Harmonised Transport Infrastructure Monitoring in Europe for Optimal Maintenance and Safety

IM-SAFE (ref. 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:

B. Riveiro Rodríguez [1], A. Sánchez Rodríguez [1] and A. Strauss [4]

Performance indicators for bridges and tunnels

Contributors:

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Damage indicators & vulnerable elements

Contributors:

B. Riveiro Rodríguez , A. Sánchez Rodríguez and A. Strauss

Speaker:

B. Riveiro Rodríguez (University of Vigo, Vigo, Spain)

Prof. Dr. Belen Riveiro Rodríguez

- University of Vigo Department of Materials Engineering, Applied Mechanics and Construction
- Expertise on the application of remote sensing in structural engineering for the automated modelling, inspection and model updating of in-service structures.
- Secretary of ISPRS WG II/10 3D Mapping for Environmental & Infrastructure Monitoring
- Coordinator of international actions on resilience of transport infrastructure to extreme events.

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Damage indicators and vulnerable elements

a. **10:30-10:45|** Damage Indicators for main damage processes for transport infrastructure

b. **10:45-11:00 |** Typologies of structures (bridges and tunnels)

Identification of vulnerable elements for bridges and tunnels

c. **11:00-11:30 | Discussion:** Applicability of Damage Indicators and surveying technologies for vulnerable elements

Q&A

Damage indicators and vulnerable elements

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Q&A

a.

Definition of Damages

IM-SAFE definition	Change in the condition of a structure, structural components or structural members that can unfavourably affect its current of future structural performance.

fib Model Code 2010:2013	*COST TU1402*	*ISO 13822:2010*	*prEN 1990-2:2021*	*ISO 2394:2015*
Physical disruption or change in the condition of a structure or its components, caused by external actions, such that some aspect of either the current or future performance of the structure or its components will be impaired.	Change in the condition of the structure that can affect the structural performance unfavourably	Unfavorable change in the condition of a structure that can affect structural performance.	Unfavourable change in the conditions of a structure that can adversely affect structural performance.	Unfavourable change in the condition of a structure that can affect the structural performance unfavourably.

Definition of Damage Indicators

IM-SAFE definition	A measurable and/or testable parameter that serves for quantitative or qualitative damage detection, damage localisation and/or damage characterisation.

Definition of Damage Assessment

IM-SAFE definition	Process of ascertaining the severity of the damage to a structure

ISO 13824:2009	*ISO 13824:2020*	*COST TU1402*
		Process of ascertaining the severity of the damage to a structure

Definition of Damage Characterization

IM-SAFE definition	Process of determining the time of occurrence, the physical location, the size and other features of the damage.

ISO 13824:2009	*ISO 13824:2020*	*COST TU1402*
		Process of ascertaining the time of occurrence, physical location and the size of the damage

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a.

Damages & Degradation Mechanisms

Bridges

Degradation mechanisms		Class of defects					
		Deformation	Destruction	Loss of material	Discontinuity	Contamination	Displacement
Physical	Accumulation of inorganic dirtiness [a, b]		□	□		■	■
	Cyclic freeze–thaw action[a, b]		■	■	□	□	
	Erosion[a, b]		□	■			
	Crystallization[a]		■	□	□		
	Extreme temperatures[a, b]	□	□	□	□	□	□
	Creep[a, b]	□					
	Relaxation[a, b]	□			□		
	Shrinkage[a]	□	□	□	■		
	Overloading[a, b]	■	□	■	■		■
	Fatigue[a, b]		■		□		
	Geotechnical condition changes[a, b]	■		□	■		
Chemical	Carbonation[a]		■				
	Corrosion[a, b]	□	■	■	□	□	
	Aggressive compounds action[a, b]		■	□		□	
	Chemical dissolving/leaching[a, b]		■	□		■	
	Reactions between material components[a, b]	□	■	■	□		
Biological	Accumulation of organic dirtiness[a, b]		□	□		■	□
	Activity of microbes[a, b]		□	□		■	
	Activity of plants[a, b]	□	□	□	□	■	□
	Activity of animals[a, b]		□			□	

Note: ■-basic degradation mechanism, □-additional degradation mechanism

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Damage Processes

Bridges

Nº	Proposed Damage Processes	Material			Impact			
		Concrete	Steel	Masonry	Change in geometry	Change in integrity	Change in material properties	Change in actions
1	abrasion	•	•	•	•	•		
2	aggradation (alluviation)	•	•	•				•
3	erosion	•	•	•	•	•		•
4	pitting corrosion	•	•		•	•	•	
5	changing geotechnical conditions	•	•	•	•	•		•
6	aging of material	•	•	•	•	•	•	
7	alkali aggregate reaction	•			•	•	•	
8	chemical action	•	•	•	•	•	•	
9	corrosion related to prestressing steel	•	•		•	•	•	
10	corrosion related to reinforcement steel	•			•	•	•	
11	corrosion related to structural steel		•		•	•	•	
12	fatigue	•	•			•	•	
13	sulphate reaction	•			•	•	•	
14	corrosion related to equipment made of steel	•	•		•	•	•	
15	corrosion related to fixings, connectors	•	•		•	•	•	
16	overloading of an element	•	•	•	•	•		•
17	biological growth	•	•	•	•	•	•	•
18	freeze-thaw	•		•	•	•	•	
19	high temperature		•		•	•	•	
20								

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a.

Damage Indicators DIs

Bridges

Class of defect	Type of defect	Category of defect
Deformation	Incorrect geometry of constructed element	Incorrect shape of concrete or steel profiles[a, b]
		Invalid arrangement of reinforcement or of bolts, rivets, welds[a, b]
		Invalid arrangement of prestressing tendons[a]
	Change of the geometry of the element axis	Excessive elastic deformation[a, b]
		Permanent deformation[a, b]
	Change of the geometry along the element length	Excessive elastic deformation[a, b]
		Permanent deformation[a, b]
Destruction of material	Change of the chemical characteristics	Change of concrete characteristics[a]
		Change of reinforcing steel characteristics[a]
		Change of prestressing steel characteristics[a]
		Change of protective layer characteristics[a, b]
		Change of profile steel or steel slabs/walls characteristics[b]
		Change of bolts, rivets, welds characteristics[b]
	Change of the physical characteristics	Change of concrete characteristics[a]
		Change of reinforcing steel characteristics[a]
		Change of prestressing steel characteristics[a]
		Change of protective layer characteristics[a, b]
		Change of profile steel or steel slabs/walls characteristics[b]
		Change of bolts, rivets, welds characteristics[b]
Loss of material	Loss of structural material	Loss of concrete[a]
		Loss of reinforcing steel[a]
		Loss of prestressing steel[a]
		Loss of profile of steel or steel slabs/walls[b]
		Loss of bolts, rivets, welds[b]

4.1.2.1.3 Damage indicators for assessment of bridges
Tables 4-5 and 4-6 show a breakdown of defects into
bridges, which can be used for a systematic arranger
processes in bridges. Since these defects in many case
makes sense to transfer this systematic to damage indica

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a.

Damage Indicators DIs

Bridges

Class of defect	Type of defect	Category of defect
Loss of material		
	Loss of the material of the protective layer	Loss of material of concrete protection[a]
		Loss of protection of reinforcing steel[a]
		Loss of protection of prestressing steel[a]
		Loss of protection of profile steel or steel slabs/walls[b]
		Loss of protection of bolts, rivets, welds[b]
Discontinuity	Crack	Crack of concrete[a]
		Crack of reinforcing steel[a]
		Crack of prestressing steel[a]
		Crack of protective layer[a, b]
		Crack of profile steel or steel slabs/walls[b]
		Crack of bolts, rivets, welds[b]
	Fracture	Fracture of concrete[a]
		Fracture of reinforcing steel[a]
		Fracture of prestressing steel[a]
		Fracture of protective layer[a, b]
		Fracture of profile of steel or steel slabs/walls[b]
		Fracture of bolts, rivets, welds[b]
Contamination	Inorganic	Aggressive[a, b]
		Neutral[a, b]
	Organic	Aggressive[a, b]
		Neutral[a, b]
Displacement	Incorrect linear displacement	Excessive movement[a, b]
		Restricted movement[a, b]
	Incorrect rotation	Excessive movement[a, b]
		Restricted movement[a, b]

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Damage Indicators DIs

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Class of defect	Type of defect	Category of defect
Loss of material		
	Loss of the material of the protective layer	Loss of material of concrete protection[a]
		Loss of protection of reinforcing steel[a]
		Loss of protection of prestressing steel[a]
		Loss of protection of profile steel or steel slabs/walls[b]
		Loss of protection of bolts, rivets, welds[b]
Discontinuity	Crack	Crack of concrete[a]
		Crack of reinforcing steel[a]
		Crack of prestressing steel[a]
		Crack of protective layer[a, b]
		Crack of profile steel or steel slabs/walls[b]
		Crack of bolts, rivets, welds[b]
	Fracture	Fracture of concrete[a]
		Fracture of reinforcing steel[a]
		Fracture of prestressing steel[a]
		Fracture of protective layer[a, b]
		Fracture of profile of steel or steel slabs/walls[b]
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a.

Damage Indicators DIs

Tunnels

Degradation mechanisms		Deformation	Destruction	Loss of material	Discontinuity	Contamination	Displacement
		Class of defects					
Physical	Accumulation of inorganic dirtiness		□	□		■	■
	Cyclic freeze–thaw action		■	■	□	□	
	Erosion		□	■			
	Creep	□					
	Relaxation	□			□		
	Shrinkage	□	□	□	■		
	Overloading	■	□	■	■		■
	Fatigue		■		□		
	Geotechnical condition changes	■		□	■		
	Temperature						
	Wet areas						
Chemical	Carbonation		■				
	Corrosion	□	■	■	□	□	
	Aggressive compounds action		■	□		□	
	Chemical dissolving/leaching		■	□		■	
	Reactions between material components	□	■	■	□		
Biological	Accumulation of organic dirtiness		□	□		■	□
	Activity of microbes		□	□		■	
	Activity of plants	□	□	□	□	■	□
	Activity of animals		□			□	

Note: ■-basic degradation mechanism, □-additional degradation mechanism

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Damage Indicators DIs

a.

Tunnels

Class of defect	Type of defect	Category of defect
Deformation	Incorrect geometry of constructed element	Incorrect shape of concrete component
		Invalid arrangement of reinforcement
		Permanent deformation**
	Change of the geometry along the element length	Permanent deformation
Destruction of material	Change of the chemical characteristics	Change of concrete characteristics
		Change of reinforcing steel characteristics
	Change of the physical characteristics	Change of concrete characteristics
		Change of reinforcing steel characteristics
		Ice formation due to water
		damages on joint tape
		damages on sealing
Loss of material	Loss of structural material	Loss of concrete***
		Loss of reinforcing steel
Discontinuity	Crack	Crack of concrete****
		Crack of reinforcing steel
		Differentiate cracks, if necessary, as different effects/causes are associated with them
	Fracture	Fracture of concrete****
		Fracture of reinforcing steel
		Take into account the void in the inner shell
		Less thick inner shell
		insufficient concrete cover
		spalling/detaching
		wet area (e.g. through cracks, joint tapes in structures that retain pressurized water, access due to damage to the plastic sealing membrane in structures that relieve pressurized water)
		drainage damages
Contamination	Inorganic	Aggressive
		Neutral
		Efflorescence/washout
	Organic	Aggressive
		Neutral
Displacement	Incorrect linear displacement	Excessive movement
		Restricted movement

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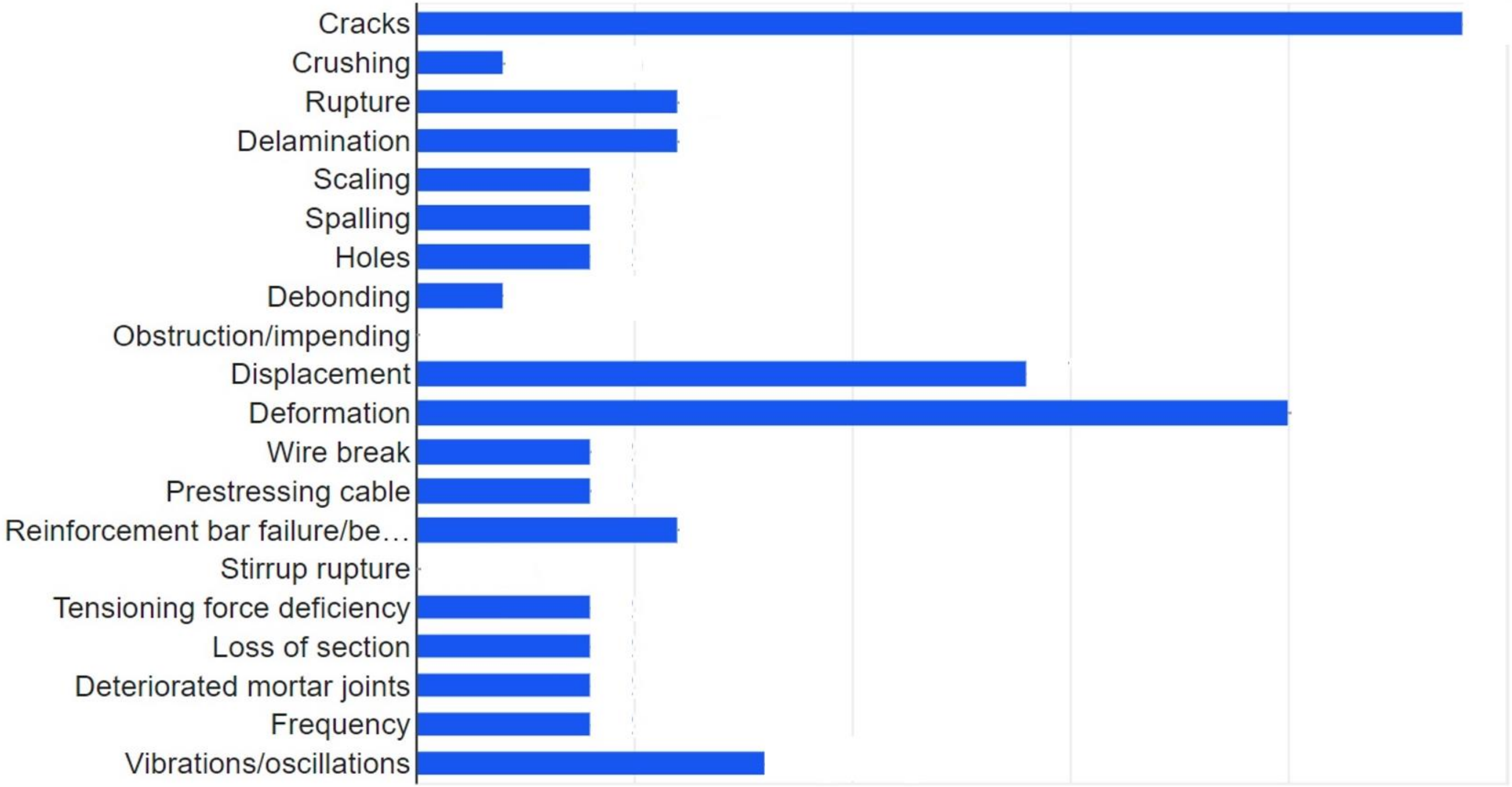
Damage Indicators – CoP feedback

Which Damage Indicators are usually monitored in your current practice?



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a.

Solicitation

We will make available tables treated in a. and ask you to provide us with your comments

Damage indicators and vulnerable elements

a. **10:30-10:45|** Damage Indicators for main damage processes for transport infrastructure

b. **10:45-11:00 |** Typologies of structures (bridges and tunnels)

Identification of vulnerable elements for bridges and tunnels

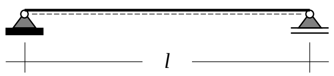
c. **11:00-11:30 | Discussion:** Applicability of Damage Indicators and surveying technologies for vulnerable elements

Q&A

Typologies of structures

Bridge typologies

Beam Bridges

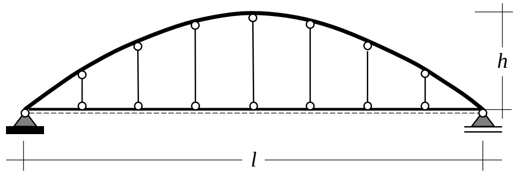


- Single beam bridge
- Multi beam bridge
- Multi beam + Gerber

Frame Bridges

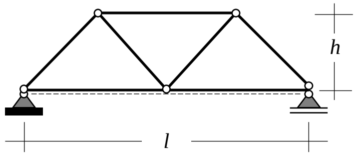
- Single frame bridge
- Multi jointed frames

Arch Bridges



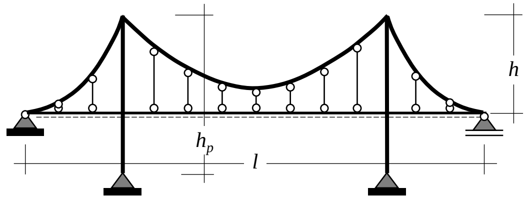
- Tied arch bridge
- Truss arch bridge
- Sickle arch bridge
- Deck arch bridge

Truss bridges



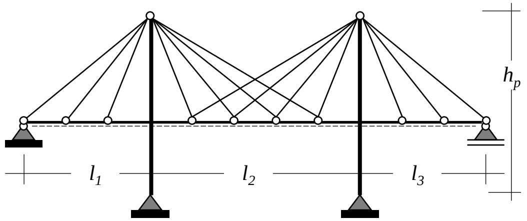
- Queenpost truss bridges
- Warren truss bridges
- Howe truss bridges

Suspension Bridges



- Simple suspension bridges
- Standard suspension bridges

Cable Bridges



- Single pylon cable bridges
- Single pylon harp cable bridges
- Double pylon cable bridges

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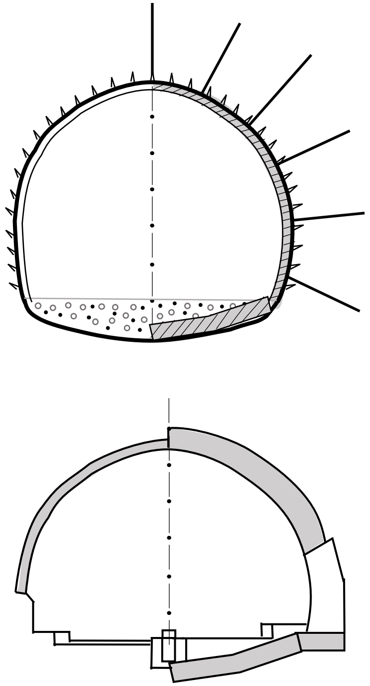
b.

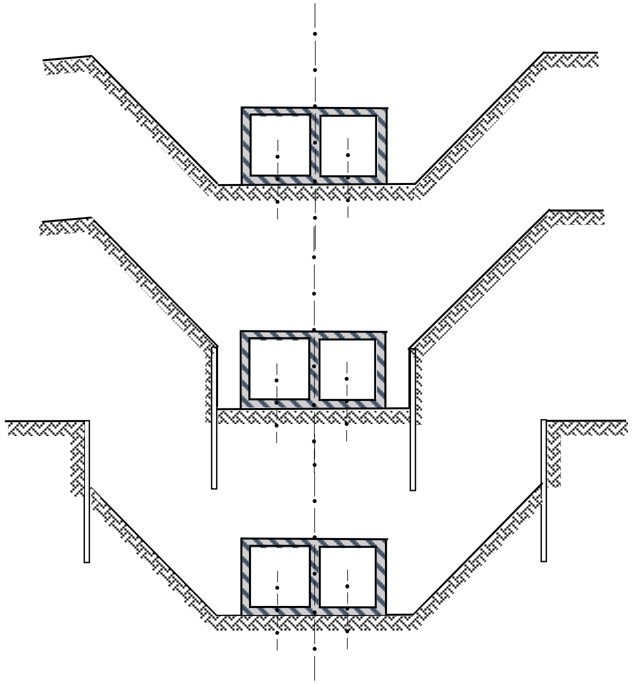
Typologies of structures

Tunnel typologies

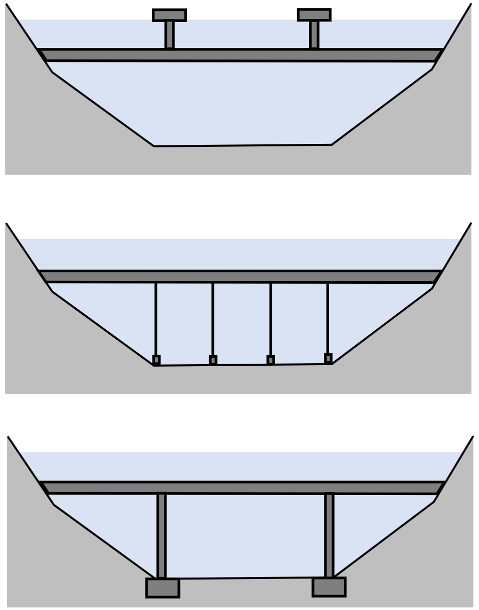
Bored Tunnels



Cut and Cover Tunnels



Submerged Floating Tunnels



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Vulnerable elements

Why address vulnerability?

- Defines the degree to which the system may react adversely during the occurrence of a hazardous event
- Implies a measure of risk associated with the physical, social and economic aspects and implications resulting from the system

How to address vulnerability for condition survey?

- Identification of those specific areas of the structure where damage is more likely to happen, thus providing a guide on where to concentrate the inspection or monitoring tasks.

Clear definition of the concept → Methods for the characterisation of vulnerable zones → Standardisation of methods for bridges and tunnels in general

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Vulnerable elements

Vulnerability concept

“Intrinsic property of an entity resulting in its susceptibility to a risk, which may be quantified by the ratio between the risks due to direct consequences of an event and the total value of the considered entity, determined bearing in mind all relevant hazards for a specified time frame.”

Vulnerable zones

“Physically distinguishable part of an entity (e.g. network, object, component or element, or the parts thereof), for which change of its condition or other direct consequences of an hazardous event have the largest impact on its performance.”

Methods for the characterization of vulnerable zones

- Robustness related detection method
- Sensitivity related detection method
- Force and loading based vulnerability analysis
- Deformation based vulnerability analysis
- Performance based vulnerability

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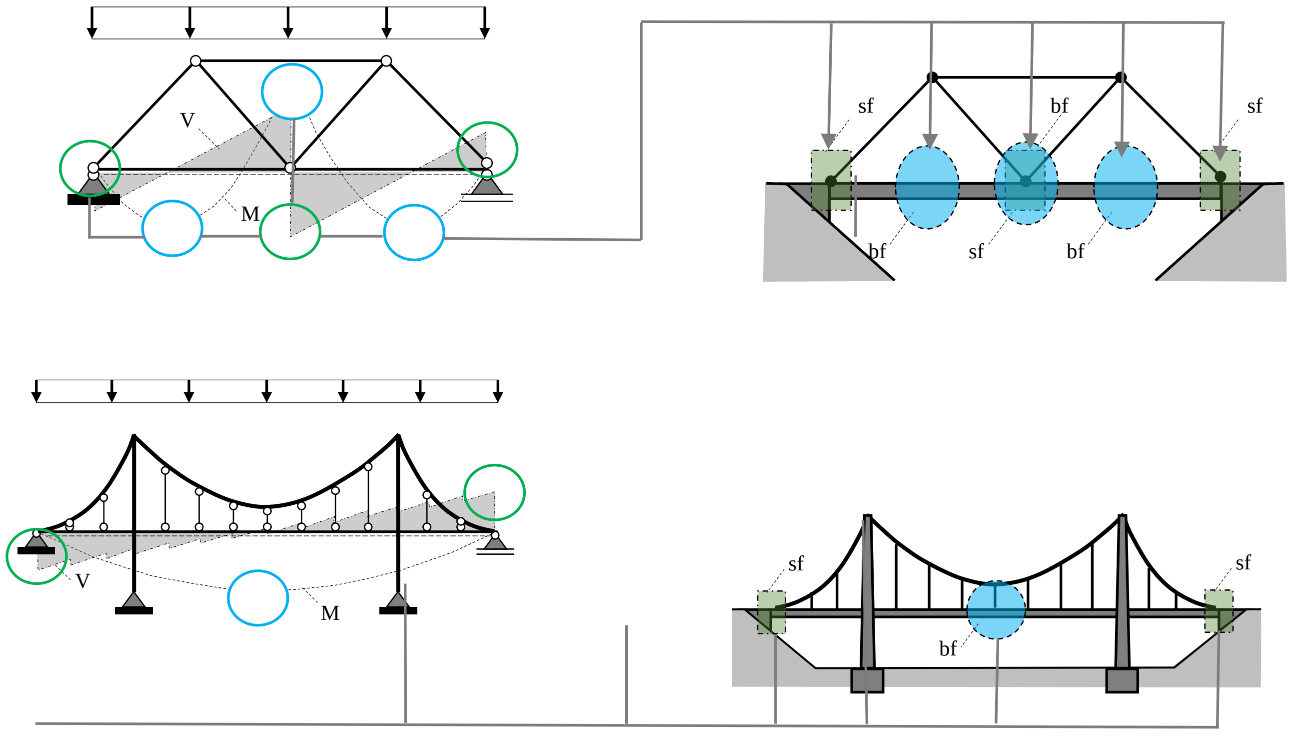
Vulnerable elements

Vulnerability on bridges – Force and loading based vulnerability

Procedure:

1. Simplified static bridge system
2. Make an actions evaluation
3. Solve the static analysis under normal load conditions.
4. Analyse the static analysis results to draw the Moment (M) and Shear (V) lines
5. Analyse zones with maximum values of Moment and Shear in order to select the bridge vulnerable zones. Maximum moment zones are BF (buckling failure) zones and maximum shear zones are SF (shear failure) zones



M= Bending Moment
V = Shear Force

sf = Shear failure
bf = Bending failure

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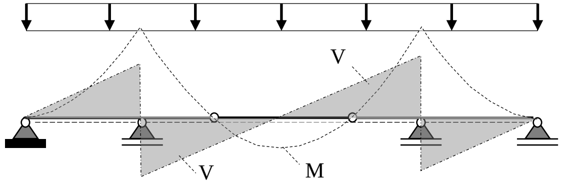
Vulnerable elements

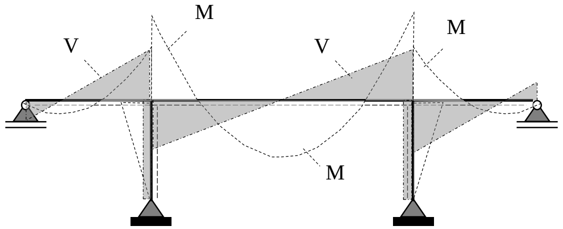
Vulnerability on bridges – Force and loading based vulnerability

Loading & Forces

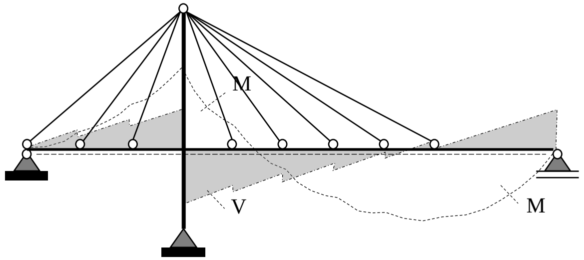
Multi Beam + Gerber:



Multi jointed Frames:

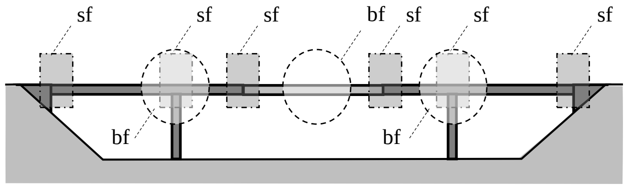


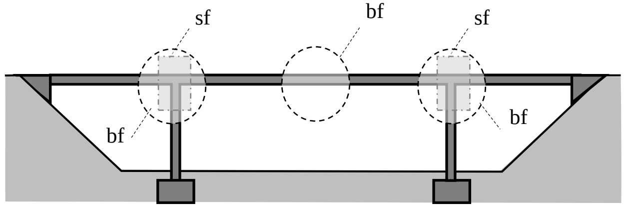
Single Pylon Cable Bridges:

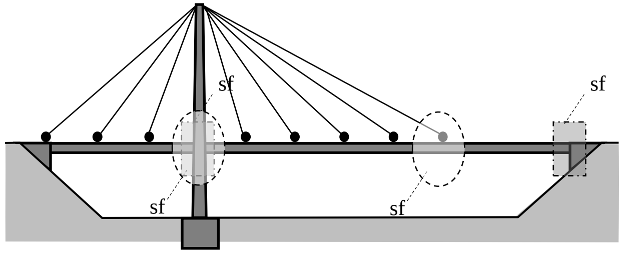


M= Bending Moment
V = Shear Force

Vulnerable Zones







sf = Shear failure
bf = Bending failure

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Vulnerable elements

Vulnerability on bridges – Force and loading based vulnerability

Procedure:

1. Simplified static tunnel system

2. Make an actions evaluation

3. Solve the static analysis under normal load conditions

4. Analyse the static analysis results to draw the Moment (M) and Shear (V) lines

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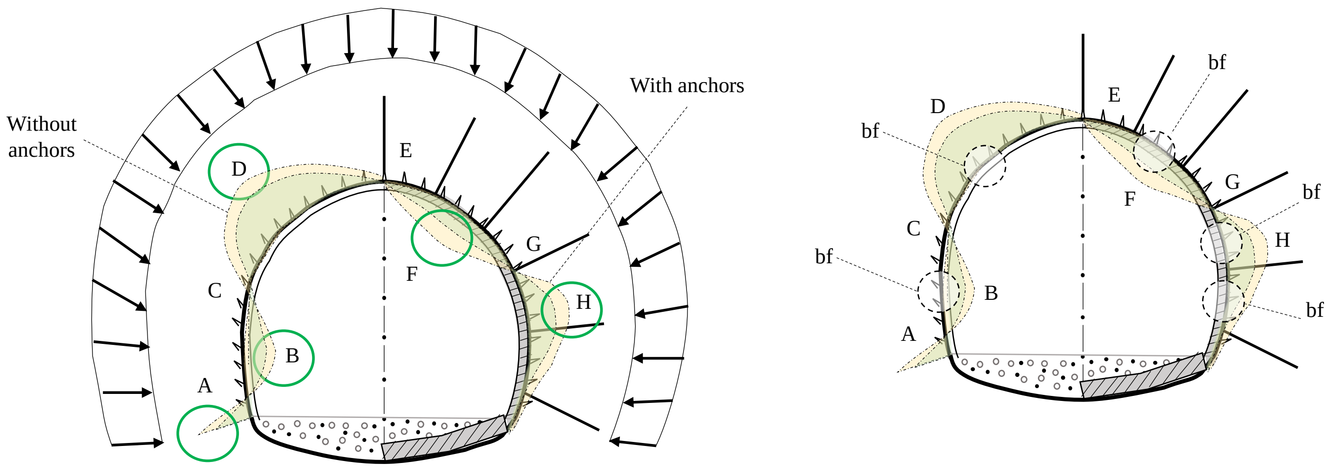

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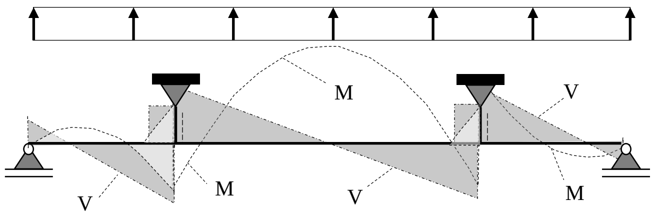
Vulnerable elements

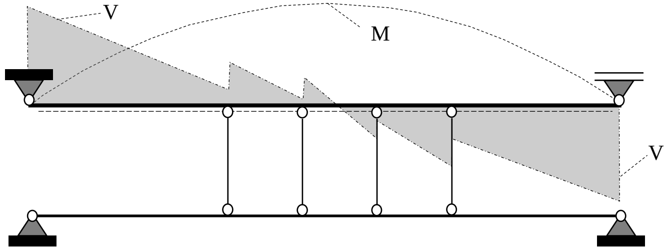
Vulnerability on bridges – Force and loading based vulnerability

Loading & Forces

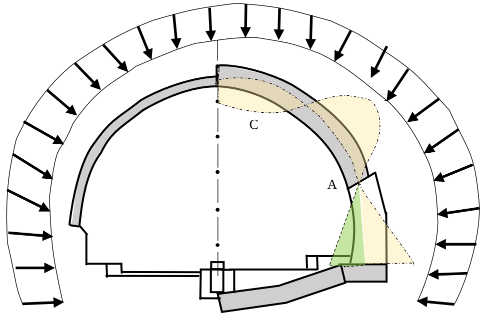
Pontoons SFT:



Tension Leg SFT:

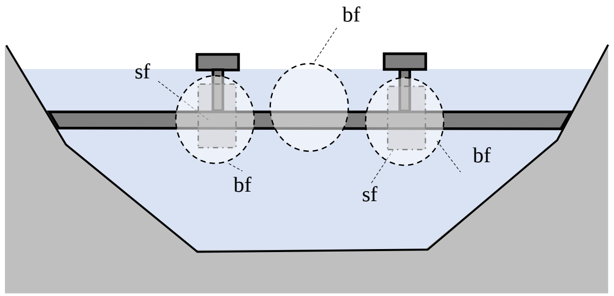


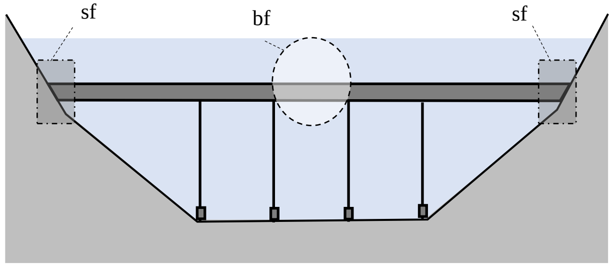
Bored Tunnel:

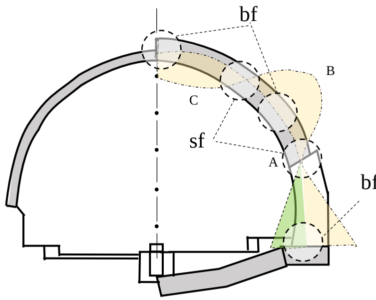


M= Bending Moment
V = Shear Force

Vulnerable Zones







sf = Shear failure
bf = Bending failure

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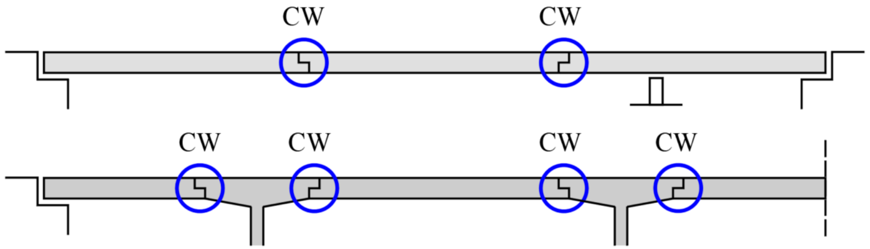
Vulnerable elements

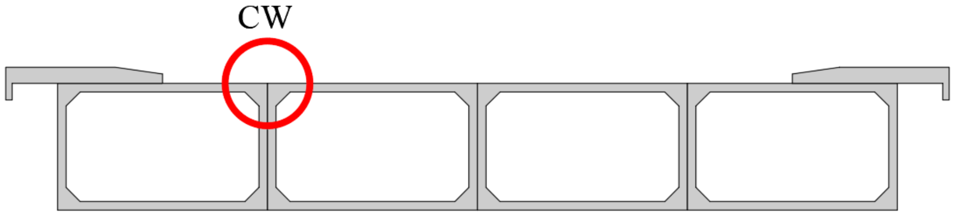
Vulnerability on bridges – Performance based vulnerability

Conceptual weakness (CW): areas of elements that need to be carefully assessed for not performing well

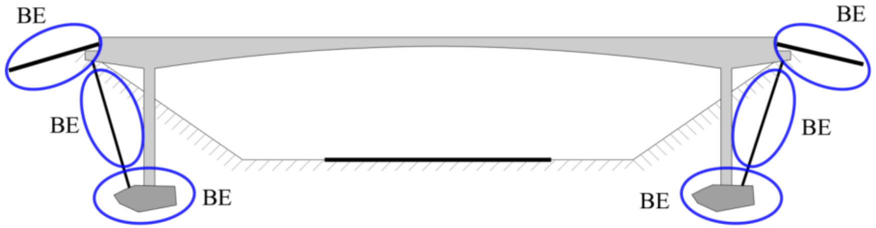
Gerber beams



Precast cross section



There are elements buried in the ground or embankment, which form a special group denominated Buried Elements (BE)



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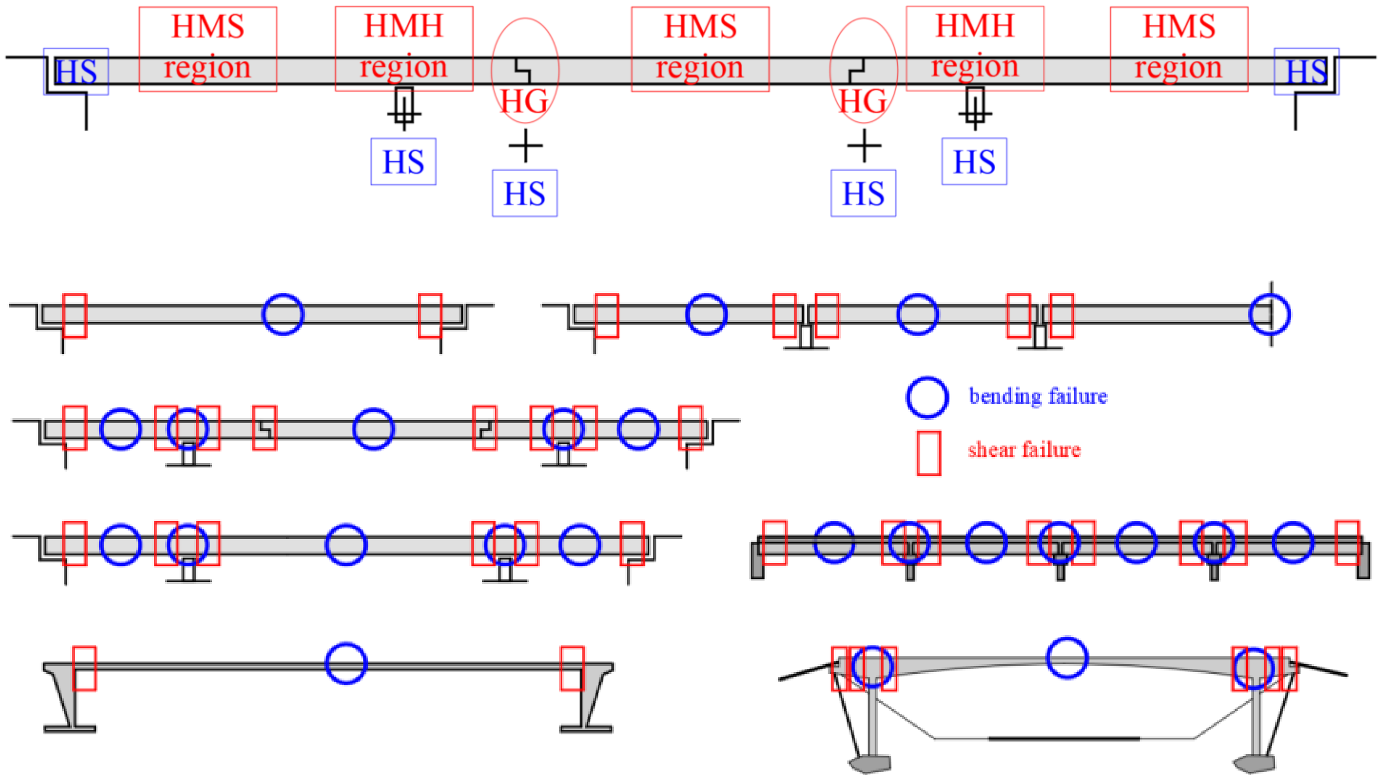
Vulnerable elements

Vulnerability on bridges – Performance based vulnerability

Vulnerable zones related to the superstructure



COST TU1406

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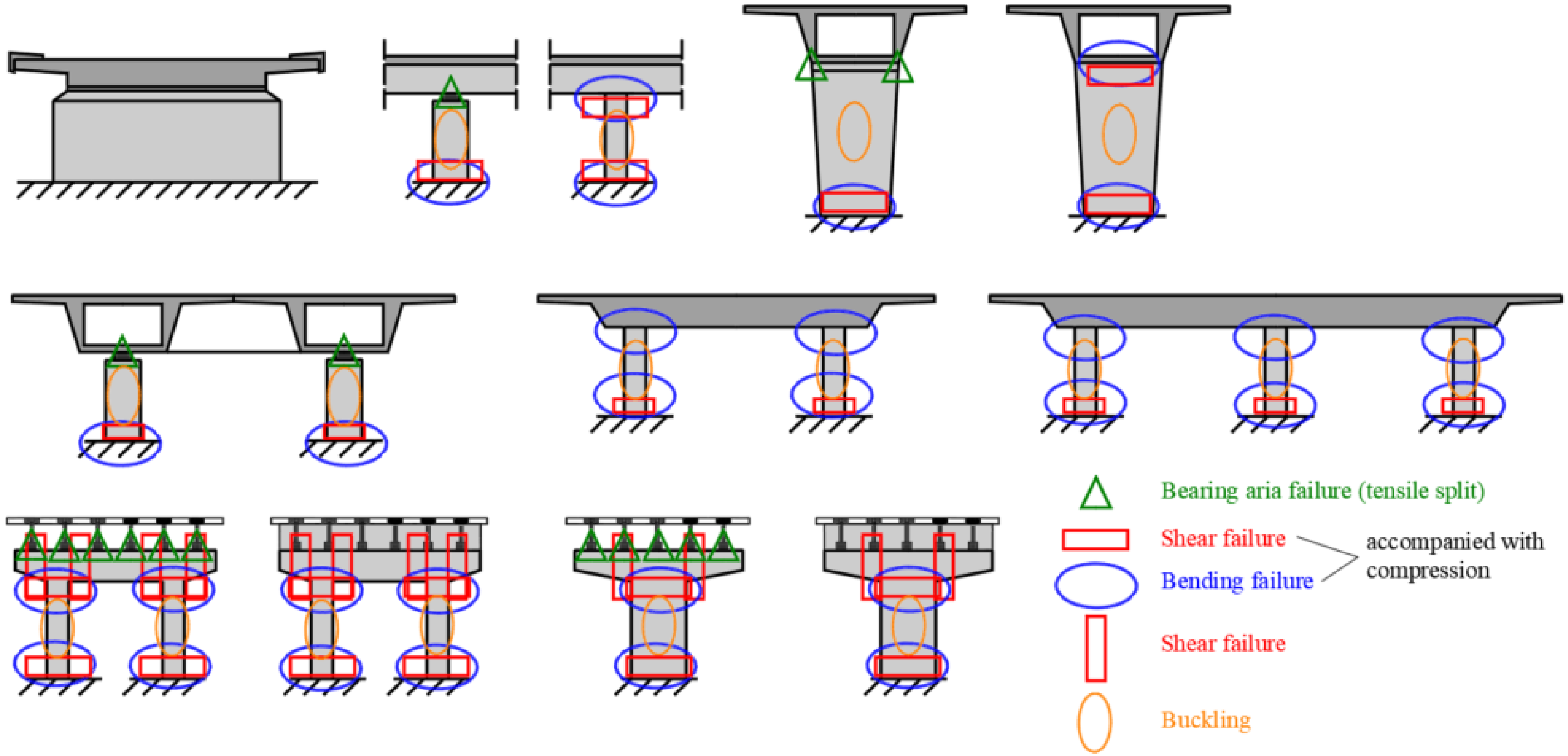
Vulnerable elements

Vulnerability on bridges – Performance based vulnerability

Vulnerable zones related to the substructure



COST TU1406

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Damage indicators and vulnerable elements

a. **10:30-10:45|** Damage Indicators for main damage processes for transport infrastructure

b. **10:45-11:00 |** Identification of vulnerable elements for bridges and tunnels

c. **11:00-11:30 | Discussion:** Applicability of Damage Indicators and surveying technologies for vulnerable elements

Q&A

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Questions and Answers

Questions (Zoom Poll):

- Is a systematized damage indicator system already in use in your country?
- Is the damage indicator system used solely for visual inspection?
- Indicate which of the following methods are used to asses vulnerable zones (or vulnerable elements) on bridges and/or tunnels as a guide to optimize monitoring or assessment. Options: Robustness, Sensitivity Analyses, Force & Load, Deformation, Performance, Other, Vulnerable zones is not considered relevant in guiding inspection/monitoring.

Questions for discussion:

- Is it reasonable and practicable to build up a systematized damage indicator system for vulnerable areas (pros and cons)?
- In your opinion, is it possible to use a damage indicator system for an objective performance evaluation?
- Is vulnerability assessment a real need for guiding the inspectors in where to concentrate their investigations?

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

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