Vulnerability – The top level performance indicator for bridges exposed to flooding hazards

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Outline

Vulnerability – The top level performance indicator for bridges exposed to flooding hazards

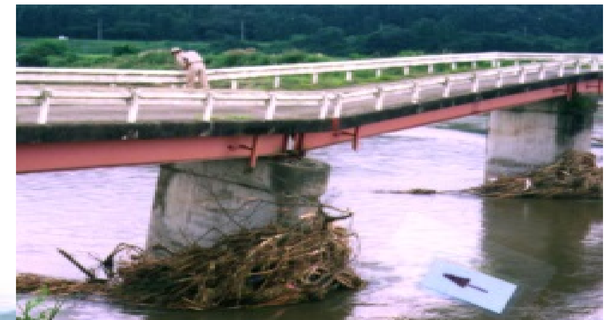
1. Introduction
2. Performance indicators related to flooding in Europe
3. Vulnerability of bridges to flooding events
4. Methodologies for quantitative risk/vulnerability assessment
5. Structuring of adequate quality control plans
6. Conclusion

Introduction - extreme flooding events around the world

- **Japan, 1998** – intensive rainfall
  road infrastructures damaged at 645 locations
  14 bridge failures

- **South Korea, 2003** – typhoon Maemi
  27 bridges and 774 roads impaired

- **Taiwan, 2009** – typhoon Morakot
  52 bridges devastated



Introduction – recent bridge failures

- Hintze Riberto bridge**, Portugal, 2001**
- Northside bridge, **UK, 2009**
- St. Adolph bridge, **Canada, 2009**
- Bridge over Filos river, **Turkey, 2012**
- Bridge across Rambla de Bejar, **Spain, 2012**
- Boneybrook bridge, **Canada, 2013**
- Two bridges in Sardinia, **Italy, 2013**

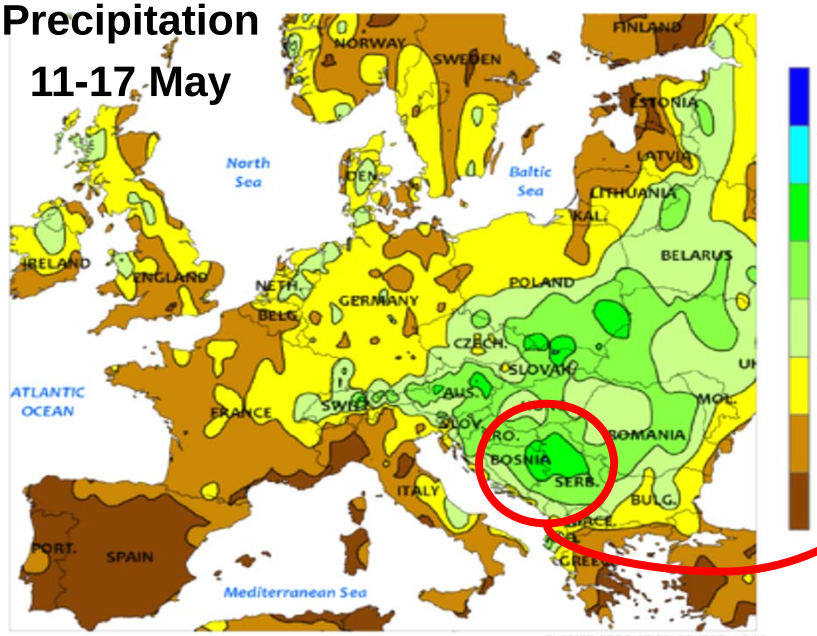





Introduction – recent flooding in Serbia

- **May 14 – 18, 2014** / Extreme flooding event:
  South-east Europe floods caused by cyclone Tamara
- **1.6 mil.** people directly affected; Damage estimated **1.0 bil. $**

Precipitation 11-17 May



Wikipedia

Wikipedia

Introduction – recent flooding in Serbia

- Torrential flooding + flood level **16ft** above the ground level at several urban areas = **59** fatalities, tens of thousands evacuated.
- **~ 2.200** public industrial and infrastructure facilities were flooded, (incl. the coal mine site “Kolubara”)

Introduction – recent flooding in Serbia

- Severe damage to the transportation infrastructure:
  ~3500 roads damaged/destroyed; **~1800** at risk - landslides!

- **~ 300** bridges affected
  The two main causes of bridge failures:
  - ✓ Washing away of access roads
  - ✓ **Local scour**





Introduction – more flooding…

4 bridges collapse in Waco, Texas, USA ~ June 1. 2016

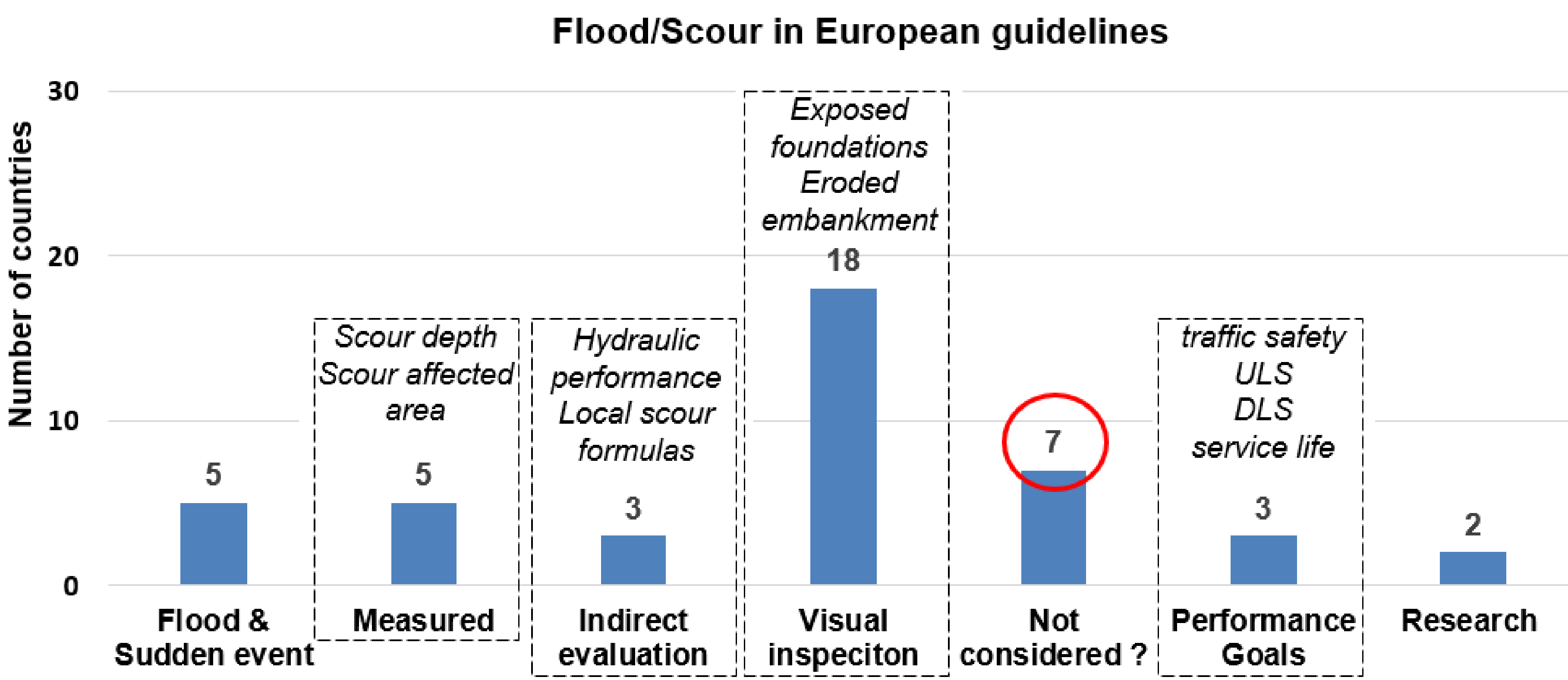
…*road will remain closed until the county bridge is repaired,*
and there is no prediction as to when that might be. (wacotrib.com)

Introduction – scour assessment in bridge management practice

- **L**ong **T**erm **B**ridge **P**erformance **P**rogram
  - ✓ **Reliable identification** of scour susceptible bridges is necessary !
- **FHWA**
  - ✓ **NBI Item 113 –** Scour vulnerable bridges
- **NYSDOT**
  - ✓ Hydraulic Vulnerability Manual
- **NCHRP 590**
  - ✓ Scour vulnerability & multi-criteria optimization in decision making
- **Software ?**
  - ✓ HAZUS-MH (USA), Road Risk (Switzerland), CAESAR (USA)
- **European research project COST TU1406**
  - ✓ Structuring of QC plans for roadway bridges
  - ✓ Dynamics and uncertainty of non-interceptable (sudden) events

Performance indicators for flooding hazards in Europe

- **COST TU1406 survey** for bridge **p**erformance **i**ndicators



Performance indicators for flooding hazards in Europe

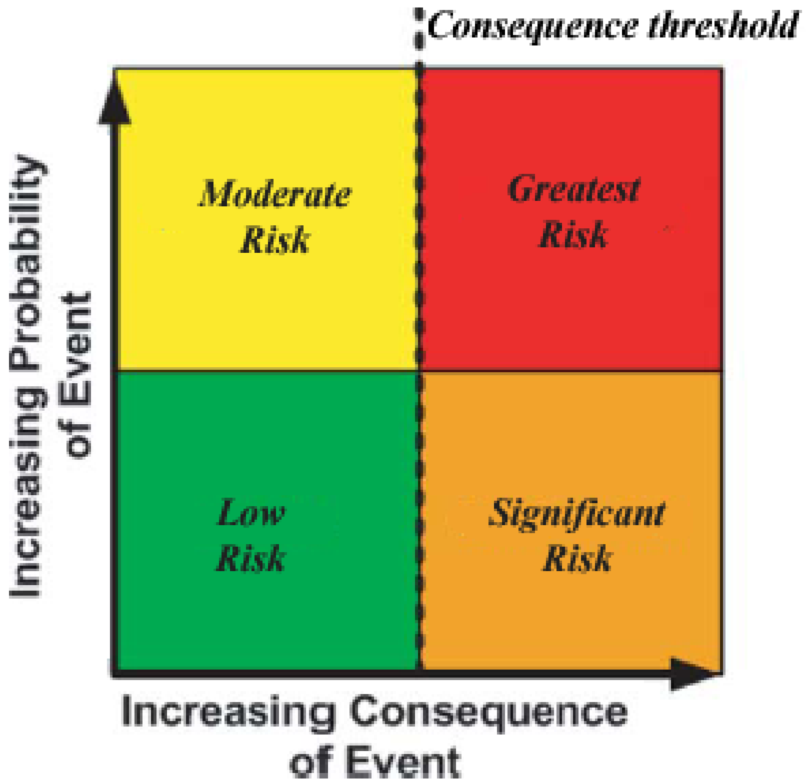
Reported terms on scour**:**

- **Visual Inspection** - exposed foundation, eroded embankment**…**
  - ✓ Possible failure scenario revealed **- not reliable**
  - ✓ Prioritization for monitoring/measuring of scour **- not reliable**
  - ✓ **Ineffective** against flash flooding**!**
- **Measurements** - scour depth and scour affected area
  - ✓ Scour cavity infill**?**
  - ✓ Cost and adequacy**?**
  - ✓ **Ineffective** against flash flooding**!**
- **Indirect evaluation** - hydraulic adequacy, scour eval. formulas…
  - ✓ Appropriateness of the applied formulas **?**
  - ✓ Overestimation of a scour depth **?**

Vulnerability of bridges to flooding events

Risk of failure

- Qualitative approaches (e.g. Likelihood & Consequences Matrix)
- Included only in several BMS !
- Easy ranking?
- How to evaluate:
  - ✓ *Likelihood* of an Event?
  - ✓ Consequences ?
- Thresholds ?
- Probability of the Event **f** = Hazard Magnitude **s** & Failure mode **n**



$$P_f = P_s P_n^s$$

Conditional probability of failure

Vulnerability of bridges to flooding events

Vulnerability is more convenient to use

$$V_n^s = P_n^s \cdot (DC_n + IC_n)$$

- Related to a given hazard magnitude ***s*** (e.g. 100-year flood)
- Scenario assumed (e.g. local scour at a pier or abutment)
- Failure mode ***n*** (e.g. combined soil-bridge kinematic mechanism)
  - ✓ Resistance of the infrastructure is accounted !
- Total related consequences are monetized (direct and indirect)

Vulnerability of bridges to flooding events

Key data for hazards**: <u>Exposure</u>, <u>Resistance</u>, <u>Consequences</u>**

- **<u>Exposure</u>** (hazard scenario)
  - ✓ Flooding magnitude and duration (i.e. hydrograph)
  - ✓ Water channel geometry & properties
  - ✓ Piers & abutments location, geometry and alignment in respect to a water flow
- **<u>Resistance</u>** (failure modes)
  - ✓ Properties of a soil at foundations (geotechnics and erodibility)
  - ✓ Type & detailing of the substructure and superstructure
  - ✓ Location and severity of damage on relevant bridge elements
- **<u>Consequences</u>** (inadequate bridge performance)
  - ✓ Costs of repairs or replacement, down time
  - ✓ Network & traffic data to account indirect costs of failure e.g. vehicle operating costs, accident costs, travel time, etc.

Methodologies for quantitative vulnerability assessment

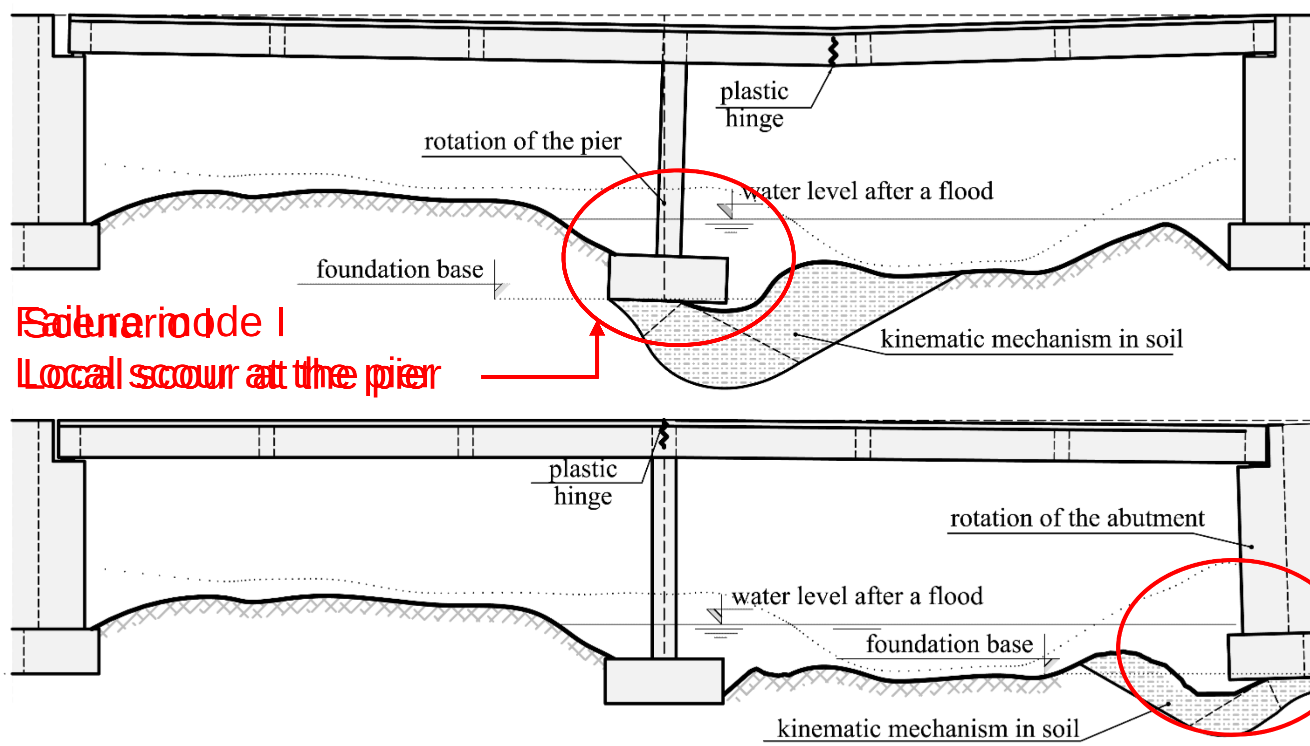
- **HYRISK Quantitative approach (bridges with unknown foundations)**

Data	PI: Risk of scour failure
Exposure	NBI Items
Resistance	Adjustment factors for types of foundation and span Probability of failure – NBI items **uncomprehensive !**
Consequences	Traffic volume **Failure type not considered !**

- Predefined **M**inimum **P**erformance **L**evels
- **QC plans -** thresholds for foundation survey, countermeasures, automated monitoring

Methodologies for quantitative vulnerability assessment

- Conditional probability of a bridge failure
  - ✓ Flooding magnitudes and related local scour action
  - ✓ Combined soil-bridge failure modes



Scenario I
Failure mode I
Local scour at the pier

Scenario II
Local scour at the abutment

Failure mode II
Local scour at the abutment

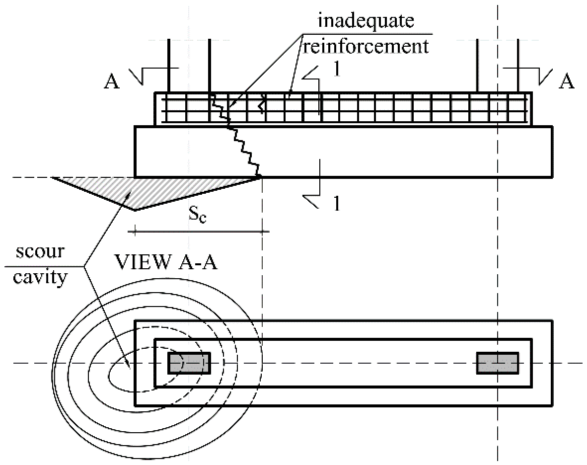
Structuring of adequate quality control plans

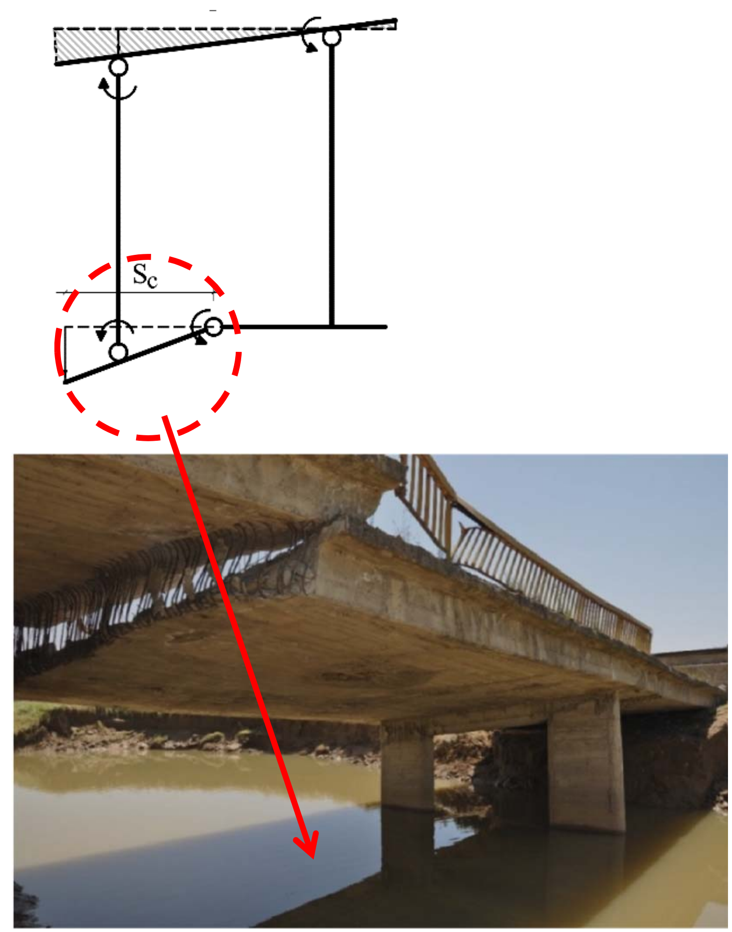
Key bridge elements for different types of resistance to local scour at a substructure

Bridge element	Attention	Resistance	Failure mode type
Affected substructure foundation	Inadequate detailing/condition state	Structure governed	**1**
Bearing/joint at the top of the affected substructure	Low plastic strength of a bearing/joint (or a poor condition state)	Governed by soil properties i.e no/low superstructure resistance	**2**
Bearings/joints at other substructures	Horizontal displacement is either free or restrained	Combined soil-bridge resistance	**3**
Main girder	Detailing	Combined soil-bridge resistance	**3**
		Failure safe	**4**

Structuring of adequate quality control plans

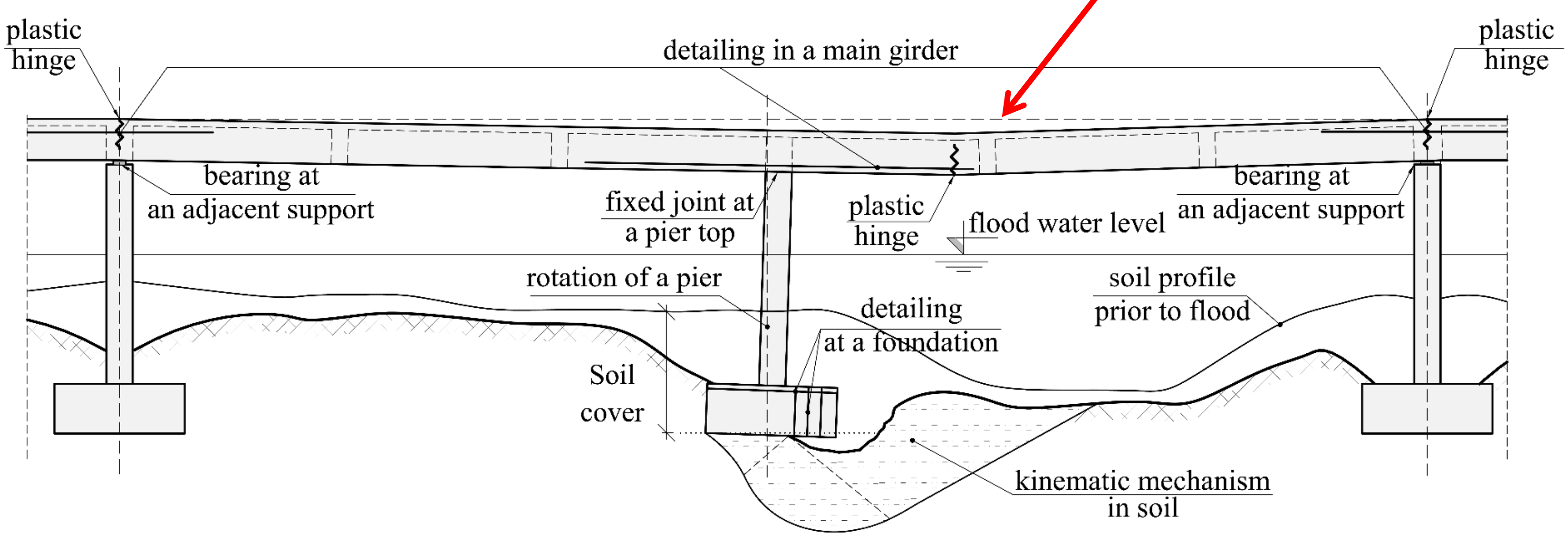
- **FM Type 1 – progressive collapse due to inadequate detailing**





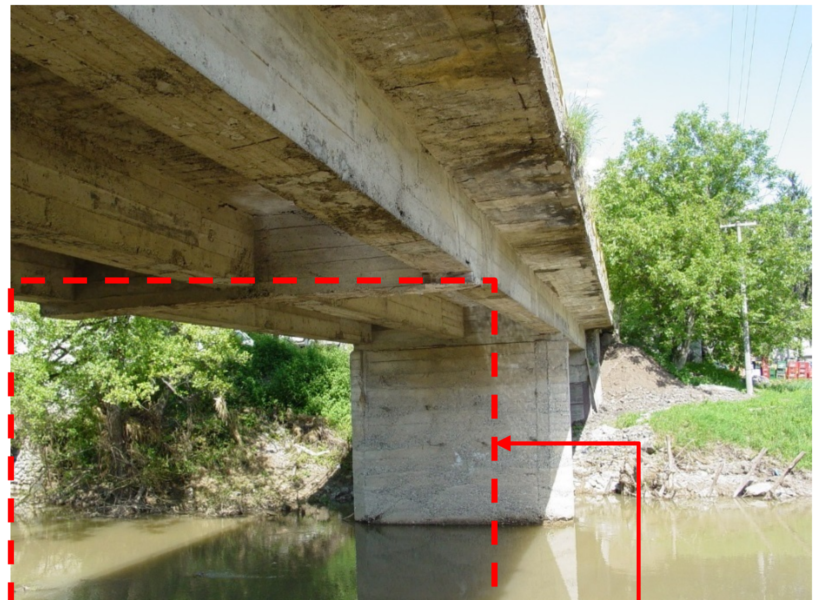
Structuring of adequate quality control plans

- **FM Type 3 – combined soil-bridge resistance**



Structuring of adequate quality control plans

- **FM Type 4**



- **Or is this FM Type 2 ?**

Missing pier !

Conclusion

- **Structuring of an adequate control plan for each bridge type**
- **Minimum set of information !**
- **Performance Indicator = Vulnerability**
- **Preventative interventions**
    - ✓ Decrease an exposure to a scenario
    - ✓ Monitoring of scour at substructures
    - ✓ Increase of a structure resistance
        - o Bridges with potential for **FM** type **1** & **2**

Acknowledgment

- **COST TU1406** Research Project: Quality specifications for roadway bridges, standardization at a European level

Thank you for the attention !