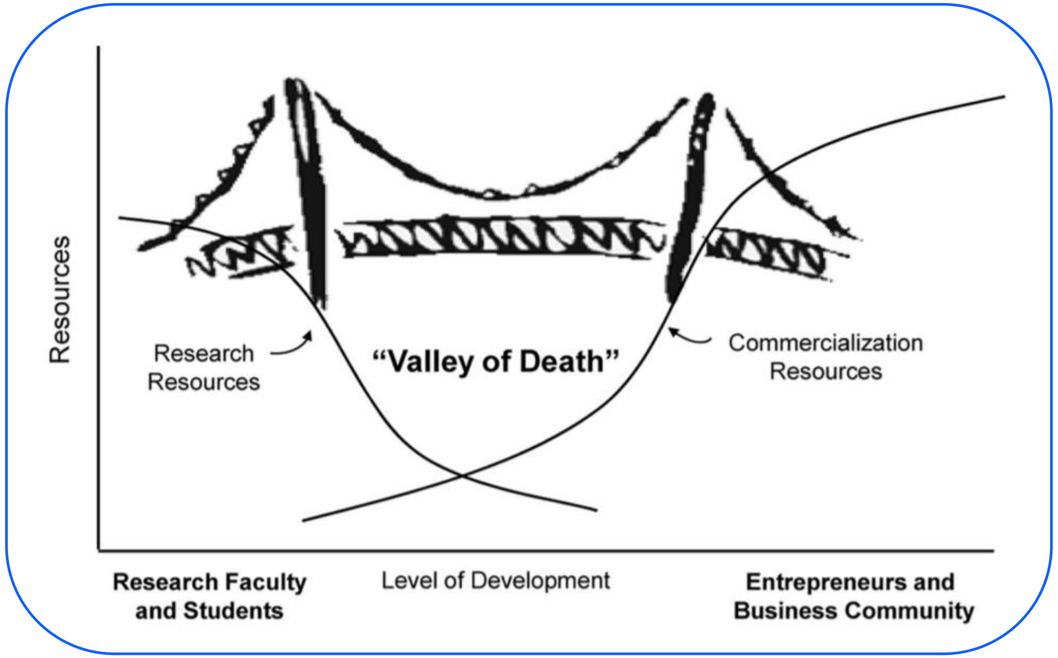
Fitness-for-purpose



The Valley of Death Bridging the Gap Between Research and Commercial Application (STEVE H. BARR et al., 2009)

Idea ✓

Research ✓

Mature technology ✓

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Fitness-for-purpose

Technological Readiness Level (TRL)

TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

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Fitness-for-purpose

Measurement of:

- Cracks
- Displacements
- Holes
- …

Through the use of application-specific **DATA ANALYSIS METHODS**

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Fitness-for-purpose

"Degree of acceptance (or relevance) of a technique/technology (models, items,…) and its associated data analysis methods in providing reliable information for the structural evaluation in a particular application"

CURRENT OR BEST PRACTICE — VS — TRENDS

- Which is the approach for measuring it?

→ To be addressed in IM-SAFE.EU

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PRINCIPLES FOR STANDARDIZATION

- **Definitions and vocabulary in the context of monitoring**
- **Decision making regarding the monitoring strategy:**
  - Definition of the objectives of the monitoring activities
  - Choice of the monitoring type
  - Choice of the measured quantities
  - Definition of the required measurement accuracy
  - Selection of the monitoring technologies
  - Design of the monitoring system
  - Evaluation of alternative monitoring strategies by a cost-benefit analysis

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SURVEYING TECHNOLOGIES

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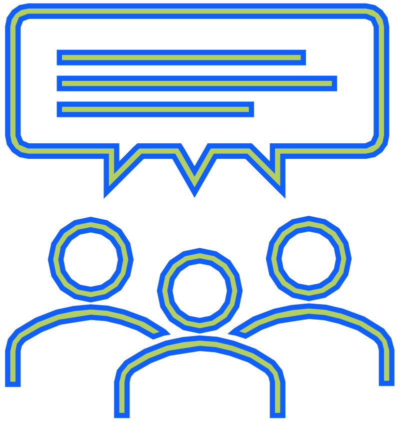
b. **09:20-09:40 |** State-of-the-practice of the most relevant surveying technologies for bridges and tunnels

c. **09:40-09:50 |** Relevant aspects to be considered in the decision-making process for survey

09:50-10:15 **Q&A**

Q&A



- **WHAT ASPECTS SHOULD BE STANDARDISED** in the context of **structural monitoring** to remain open for other technologies?

- Does the **SPECIALIZED TRAINING** required for the various surveying technologies **prevent their adoption in practice**?

- Does advance training equally influence the **different phases of data collection** (sensor installation, calibration, initialization, data gathering)?

Other questions:

- When implementing any of the surveying technologies for condition survey, do you use any quality specifications or requirements?

Thank you all for attending, questions, input, etc.

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