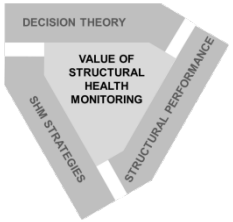
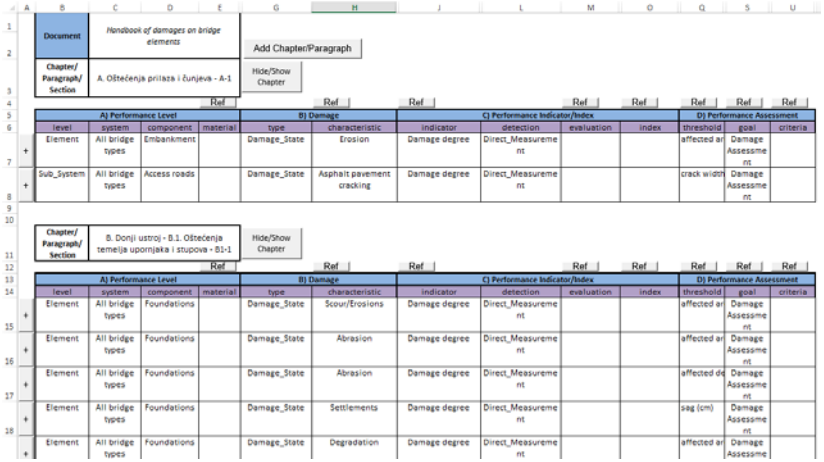


Performance indicators for road bridges

Alfred Strauss, University of Natural Resources and Life Sciences, Wien
Ana Mandić Ivanković, Faculty of Civil Engineering, University of Zagreb
Helder Sousa, BRISA S.A., 2785-599 S. Domingos de Rana, Portugal
University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom

OVERVIEW



Document: *Handbook of damages on bridge elements* — Add Chapter/Paragraph

Chapter/Paragraph/Section: A. Oštećenja prilaza i čunjeva - A-1 — Hide/Show Chapter

A) Performance Level				B) Damage		C) Performance Indicator/Index				D) Performance Assessment		
level	system	component	material	type	characteristic	indicator	detection	evaluation	index	threshold	goal	criteria
Element	All bridge types	Embankment		Damage_State	Erosion	Damage degree	Direct_Measurement			affected ar	Damage Assessment	
Sub_System	All bridge types	Access roads		Damage_State	Asphalt pavement cracking	Damage degree	Direct_Measurement			crack width	Damage Assessment	

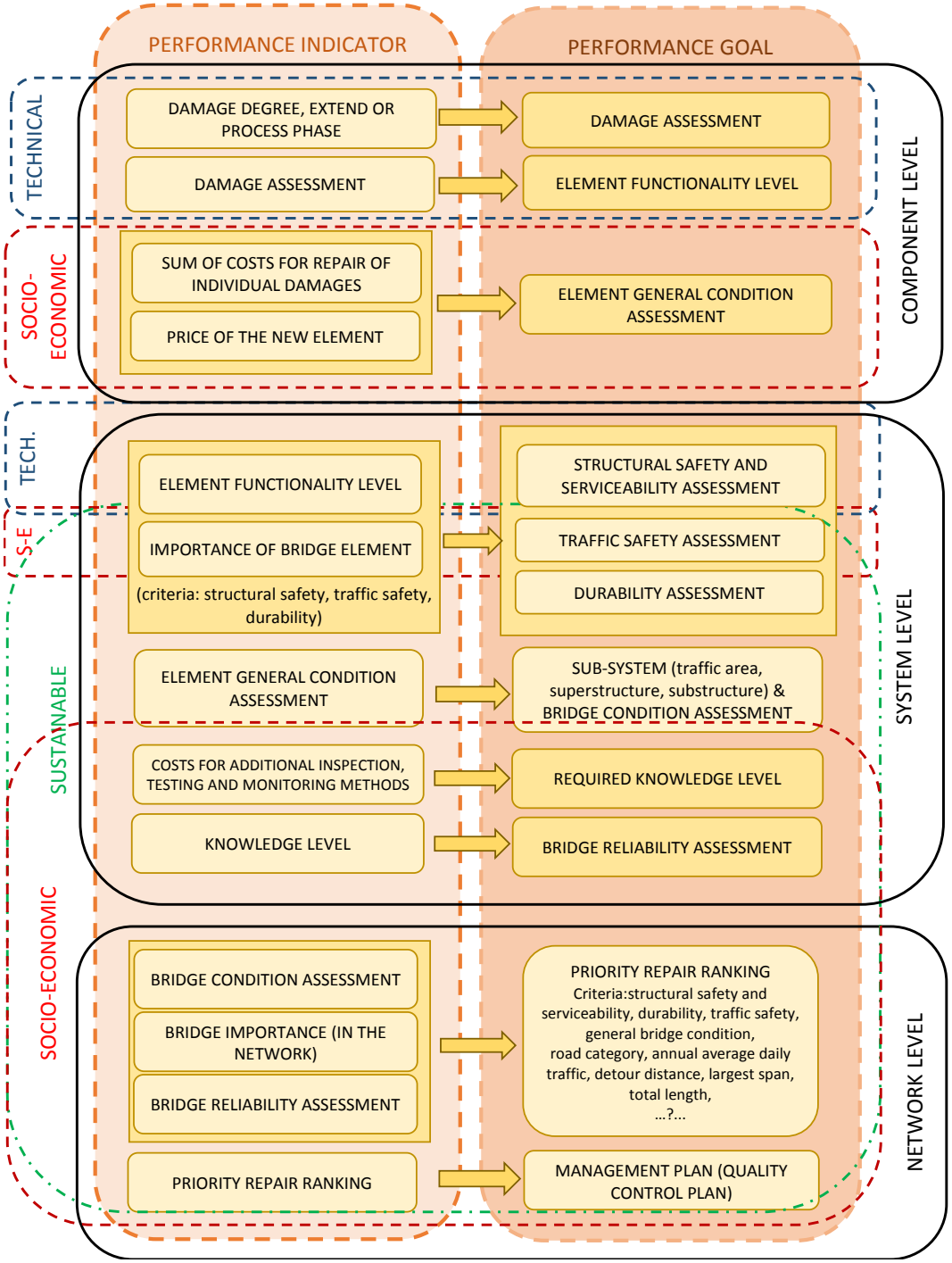
Chapter/Paragraph/Section: B. Donji ustroj - B.1. Oštećenja temelja upornjaka i stupova - B1-1 — Hide/Show Chapter

A) Performance Level				B) Damage		C) Performance Indicator/Index				D) Performance Assessment		
level	system	component	material	type	characteristic	indicator	detection	evaluation	index	threshold	goal	criteria
Element	All bridge types	Foundations		Damage_State	Scour/Erosions	Damage degree	Direct_Measurement			affected ar	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Abrasion	Damage degree	Direct_Measurement			affected ar	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Abrasion	Damage degree	Direct_Measurement			affected de	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Settlements	Damage degree	Direct_Measurement			sag (cm)	Damage Assessment	
Element	All bridge types	Foundations		Damage_State	Degradation	Damage degree	Direct_Measurement			affected ar	Damage Assessme	

- PI ↔ PG
- Clustering and categorisation of PI
  - Overview for roadway bridges, based on results of the screening process of the inspection and evaluation documents performed so far under the auspices of COST action TU 1406
  - Collection and categorisation of PI is ongoing, particularly in the area of research-based indicators.
  - Critical overview and feedback in the developed PI database is still under progress.
- Damage assessment
- Further steps

PI ↔ PG

- interactions are contemplated, as they are crucial for optimal quality control and management of road bridges



PI ↔ PG: COMPONENT LEVEL

- Inspection carried out by components forming three main sub-systems

Substructure	Superstructure	Roadway + equipment
Foundations (concrete)	Superstructure (reinforced concrete)	Pavement
Deep foundations, piles (concrete)	Superstructure (prestressed concrete)	Curb & Cornices
Deep foundations, piles (steel)	Superstructure (steel)	Railings & anchorage, barriers
Deep foundations, piles (timber)	Superstructure (composite)	Sidewalk (Pedestrian walkway)
Abutments (concrete)	Superstructure (timber)	Bearings
Abutments (masonry)	Superstructure (brick)	Expansion joints
Piers (concrete)	Superstructure (stone)	Drainage
Piers (steel)	Arch (concrete)	Lighting
Piers (masonry)	Arch (masonry)	Signalization
…	…	…



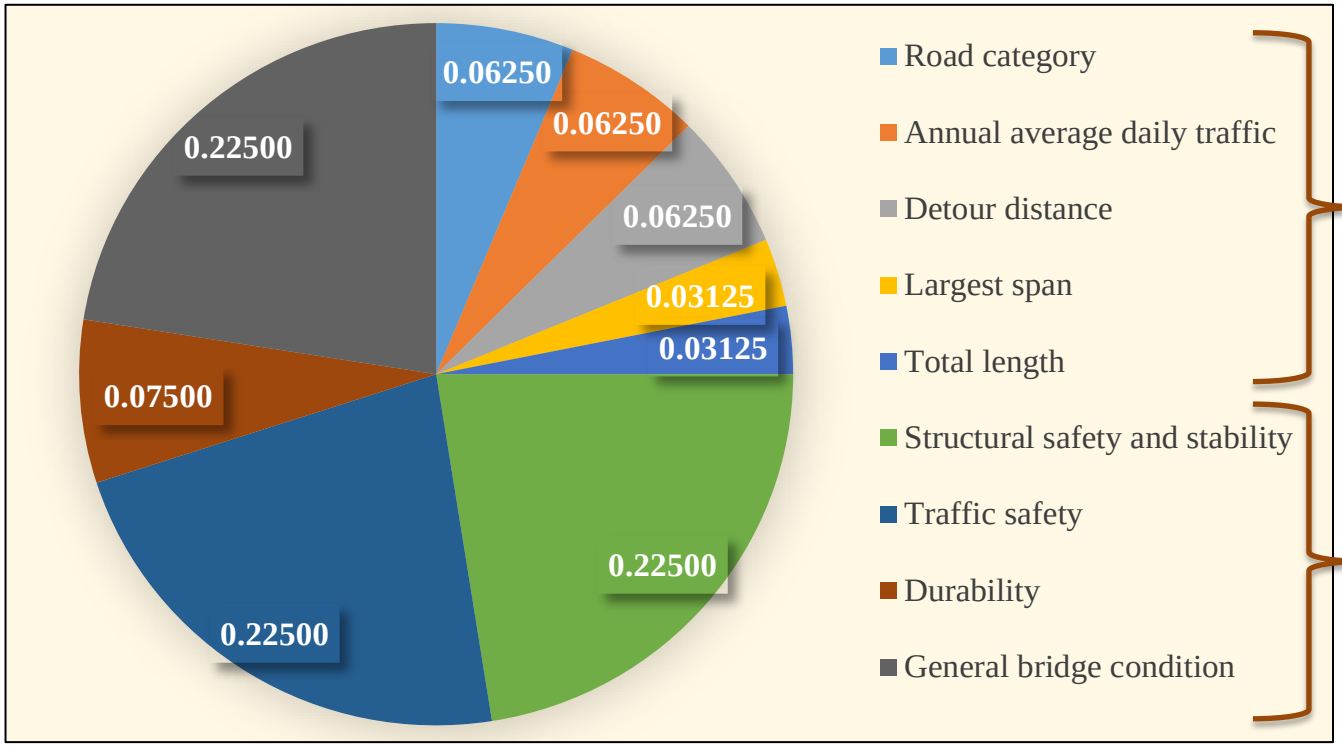
PI ↔ PG: SYSTEM LEVEL

- Importance of the component to evaluate impact to the entire structure

Structural safety criteria		Traffic safety criteria		Durability criteria	
collapse of particular element…					
have no influence to the bridge safety *railing, curb, embankment,…*	1	has no influence to traffic flow *cornices, …*	1	have no influence to durability of other components *railing, main girder, arch, pier, foundation, …*	1
has influence to a part of a bridge structure *cornices, cross girders, bearing, abutment wing, …*	2	causes speed limitation *sidewalk with barrier, …*	2	will cause reduced durability of other components *expansion joint, pavement, curb, drain, embankment …*	2
has influence to an entire bridge structure *main girders, arch, pier, abutment wall, foundation,…*	3	causes local traffic redirection *sidewalk, embankment, curb, drainage, …*	3		
		complete traffic suspension *barriers, pavement, expansion joint, roadway slab, wing, …*	4		

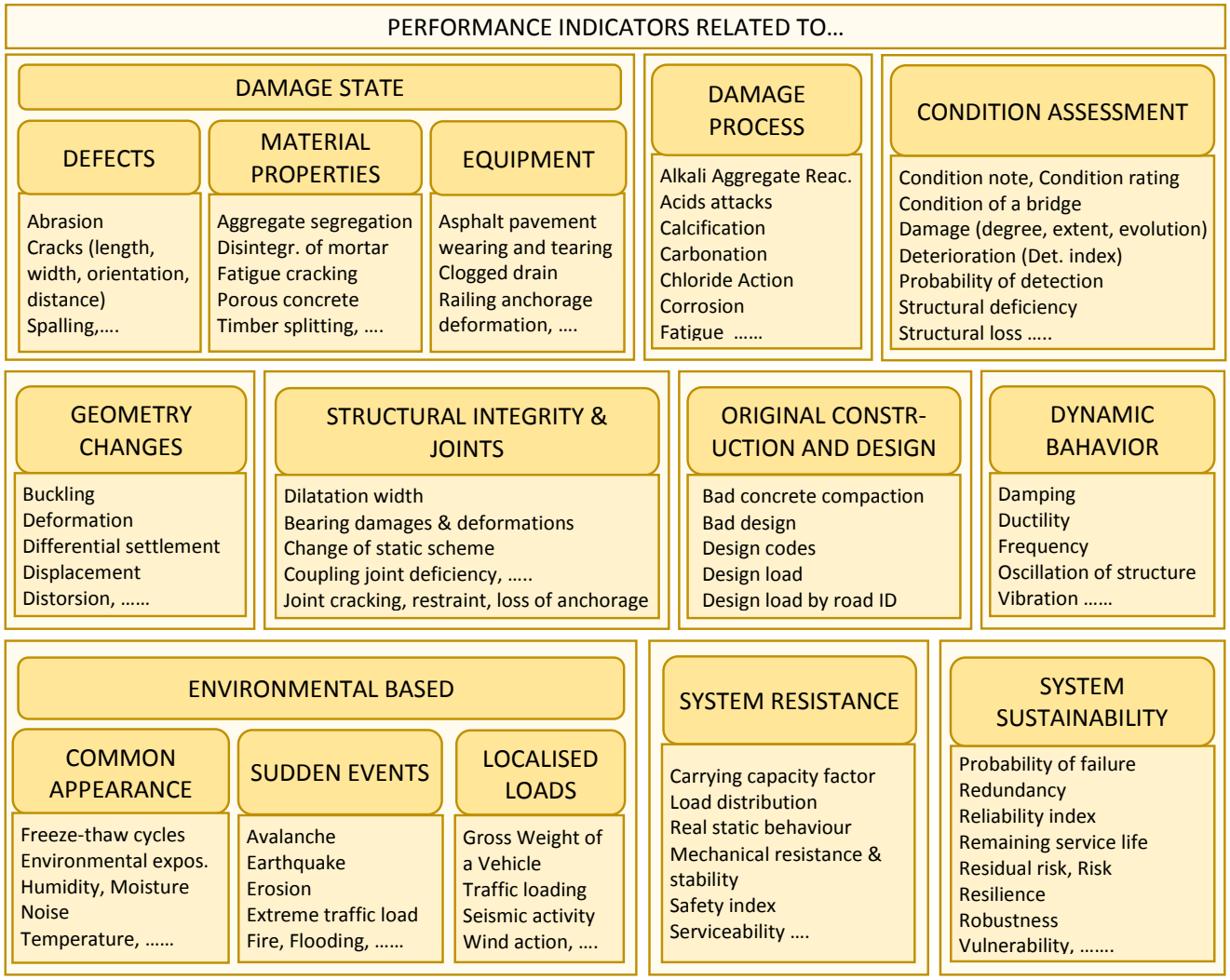
PI ↔ PG: NETWORK LEVEL

- Example of weight of performance criteria for priority repair ranking



CLUSTERING OF PI

- to more easily identify:
  - their origin,
  - methods and procedures for their revealing and quantification
  - level and extend of their influence to a certain structural performance type

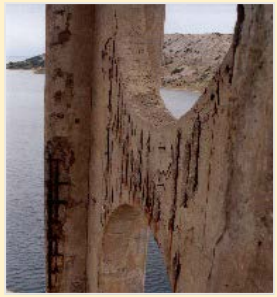


DAMAGE ASSESSMENT

- … implies detection of damages as well as their identification and evaluation.

DAMAGE DETECTION

Visual inspection



Chloride content measurements

DAMAGE IDENTIFICATION

Delamination + corrosion at the bridge pier due to aggressive maritime environment and thin concrete cover, which may lead to reduced resistance and durability.

D. EVALUATION based on D. THRESHOLD

Based on affected area – heigh degree of damage;

Based on chloride content – advanced deterioration process

DAMAGE ASSESSMENT

More detailed inspections and testing are necessary.

Damage assessment may lead to a routine or special repair.

DAMAGE ASSESSMENT

- Four main approaches in damage detection are:
  - visual inspection,
  - non-destructive testing,
  - probing and
  - SHM.




EXAMPLE OF DAMAGE CATEGORISATION

Damage type (characteristics)	Damage indicator	Damage detection	Damage threshold	Damage evaluation
Abrasion	Affected area (m2) + Affected depth (cm)	Visual inspection + Direct measurement	Classes / upper value + damage phase duration	Grades according to handbook of damages
….				
Cavities	Speed of reflected signal	Acoustic emission		Results analysis
	Resonance in amplitude-frequency spectra	Impact-echo test		Results analysis
Corrosion	Affected area (m2)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
	Percentage of damaged cross section of reinforcement (%)	Specialist detailed inspection	Upper values of the phase + damage phase duration	Grades according to handbook for assessment
	Physical parameter	In situ testing		Testing analysis
	Potential (mV)	Half cell potential measurements	Classes and lower limit	Evaluate risk of corrosion
	Chloride content (%)	Probing at concrete samples in laboratory	Critical value	Quantitative analysis
	Carbonization depth (mm)	Laboratory testing of collected material	carbonization depth limit	Evaluate risk of corrosion
		Corrosion Monitoring systems		*Monitoring of corrosion progress*
Cracks	Crack width (mm)	Visual inspection + Direct measurement	Classes / upper value + damage phase duration	Grades according to handbook of damages
	Crack width/depth	Ultrasonic velocity test	Upper limit	Testing analysis
	Existence	Hammer sounding		
		SHM of cracking		*Monitoring of cracks evolution*

EXAMPLE OF DAMAGE CATEGORISATION

Damage type (characteristics)	Damage indicator	Damage detection	Damage threshold	Damage evaluation
Abrasion	Affected area (m2) + Affected depth (cm)	Visual inspection + Direct measurement	Classes / upper value + damage phase duration	Grades according to handbook of damages
….				
Cavities	Speed of reflected signal	Acoustic emission		Results analysis
	Resonance in amplitude-frequency spectra			Results analysis
Corrosion	Affected area (m2)			Grades according to handbook of damages
	Percentage of damag cross section of reinforcement (%)			Grades according to handbook for assessment
	Physical parameter			Testing analysis
	Potential (mV)			Evaluate risk of corrosion
	Chloride content (%)	Probing at concrete samples in laboratory	Critical value	Quantitative analysis
	Carbonization depth (mm)	Laboratory testing of collected material	carbonization depth limit	Evaluate risk of corrosion
		Corrosion Monitoring systems		*Monitoring of corrosion progress*
Cracks	Crack width (mm)	Visual inspection + Direct measurement	Classes / upper value + damage phase duration	Grades according to handbook of damages
	Crack width/depth	Ultrasonic velocity test	Upper limit	Testing analysis
	Existence	Hammer sounding		
		SHM of cracking		*Monitoring of cracks evolution*

TU 1402 related task:

! Identify PI that may be detected/evaluated and possibly quantified with available SHM technologies !

EXAMPLE OF DAMAGE CATEGORISATION

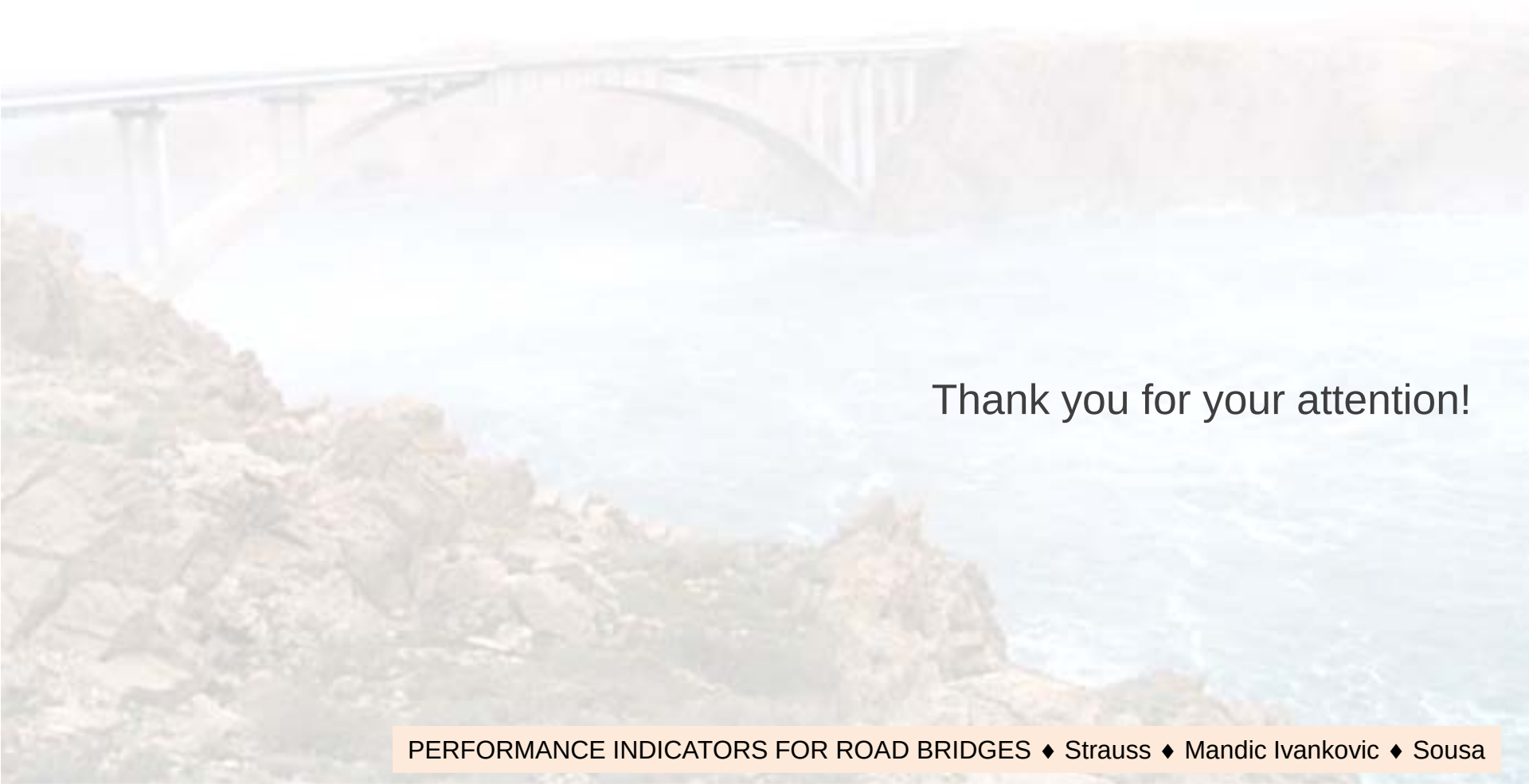
Damage type (characteristics)	Damage indicator	Damage detection	Damage threshold	Damage evaluation
Delamination	Affected area (m2) + Affected depth (cm or mm)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
Deflection	Long-term deflection	Visual inspection + *Direct (periodic long lasting) measurement*	Upper limit	*Monitoring of deflection evolution*
Fatigue	Damage degree	Visual inspection	Classes	Damage catalogue
		Fatigue damage or fatigue cracks sensors		*Monitoring of fatigue damage evolution*
Insufficient concrete cover	Affected area (m2)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
Insufficient concrete quality	Physical parameter	Probing		Probing analysis
		Rebound hammer		
Scour	Hydraulic inadequacy, depth	Direct measurement	Upper limit	Inspection
	Differential rotation + displacements	Direct measurement	Upper limit	Monitoring of score criticality
	Differential settlement	Direct measurement	Upper limit	Monitoring of score criticality
		Scour monitoring devices		*Monitoring of score criticality*
Spalling	Affected area (m2) + Affected depth (cm or mm)	Visual inspection + Direct measurement	Classes	Grades according to handbook of damages
…..				

FURTHER STEPS

overview of PI in bridge management domain

1. identify all PI that may be detected/evaluated and possibly quantified with available SHM technologies
   - quantify relations between indicators and levels of their contribution to a certain structural performance assessment (PG)
2. to extend PI ↔ PG to the performance assessment of structures in general
3. surveying of research-based PI
   - those that may be put in practice
   - those in whose development is worth investing
4. improve existing structural performance assessment methods

Performance indicators for road bridges



Thank you for your attention!