TU1406
COST ACTION

FACULTY OF CIVIL ENGINEERING
CTU IN PRAGUE

Training School COST Action TU 1406 on Bridge Quality Control

ISBN: …………………

PREFACE

The second Training School of COST Action TU1406 took place between 25th – 28th September 2017 in Faculty of Civil Engineering CTU in Prague. It covered several topics related to diagnostics of steel, concrete and masonry bridges, quality control and performance assessment of bridges, performance indicators, life cycle costing and bridge management. It involved 6 trainers and 21 trainees from 21 European Countries and from different stakeholders (from academia to industry). A good gender and inclusiveness countries balance was also achieved.

The group was very interesting, and networking was automatically done not only through the development of the different assignments which were given by the trainers but also by all the social activities (networking dinner, bridge inspection, team work). The provided assignments were related to the evaluation of the quality control plans for three bridges (steel, concrete and masonry), which cover the COST Action topics. Main results will be then used for the technical report of this Action, and the best assignments as case studies.

The following eBook covers all the addressed topics by the different lecturers in the same order of the training school. It will be important not only for future training schools, but also for those interested in the quality control of roadway bridges. As Chair of the Action and as local organiser, we would like to acknowledge all who contributed to this important material from the trainers and the trainees. This was in fact a very important step towards the following training schools of COST Action TU1406.

Jose C. Matos
Chair COST Action TU1406

Pavel Ryjáček
Local organiser, KTH

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COST ACTION TU1406: QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control , Septmeber 25 – 28, 2017
Faculty of Civil Engineering CTU, Prague, Czech Republic

QUALITY CONTROL FOR ROADWAY BRIDGES APPROACH AND APPLICATION

Prof. Dr. Rade Hajdin - University of Belgrade, Serbia

Грађевински факултет Универзитет у Београду

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COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

What is Quality?

- Wiki: **Philosophy** and **common sense** tend to see qualities as related either to subjective feelings or to objective facts. The qualities of something depends on the criteria being applied to and, from a neutral point of view, do not determine its value (the philosophical value as well as economic value). Subjectively, something might be good because it is useful, because it is beautiful, or simply because it exists. Determining or finding qualities therefore involves understanding what is useful, what is beautiful and what exists. Commonly, quality can mean degree of excellence, as in, "a quality product" or "work of average quality".
- Wiki: In **business, engineering and manufacturing**, quality has a pragmatic interpretation as the non-inferiority or superiority of something; it's also defined as **fitness for purpose**. Consumers may focus on the **specification quality of a product/service**, or how it compares to competitors in the marketplace. Producers might measure the **conformance quality**, or degree to which the product/service was produced correctly.

What is Quality regarding bridges?

- In ISO 9000: Degree to which a set of inherent characteristics of a **product** or **service** fulfills requirements.
- Bridge is definitely a product that has to fulfill certain requirements
- The requirements are defined in “codes of practice”. Typical requirements are defined to **safety** and **serviceability**.
- The bridge is fit for purpose if safety and serviceability requirements are met.
- Safety and serviceability are inherent characteristics (following the above definition) of a bridge
- In realm of bridge management the term “performance goals” are often use instead of “requirements”.
- The evaluation if safety and serviceability goals are met can be performed in any time instance.
- These goals are normally met at the time of acceptance.

Quality of existing bridges

- Wiki: Support personnel may measure quality in the degree that a product is **reliable**, **maintainable**, or **sustainable**. A quality item (an item that has quality) has the ability to perform satisfactorily in service and is suitable for its intended purpose.
- Fulfillment of the **safety and serviceability goals over time**.
- Assuming that the safety and serviceability goals are met at acceptance (-> handover to the owner or operator) what wouldn't they be met in some time in future.

Ravages of time

- Slow, observable and therefore interceptable processes (corrosion, frost, alkali aggregate(?), climate, traffic)
- Slow unobservable and therefore non-interceptable processes (corrosion of posttensioning steel, alkali aggregate)
- Sudden events (flooding, earthquake, fire)
- These processes can endanger the fulfillment of these requirements.

Quality control

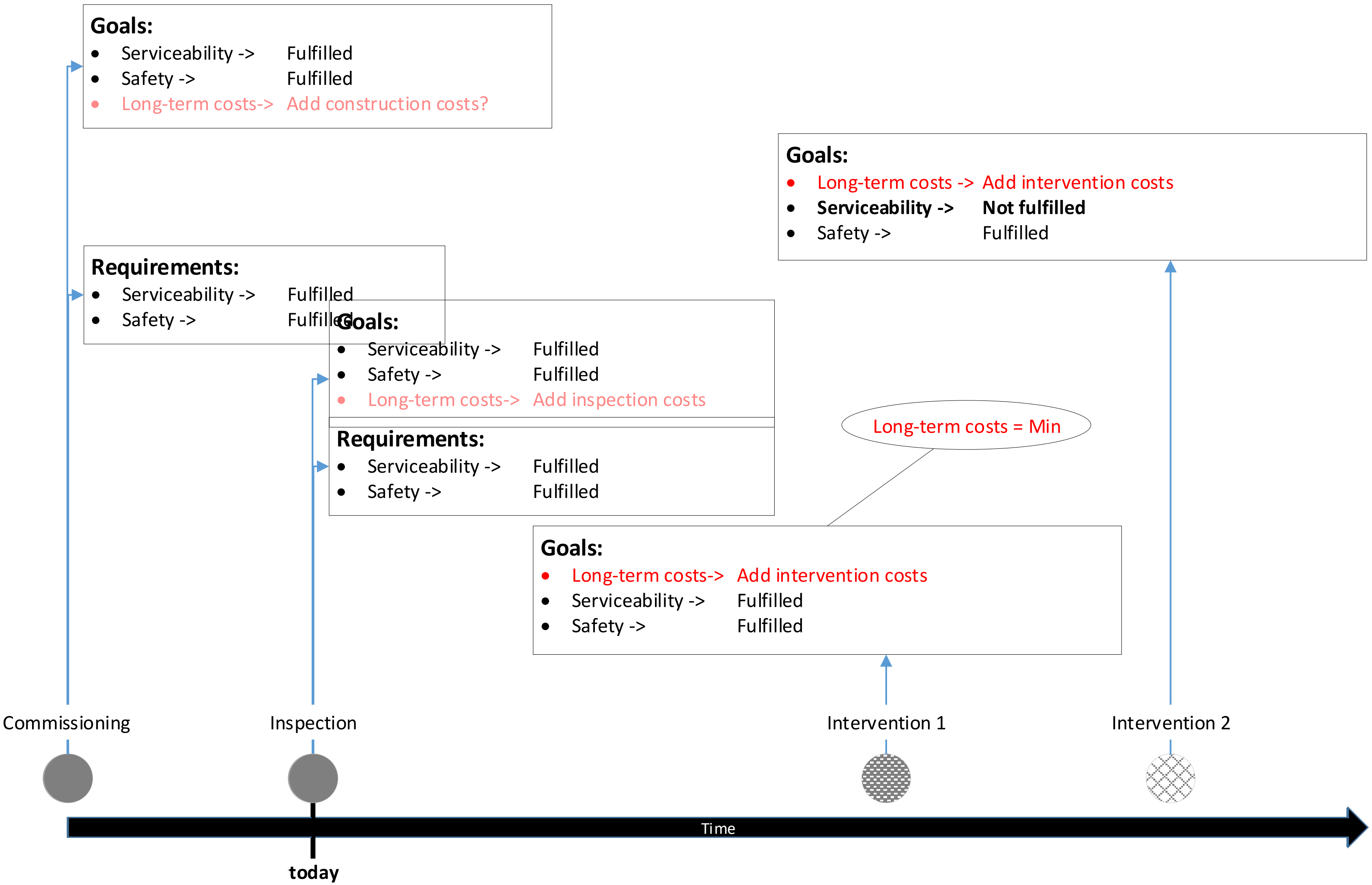
- There are quite a few definitions reflecting the ambiguous meaning of the word “control” as
  - Verify, check or inspect or
  - Command, direct or rule.
- In business the quality control is defined as:

  “The process of inspecting products to ensure that they meet the required standards” or

  “The activity of checking goods as they are produced to make sure the final products are good”
- The first definition applies to the topic of this COST Action.
  - Check if product meet the standards, requirement or goals.
  - Car check, health check, etc.
- However, this COST Action goes beyond mere checking and verifying and provide guidance to “command and direct” actions to ensure long-term quality.

Quality control for bridges

- **Static (snap shot) interpretation**: Inspect and investigate a bridge and determine whether the serviceability and safety goals are met.
  - Basis for the decision making on actions
- **Dynamic interpretation**: Static interpretation + plan and execute actions to **ensure long term fulfillment of safety and serviceability goals. -> Bridge Management**
- There are different ways to ensure that goals are met on the long-term:
  - Preventive action
  - Corrective actions
  - Operational actions
- Which one to take? What is the criterion for decision making?
  - Economics (Cost); Which costs? One time costs or long term costs?
- There is therefore another goal of Quality Control -> **Economics!!!**


Goals:
Serviceability -> Fulfilled
Safety -> Fulfilled
Long-term costs-> Add construction costs?
Requirements:
Serviceability -> Fulfilled
Safety -> Fulfilled
Goals:
Serviceability -> Fulfilled
Safety -> Fulfilled
Long-term costs-> Add inspection costs
Requirements:
Serviceability -> Fulfilled
Safety -> Fulfilled
Goals:
Long-term costs -> Add intervention costs
Serviceability -> Not fulfilled
Safety -> Fulfilled
Long-term costs = Min
Goals:
Long-term costs-> Add intervention costs
Serviceability -> Fulfilled
Safety -> Fulfilled
Commissioning
Inspection
Intervention 1
Intervention 2
Time
today

Performance goals

- The goal of road users is simple: to get from A to B safely in expected time.
- The road connection has to be reliable.
- Operational reliability -> not directly considered
- Structural **reliability!**
  - EN 1990:

    "Ability of a structure or a structural member to fulfil the specified requirements, including the design working life, for which it has been designed. Reliability is usually expressed in probabilistic terms
    NOTE: Reliability covers **safety, serviceability** and durability of a structure."

    Durability: The structure shall be **designed** such that deterioration over its design working life does not impair the **performance** of the structure below that intended, having due regard to its environment and the anticipated level of maintenance.
  - EN 1992:

    A design using the partial factors given in this Eurocode (see 2.4) and the partial factors given in the EN 1990 annexes is considered to lead to a structure associated with reliability Class RC2 -> $\beta_{safety} = 3.8$, $\beta_{serviceability}=1.5$ for 50years

Further performance goals

- **Reliability** include the probability of structural failure (safety) or operational failure (serviceability).
- **Availability** is the proportion of time a system is in a functioning condition.
  - WG2 (somewhat cryptical): Meet object specific requirements with regard to the fulfilment of object function.
  - For our purposes: Additional travel time due to imposed traffic regime on bridge.
  - ***Not reliability-related disruption of bridge users***
- **Economic efficiency** -> minimizing long term cost
- **Safety** (not structural safety) minimize (eliminate) the **harm people** during the service life of a bridge. Loss of life and limb due to structural failure is normally not included!
- **Environmental friendliness** -> minimize the **harm to environment** during the service life of a bridge.

RAMSSH€EP

- **Reliability**
- **Availability**
- **Maintainability** is the ease with which a product can be maintained in order to correct defects or their cause, repair or replace faulty components without having to replace still working parts and prevent unexpected working condition -> *design aspect and is covered with economic efficiency*
- **Safety**
- **Security** is degree of protection against vandalism -> *similar to maintainability is design aspect included in economic efficiency*
- **Health** is absence of non-failure causes of illnesses (e.g. asbestos) -> *regulated*
- **€conomics**
- **Environment** -> regulated
- **Politics** include elimination of causes for public outcry, image protection etc. -> downstream performance goal; Fulfilled if RAS€E goals are met.

Conclusion

- Within the QC Framework
  - Reliability
  - Availability
  - Safety
  - €conomics

  will be evaluated for different maintenance scenarios
- Environment is mostly regulated, but in some cases can be also included.
- **Snapshot or static quality** control includes
  - Reliability (structural safety and serviceability) and
  - Safety (not structural safety) regarding loss of life and limb
- **Dynamic quality control** (bridge management) include
  - Feasible maintenance scenarios that define costs and availability over certain time frame
  - Reliability and Safety forecasts

Scope of the training school - I

- Preforms snapshot quality control
  1. Preparatory work
     - Study inventory information
     - Identify weaknesses of the original design
     - Identify the material weaknesses
     - Compare the current traffic loads to traffic load model used in original design
     - Define the vulnerable zones
     - Evaluate à priori reliability
  2. Inspection on site
     - Identify damages (cracks, spalling, deformations, etc.)
     - Measure on site material properties
     - Collect samples

Scope of the training school - II

3. Lab test
    - Carbonatization depth
    - Chloride ingress
4. Assessment of reliability
    - Qualitative assessment of resistance reduction based on observed damages
    - Qualitative assessment of reliability (structural safety and serviceability)
5. Assessment of safety (life and limb)

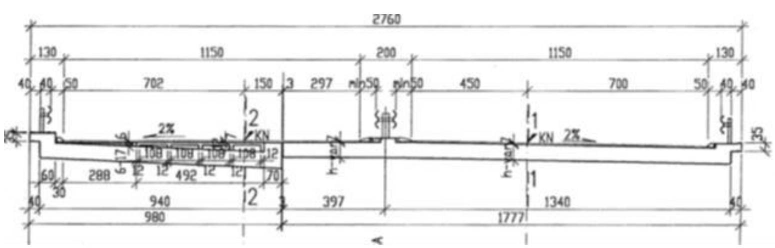
- Perform dynamic quality control (as far as possible)

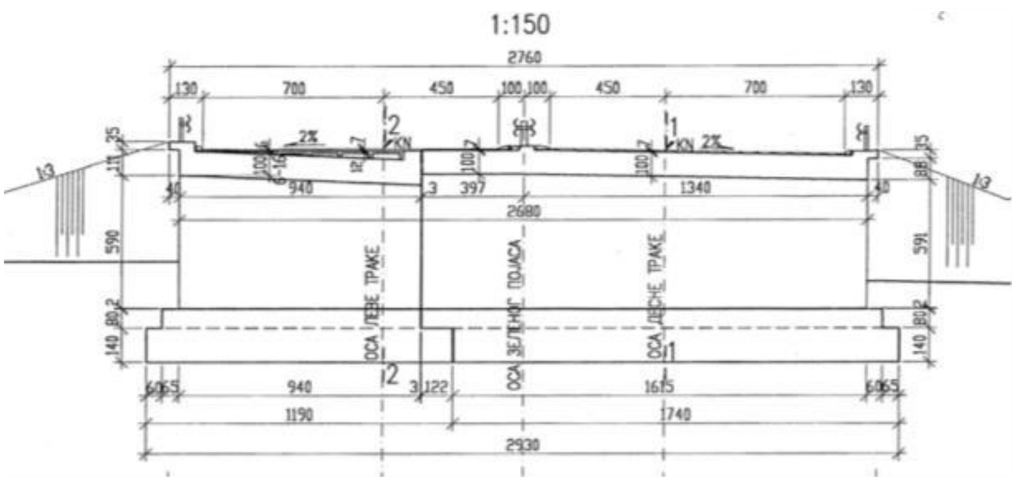
6. Assessment of a remaining service life
    - Assessment of the speed of active damage processes
    - Damage forecast
    - Reliability and safety development over time

Scope of the training school - III

7. Maintenance scenario
    - Reference scenario – intervention at the end of service life
    - Preventative scenario
    - Estimate long term costs for all scenarios
    - Estimate availability for all scenarios
    - Estimate an effect of maintenance on reliability and safety
8. Decision making
    - Preform multi-attributive or multi-objective optimization
    - Monetize non-monetary KPIs
    - Determine the optimum scenario

1. Preparatory work – inventory information

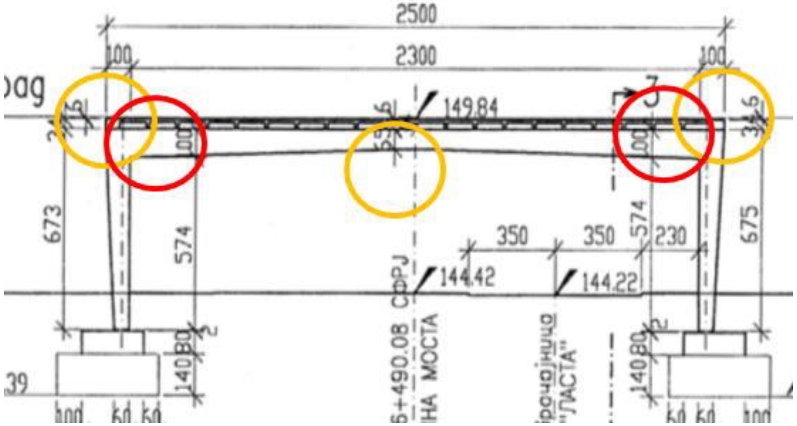




RC Frame
ADT 10’000
Construction year 1963
Widened in 1977
No natural hazards

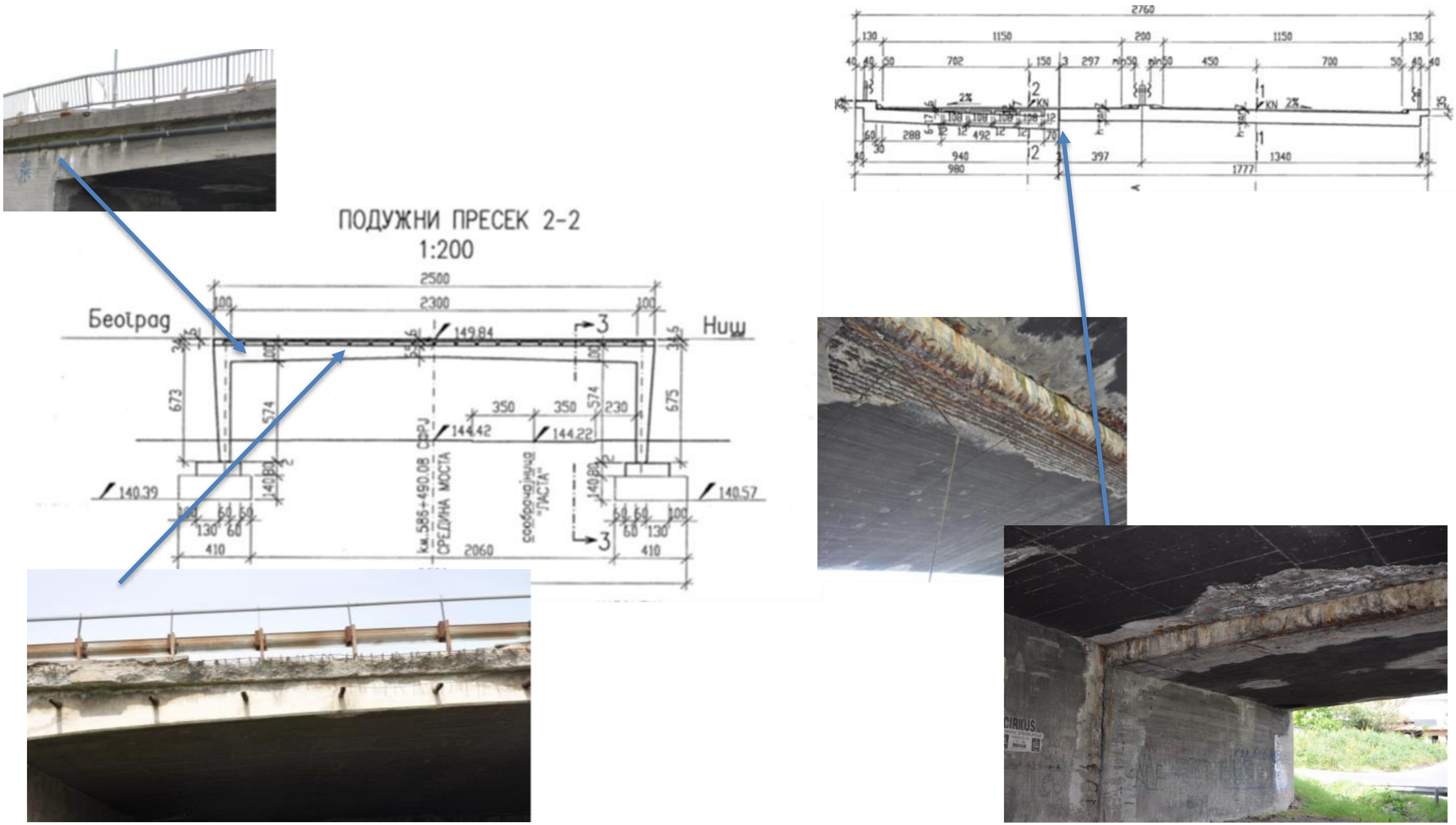
1. Preparatory work – other information

- No particular weaknesses of original design
- The obvious weakness is longitudinal joint connecting the old and the new parts of bridge
- No particular material weaknesses are known – steel bars didn't have any ductility problems
- The traffic load in code of practice did increase since 1963, but the bridge was recalculated in 1977.
- Prior reliability index (safety) is 3.8



HMS-high suging moment zone	orange circle	ductile
HMH - high hoging moment zone		
HSS - high shear zone	red circle	britle

2. Inspection on site – damages



2. Inspection on site – other hazards

- There is a road beneath the bridge
- It is rural road with low traffic volume
- There is however a danger of falling concrete on vehicles or persons
- Railings can’t performed as designed

4. Assessment of resistance reduction

- There are some indication of diminished resistance:
  - Spalling at the width of (in average) 1.5 meters over the whole span.
  - Uncertain bonding
  - Significant corrosion ~10% section loss (old structure)
  - Corrosion to ~5% section loss in vulnerable zone (new structure)
  - Based on the symptoms there is probably corrosion over the piers, which is a vulnerable zone belonging to same failure mechanism
  - Redistribution in perpendicular sense has positive effects.
  - Uncertain cause and development of the diagonal crack.
- Based on experience and elementary statics the resistance reduction has been assessed to 10% (probably conservative)
- There is no urgent necessity to perform in depth investigation.
- Clearly, the assessment is rather rough and based on inspector's experience but so is condition rating.

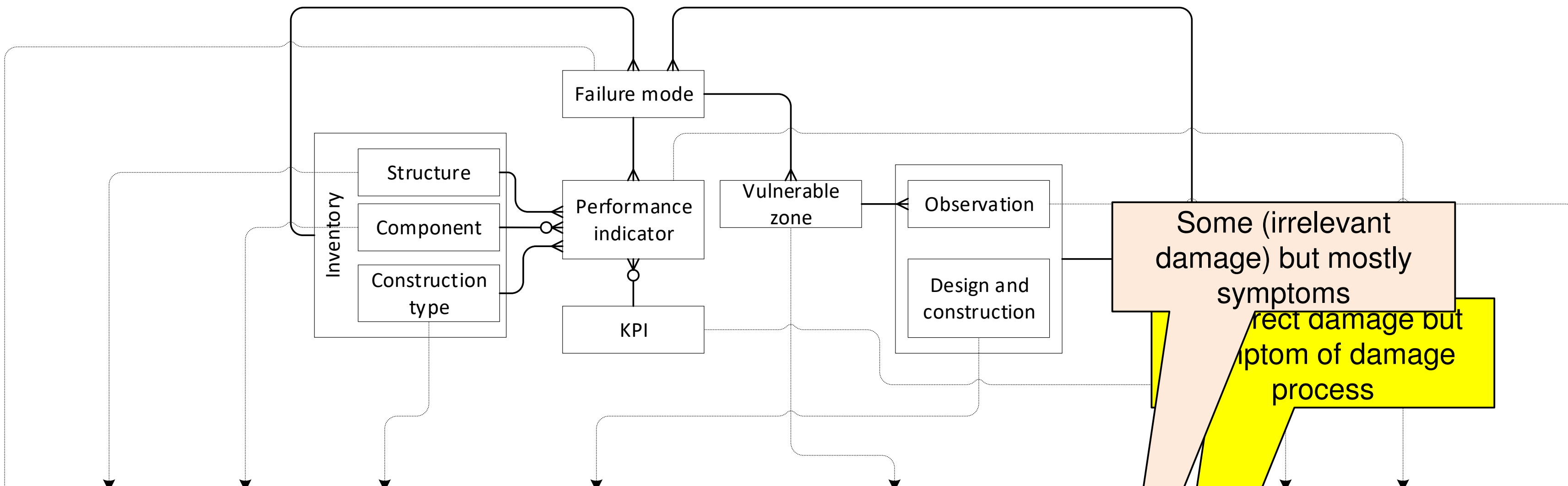
4. Qualitative assessment of reliability

4. Some comments

- The value of virgin reliability due to current loading is critical!
- It is advisable for old bridges to estimate the real loading by means of axle load measurements. The real traffic loading can be sometimes higher but sometimes significantly lower (less aggressive).
- In this particular case the traffic loading increased from 1977.
- The assessment od reliability is similar to the condition assessment with two crucial differences:
  – It takes into account virgin reliability,
  – focuses on failure modes and
  – related vulnerable zones.
- Most inspection practices focus implicitly on the latter two, but not explicitly.
- Hint: Thinking in failure mechanisms helps since it allows one to estimate the reduction of dissipation work due to damages.
- The example bridge will probably not fail catastrophically but rather experience a warping deformation.

5. Assessment of safety (life and limb)

- The loss and life and limb due to structural failure is **not included**.
- Falling concrete cover can endanger persons in and outside the vehicles.
- It is very unlikely that large chunks are going to fall down.
- The chunks that are found on the street were maximum 10x10x2 cm.
- The traffic volume is very low both pedestrian and vehicles.
- The capacity for spalling has also diminishes as water cannot reach reinforced bars that are still covered with concrete.
- The falling height is relatively small.
- The damaged railings jeopardize traffic safety
- Taking the observations into account and the above reasoning the danger for life and limb is relatively small i.e. 2.
- The performance indicator of 1 is no danger (injury return period > 100 years) and performance indicator of 5 characterizes immediate danger (injury return period < 10 years)



Frame bridge	Deck (old)	Reinforced concrete	1963	Bending failure mode	HMS	Corroded reinforcement	Reliability (Structure safety)	3	3
	Deck (new)	Reinforced concrete	1977			Corroded reinforcement			
	Deck (old)	Reinforced concrete	1963			Spalling			
	Deck (new)	Reinforced concrete	1977			Spalling			
	Deck (new)	Reinforced concrete	1977		HMH	Corroded reinforcement			
	Deck (old)	Reinforced concrete	1963			Corroded reinforcement			
	Deck (new)	Reinforced concrete	1977			Spalling			
	Deck (old)	Reinforced concrete	1963			Spalling			
	Deck (new)	Reinforced concrete	1977			Efflorecences			
	Deck (old)	Reinforced concrete	1963			Efflorecences			
	Deck (old)	Reinforced concrete	1963	Shear failure mode	HSS	Crack		2	
	Deck (old)	Reinforced concrete	1963	Falling chunks		Spalling	Safety (Life and limb)	2	2
	Deck (new)	Reinforced concrete	1977			Spalling		2	
	Railings	Steel	1977	Falling of the bridge		Broken		2	

Catalog of observations

- WG1 collected observations from almost all European countries.
- The observations were clustered in different categories.
- WG 3 reduced the list by focusing on “real” observation and not interpretation.

changes in dynamic behavior
approach slab settlement
porous concrete
insufficient concrete cover
aggregate segregation
cladding damages
cladding deformations
deformation
cracks
crushing
rupture
delamination
scaling
spalling
coupling joint deficiency
wire break

presstresing cable failure
reinforcement bar failure
stirrup rupture
efflorescence/crypto-florescence
holes
wet spots
gel exudation
hydroxide calcium exudation
chloride content
shear connection failure
anchorage failure
debonding
protection duct damage (of prestreesed cable)
grouting deficiency
damaged adhesive
tensioning force deficiency

Uncertainties and lack of information

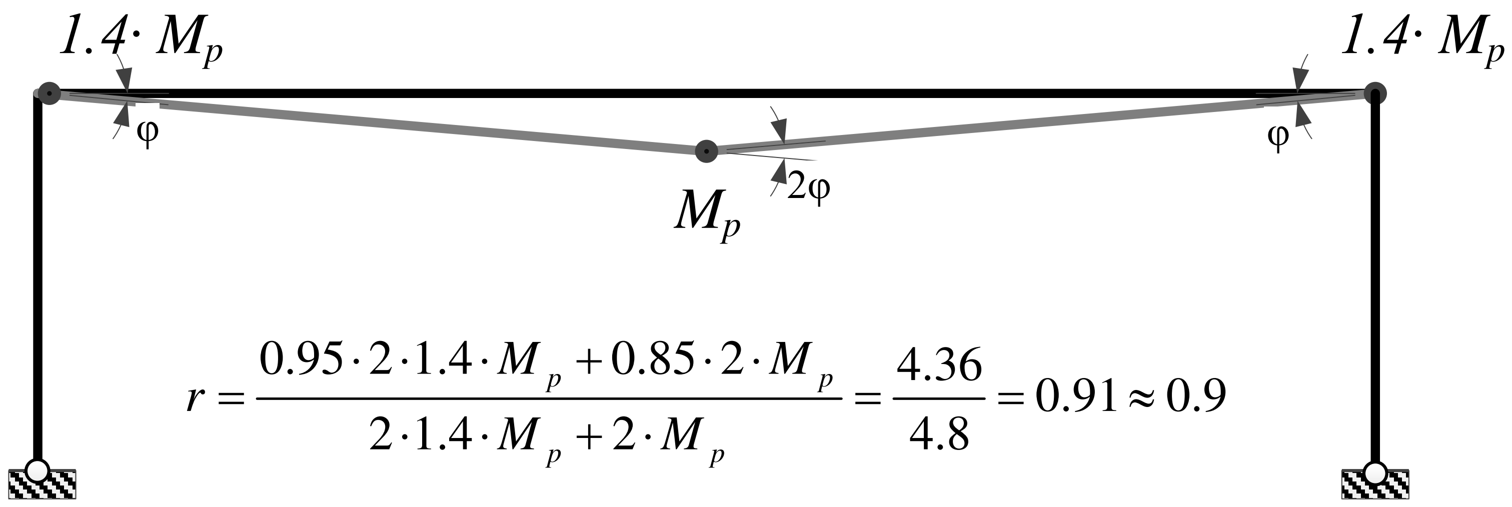
- The same observation (actually the observed "thing") can have different causes.
- A crack > 0.2 mm indicated that the reinforcement yielded
- This can be due to a one-time overloading or error in design.
- The inspector can decide which of this possibility is more likely and attach his/her degree of belief.
- If the crack is closed due to bleaching it is unlikely that the element is under designed.
- If however the crack width changed between the inspection it can well be that the resistance is not sufficient.
- Similar reasoning can be applied to other observations e.g. fatigue cracks

Reliability against which failures?

- Failure – Ultimate Limit State
  - Rigid body movement
  - Internal mechanism (plastic, brittle)
  - Fatigue (brittle)
- Failure – Serviceability Limit State
  - Functionality
  - Comfort
  - Visual appearance
- Probability that stresses in a cross-section exceed certain value
- Probability of development of a mechanism
- Probability of undesired appearance -> RAMSSH€E**P(olitics)**
- Each country has to establish guidelines according to their value system.

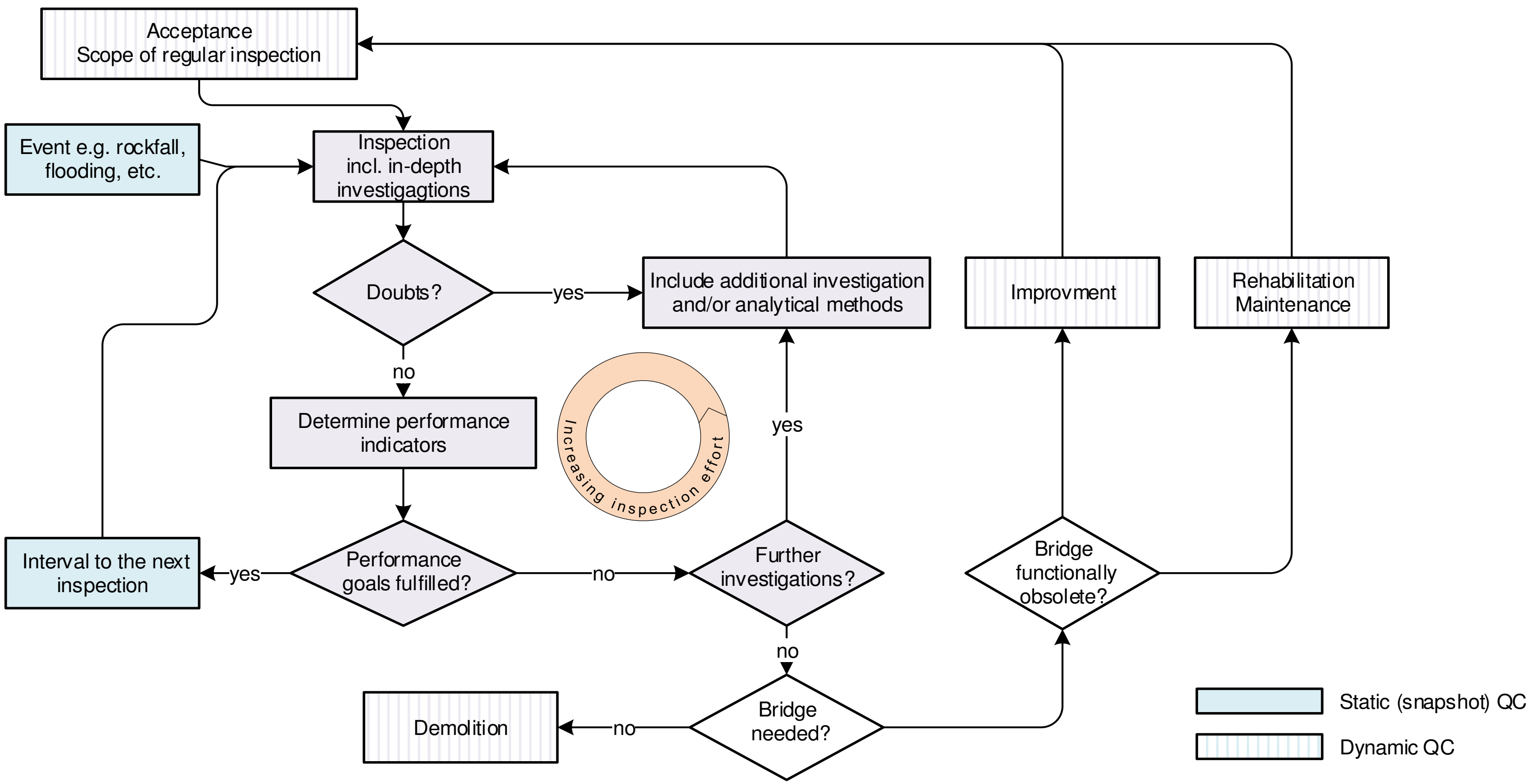
Assessment of reliability related to ULS

- Kinematic theorem of the theory of plasticity can be quite useful.
- Upper bound -> not on the safe side.
- Failure mechanism can be assumed -> relatively simple for vertical loads
- Resistance is essentially internal dissipation rate that decrease with each damage.



$$r = \frac{0.95 \cdot 2 \cdot 1.4 \cdot M_p + 0.85 \cdot 2 \cdot M_p}{2 \cdot 1.4 \cdot M_p + 2 \cdot M_p} = \frac{4.36}{4.8} = 0.91 \approx 0.9$$

Stages of investigation



Return period and remaining service life

- The reliability index β for structural safety expresses the probability of failure due to combination of excessive load and uncertainty related to resistance of a bridge for a **given design life**.
- The design life is actually **failure return period**!
- It does not include **damages** that may or may not occur during the service life nor the **change in traffic loads**.
- The damages can reduce the resistance of a bridge resulting the in lower reliability index for safety and therefore also shorten failure return period.
- This should not be confused with the remaining service life due to deterioration.
- The failure return period of a heavily deteriorated bridge can be 10 years, which can be regarded as a threshold value to close a bridge. It is not connected with the time period in which this deteriorated state has been reached.

6. Assessment of the remaining service life

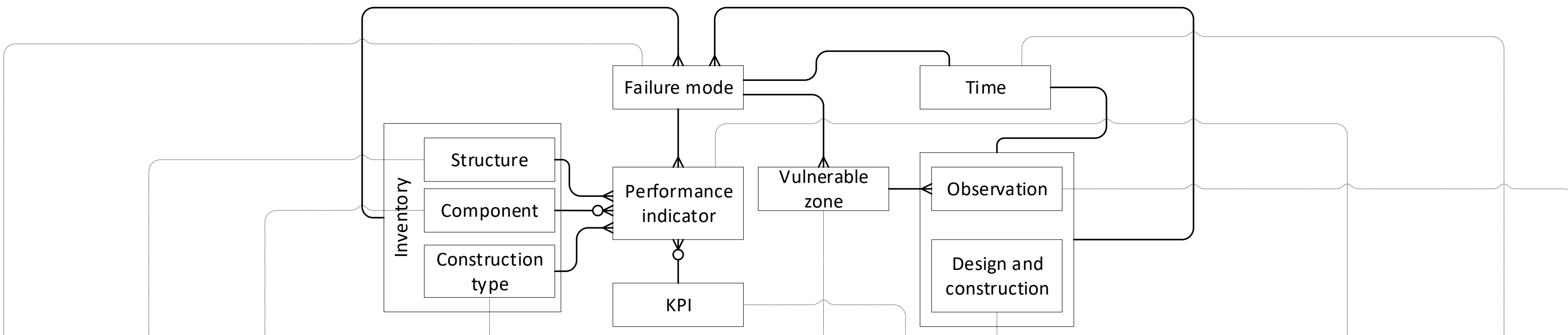
- The identification of active damage process and its drivers is essential for dynamic quality control.
- The further development of observed damages or behavior of the bridge is governed by damage processes.
- The development of these processes over time can be modelled based on physical processes and/or statistical data.
- In Bridge Management Systems different deterministic and probabilistic models are implemented, mostly for condition state.
- Common model for condition development is Markov Chains.
- The focus of this school is not on the time models for KPI but rather on principles that govern decision making.
- The remaining service life defined the point in time, at which the reliability of safety reach some threshold.

7. Maintenance scenarios

- Availability and Economics are governed by maintenance scenarios.
- The snapshot assessment of availability is of little interest as the bridge is either available or not. The key issue lied with the duration of restricted availability or closure.
- The costs that are required to assess economics are even less reasonable to asses as snapshot indicator. It is the cash flow over time that need to be assess.
- To compare different scenarios it is necessary to define a reference scenarios. This can be any scenario, but most common is to choose a “do nothing” scenario, in which the action are taken only at threshold values of a KPI.
- Mostly the reliability (in the current practice the condition state) is the triggering criterion for the interventions.

7. Maintenance scenarios - Forecasts

- Forecasts of reliability and safety
  - There are many model to forecast condition state of components and whole structures.
  - There are some models to forecast development of existing damages in the future (Germany, Switzerland).
  - These can be used as basis for the model that forecast the reliability level in the future.
  - The alternative is to let the inspector decide on remaining service life (=reaching reliability level 5)
- The speed of deterioration (=diminishing reliability and safety) depends highly on observations of both damages and symptoms
- Symptoms are not damages but observable and measurable artefacts that accompany damage processes.



Frame bridge	Deck (old)	Reinforced concrete	1963	Bending failure mode	HMS	Corroded reinforcement	Reliability (Structure safety)	3	3	15 years
	Deck (new)	Reinforced concrete	1977			Corroded reinforcement				
	Deck (old)	Reinforced concrete	1963			Spalling				
	Deck (new)	Reinforced concrete	1977			Spalling				
	Deck (new)	Reinforced concrete	1977		HMH	Corroded reinforcement				
	Deck (old)	Reinforced concrete	1963			Corroded reinforcement				
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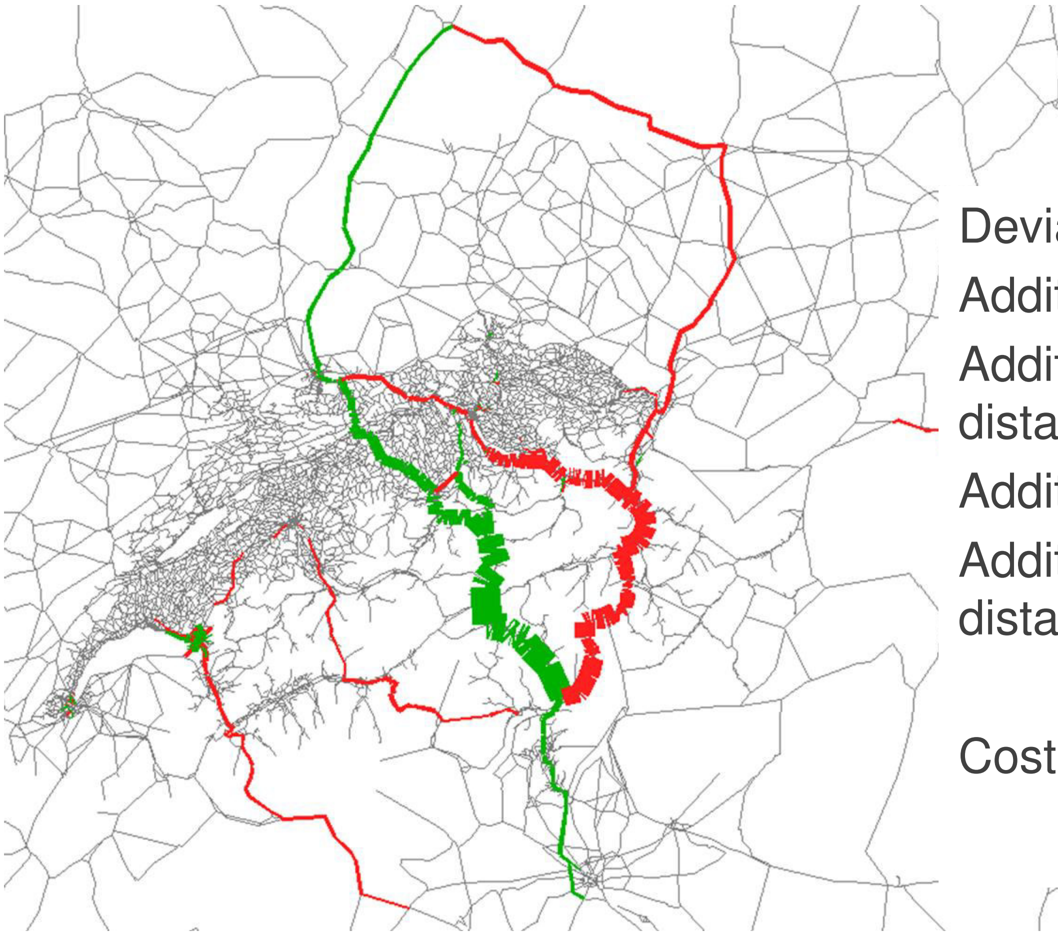
	Deck (new)	Reinforced concrete	1977			Efflorecences				
	Deck (old)	Reinforced concrete	1963			Efflorecences				
	Deck (old)	Reinforced concrete	1963	Shear failure mode	HSS	Crack		2		
	Deck (old)	Reinforced concrete	1963	Falling chunks		Spalling	Safety (Life and limb)	2	2	40 years
	Deck (new)	Reinforced concrete	1977			Spalling		2		
	Railings	Steel	1977	Falling of the bridge		Broken		2		

7. Maintenance scenarios - Availability

- Maintenance interventions require certain traffic regime, which may include closure for certain type of vehicles or lane closure or narrower lanes.
- Deteriorated bridge may be also closed for certain type of vehicles, which may be also regarded as traffic regime.
- For a given bridge there are not many possible traffic regimes, so they can denoted by letters or integer. The traffic regime 1 is the one with no restrictions.
- The other traffic regimes can be ranked by the additional travel time they cause for the road users.
- More appropriate would be to monetize these addition travel times based on the type of the vehicles and rank them.
- The complete closure is the worst case.

7. Additional travel time

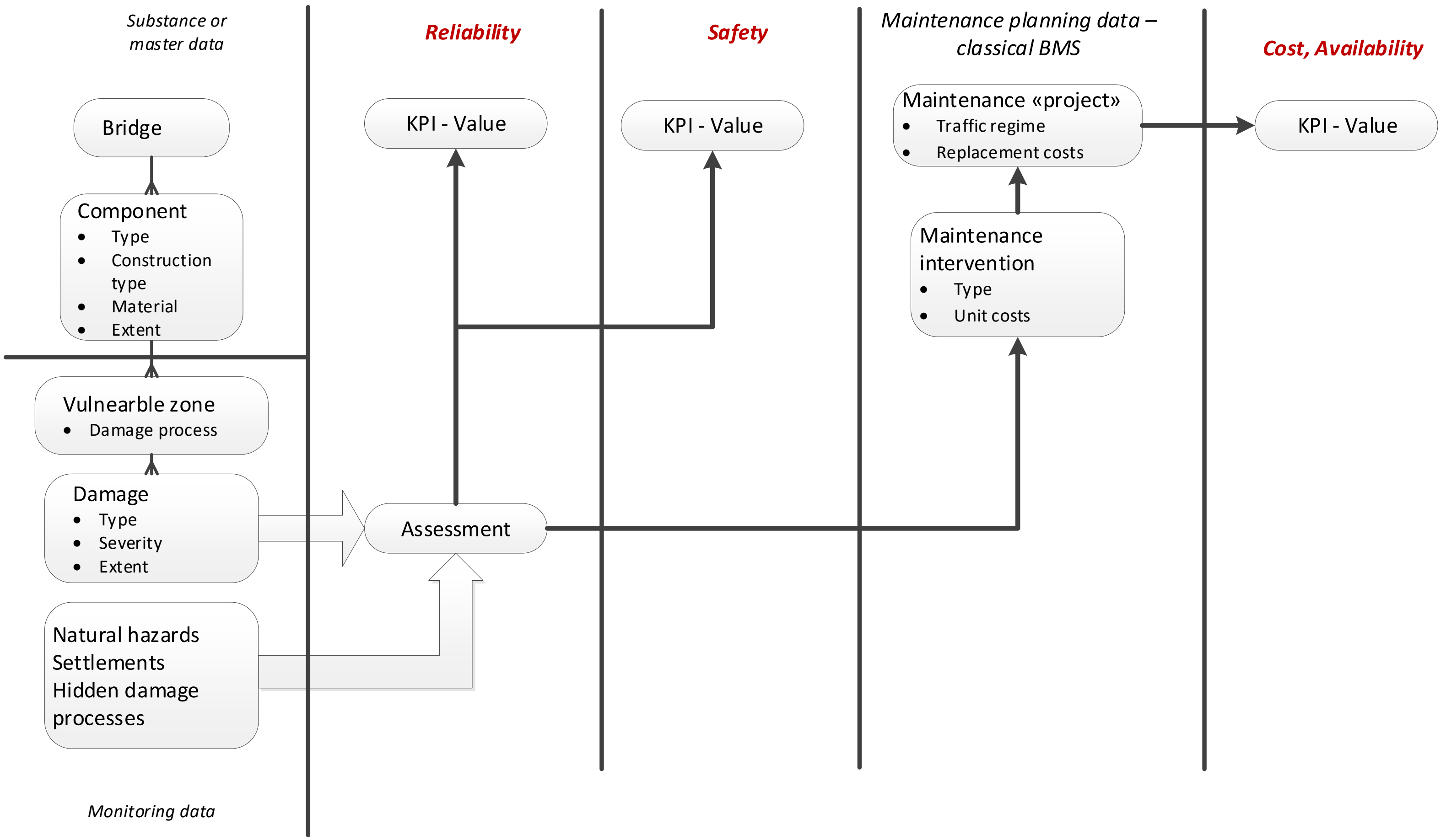


Deviated vehicles:	18’053/d
Additional travel time:	15’673 h/d
Additional travel distance:	1.3 Mio. Km
Additional travel time:	55 min./veh.
Additional travel distance:	57 km/veh.
Costs:	652’000 CHF

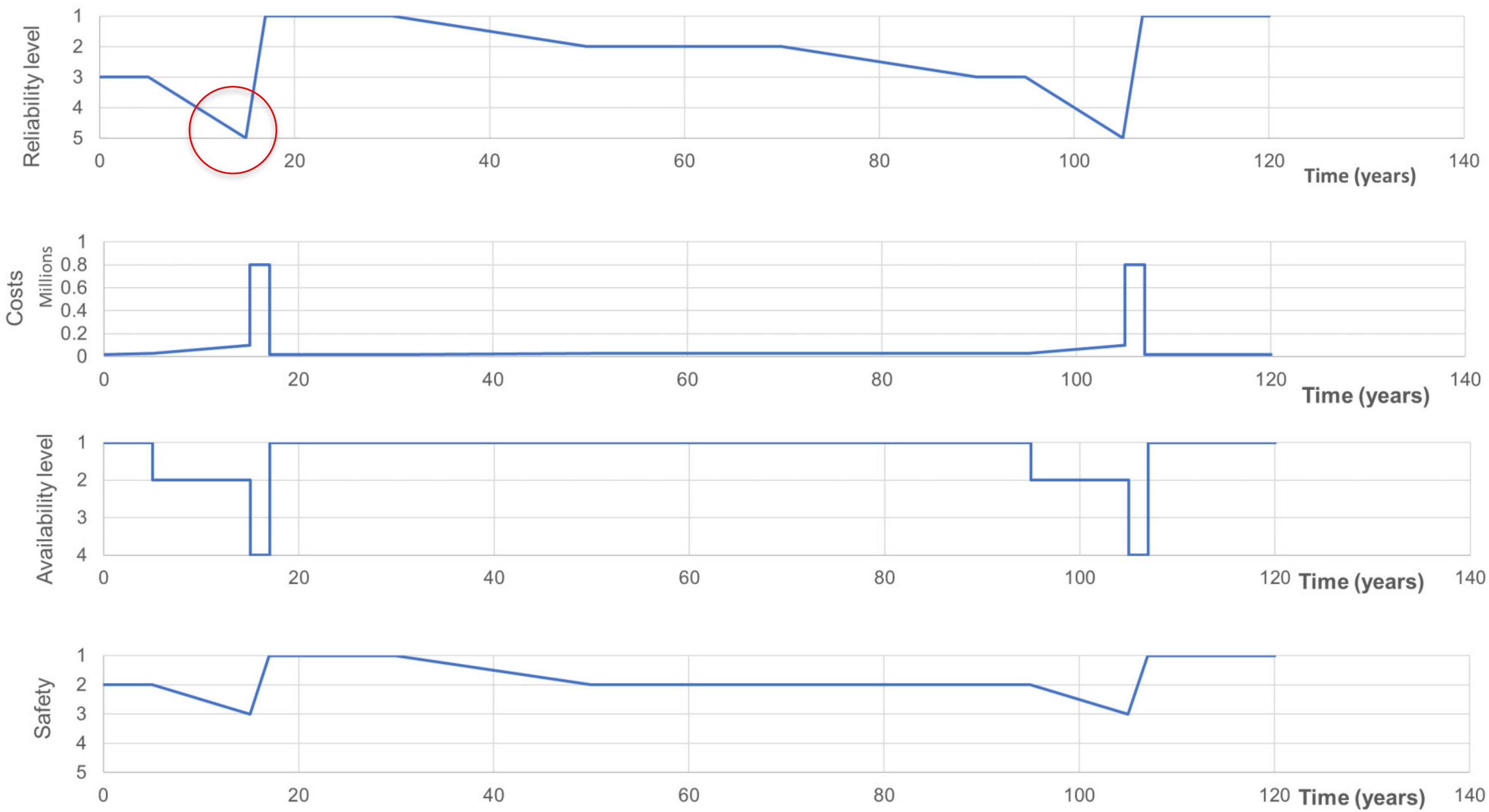
7. Maintenance scenarios - Cost

- "Classical" BMS
- Inspection results:
  - Severity of damage
  - Extent of damage
  - Location (Component)
- Unit costs
- Mobilization costs
- Damage forecast
- Generation of "Maintenance Intevention"
  - Type (Repair, Rehabilitation, Replacement)
  - Estimated costs

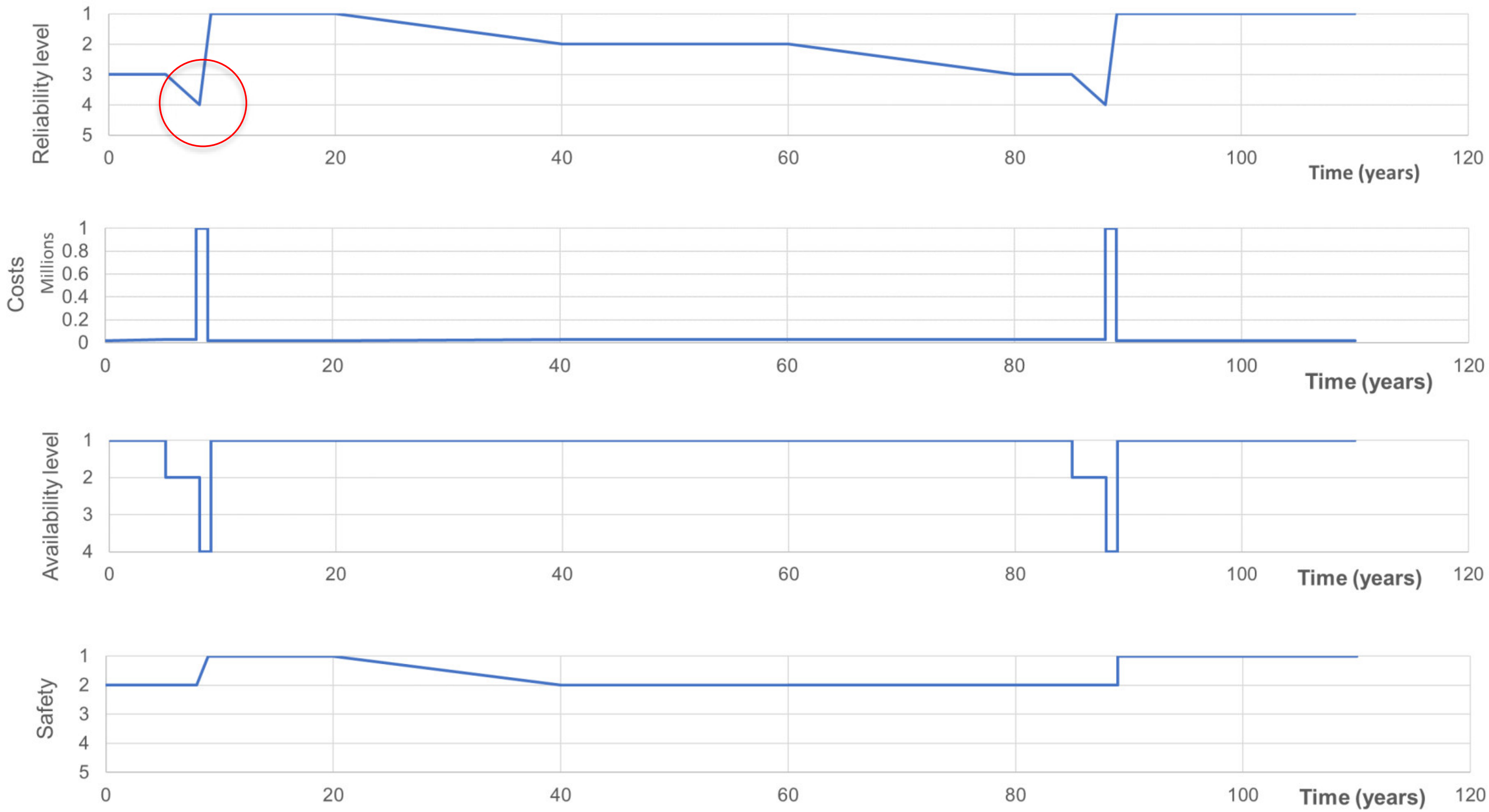
7. Maintenance scenarios - Summary



7. Reference scenario



7. Preventative scenario



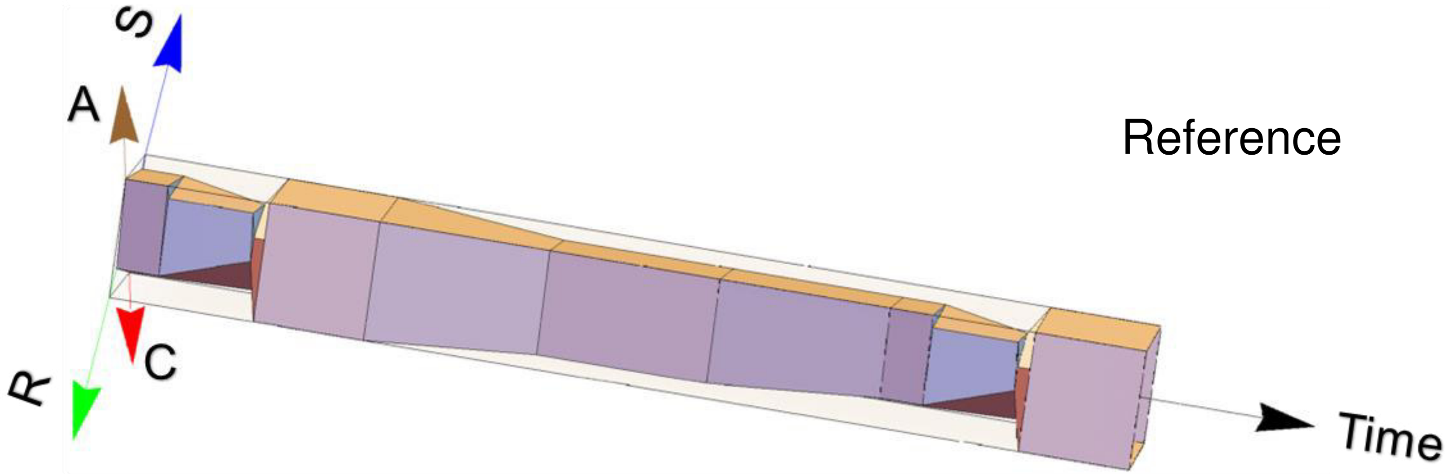
8. Comparing scenarios

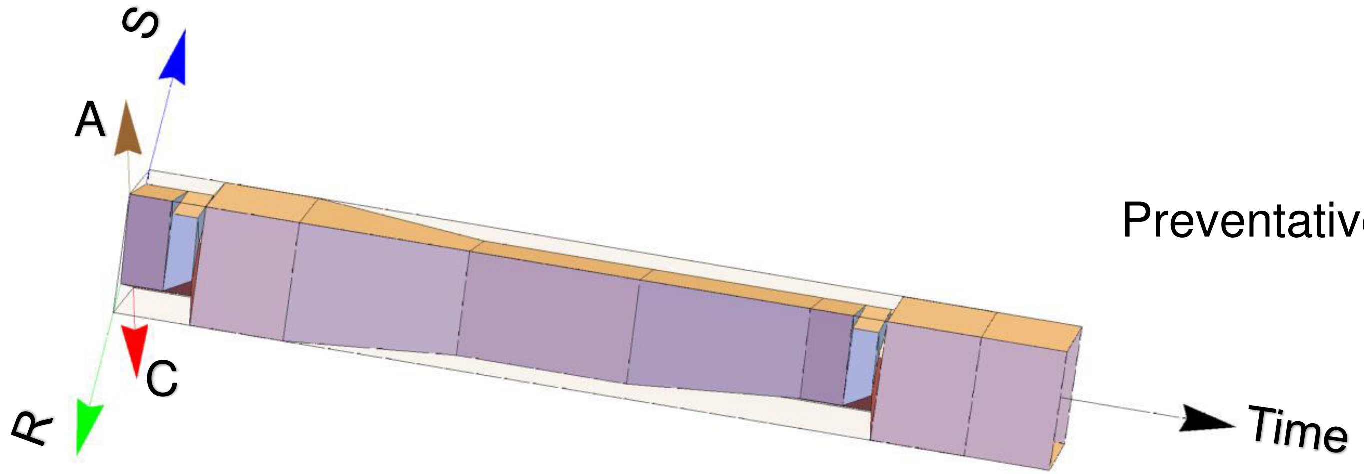
- Monetization
  - Cost are already monetized
  - Availability can be easily monetized
  - Reliability can be only monetized together with the consequences of “failure” -> Risk
  - Safety can be only monetized together with the consequences for “life and limb” -> Risk
- The monetization is widely adopted method in research community.
- In this COST Action this approach was not chosen.
- The scenarios can be only compared if the consequences of the “failure” and for the “life and limb” are equal.

8. Spider Diagram

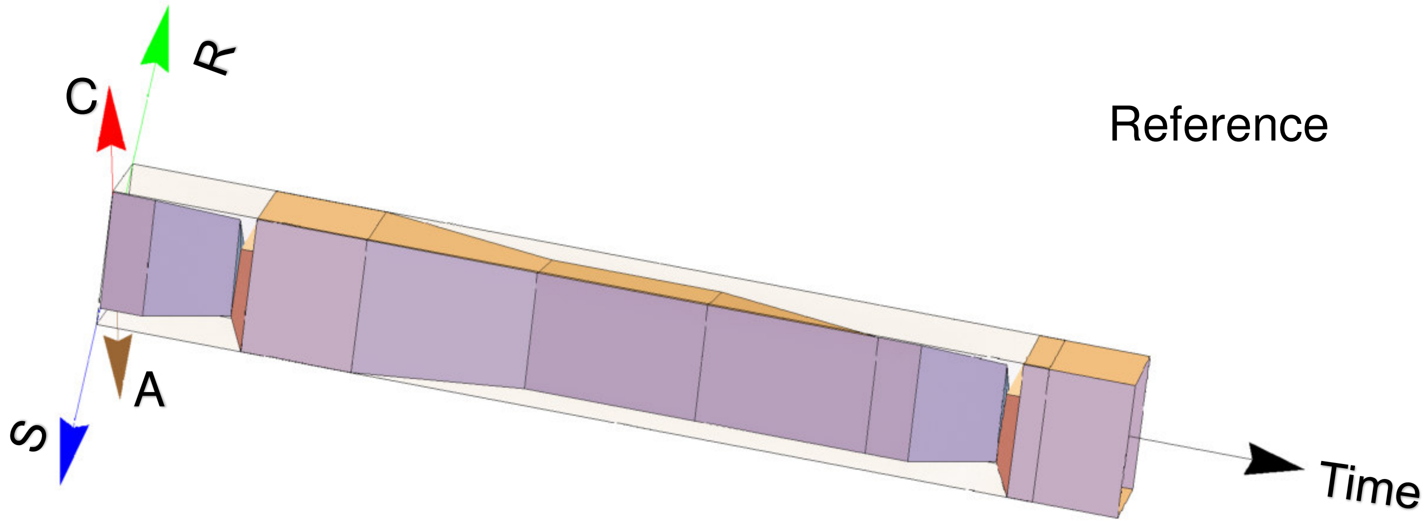
- All relevant KPI are to be expressed on the scale from 1 to 5.
- Rating 1 is the best and 5 is the worst.
- Reliability and Safety is already expressed in this manner.
- Availability will be transformed from the 1 to 4 scale into 1 to 5 scale.
- Zero costs are expressed with 0 and the highest costs/year are expressed as 5
- The highest costs/year in both scenarios are 1Mio/year -> rating 5
- In this manner a 3D spider diagram for both scenarios can be generated.

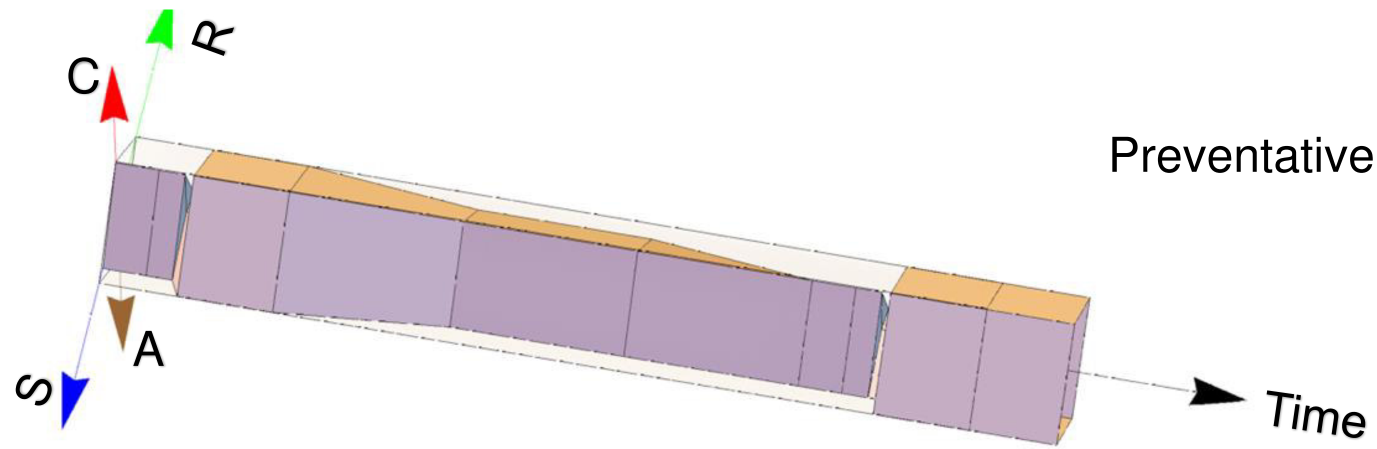
8. Decision making – 3D Spider/front view





8. Decision making – 3D Spider/rear view



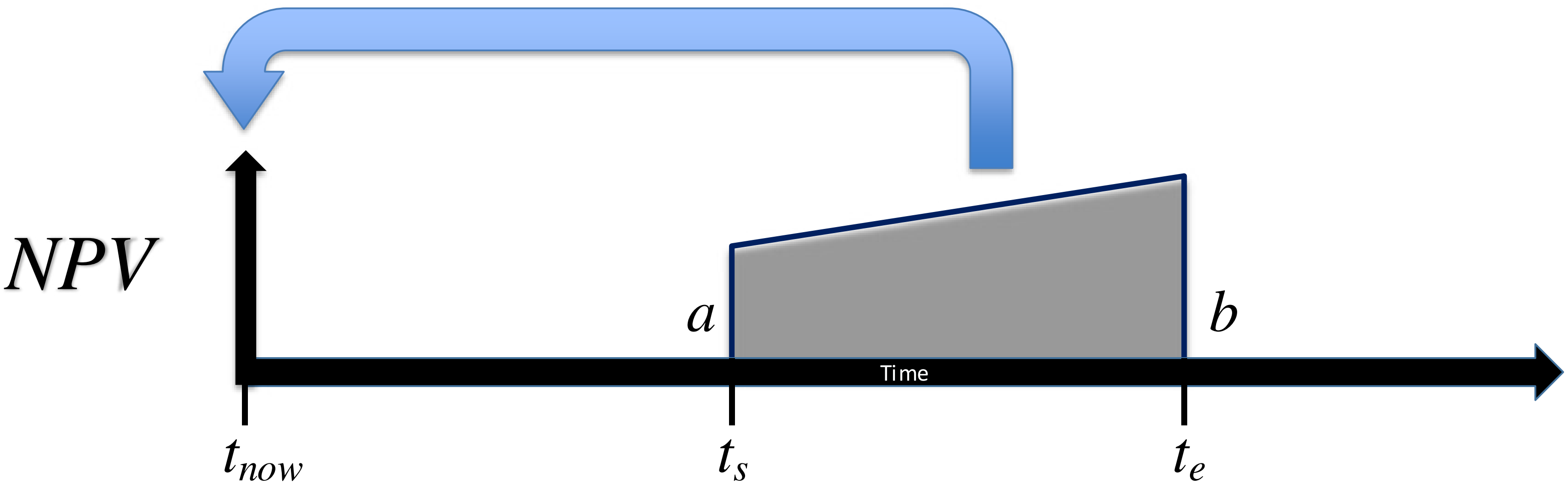


8. Time preference

- How to evaluate future events and compare them with present events?
- What is more important? A reliable bridge now or in the future?
- For costs or cash flows there is an established procedure: Discounting
- The future expenditures are discounted to present: NPV (Net Present Value)
- With the discount rate or 2% the expenditure of € 1.02 in a year is equal to € 1.00 today.
- How about availability, reliability or safety?
- There are different methods but essentially it comes also to discounting?
- The reliability, availability and safety is more important today then in 1, 2 or 10 years.
- This seems fair: The interventions on the short term are more expensive but the benefits are also more valuable!

8. Discounting

$$NPV = \frac{\{[r\cdot(t_e - t_s) - 1]\cdot b + a\}\cdot e^{-rt_e} + \{[r\cdot(t_s - t_e) - 1]\cdot a + b\}\cdot e^{-rt_s}}{r^2\cdot(t_e - t_s)}$$

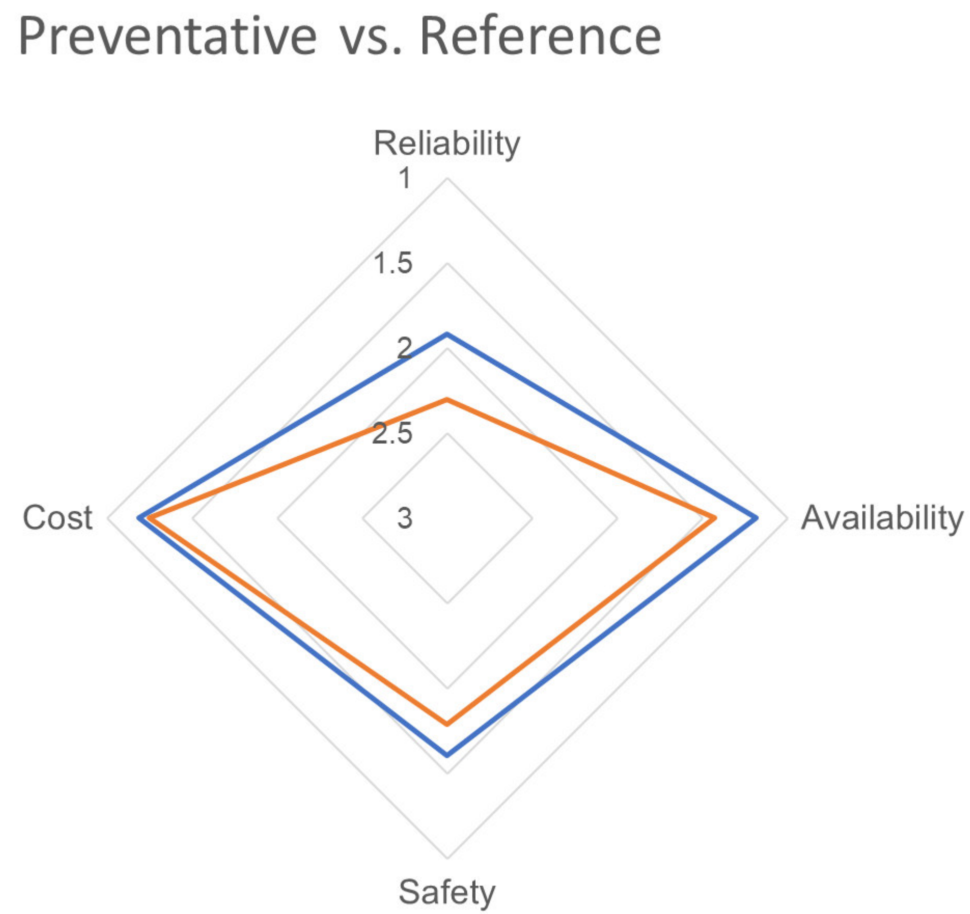


r = continuous discount rate

8. Normalization

- Net present value of all KPIs is already directly comparable due to the same scale.
- In order to reduce the KPIs to the same scale as for any time instance the NPV is divided with NPV which is calculated if all KPI were 1 over the whole investigation period.
- These value can be regarded as “average” long term KPIs.

8. Decision making – Net present KPIs



TU1406
COST ACTION

COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control
25th – 29th September, 2017
Faculty of Civil Engineering CTU in Prague
Prague, Czech Republic

Performance-based bridge assessment

Joan R. Casas- Vicechair
UPC-BarcelonaTech

EUROPEAN SCIENCE FOUNDATION
ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

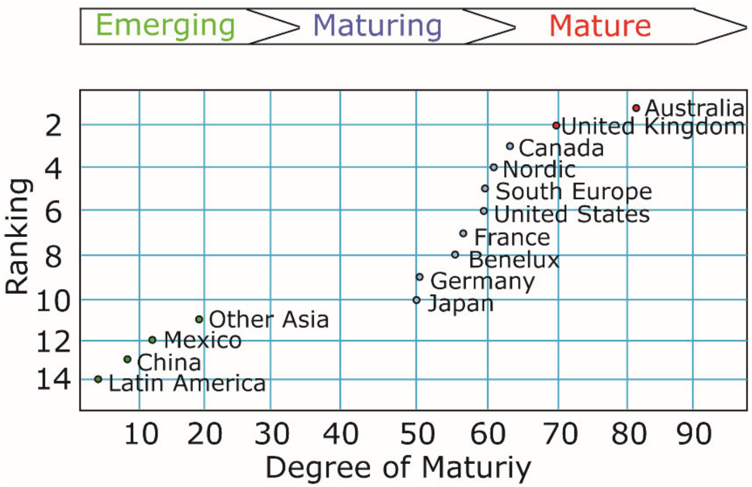
cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

OUTLINE

- COST Action TU 1406 – General issues
  - Introduction to the Action: Motivation and Main objectives
  - Expected outcomes from the Action
  - Status of the Action
  - Performance-based bridge assessment
  - Motivation of the Training School

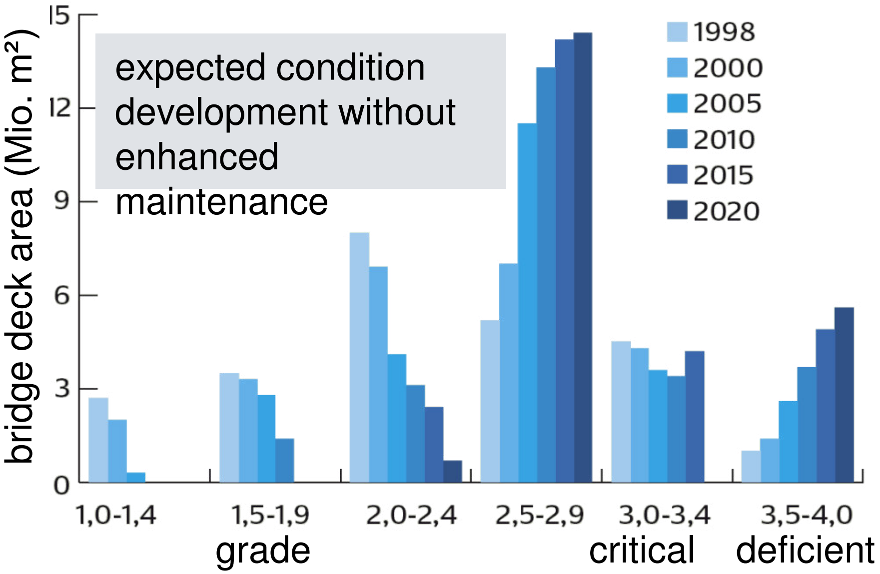
MOTIVATION AND OBJECTIVES

1. BACKGROUND



The OECD noted that by 2030 "... *a larger effort will need to be directed towards maintenance and upgrading of existing infrastructures and to getting infrastructures to work more efficiently*"

"… *it is therefore extremely important for countries to prioritize their budget expenditures in this topic by improving the way infrastructures are being managed.*"



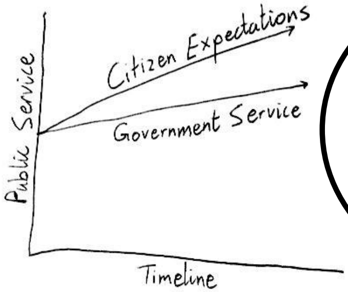
BACKGROUND

Decay Process

Public Demands

Efficient Management

Limited Resources

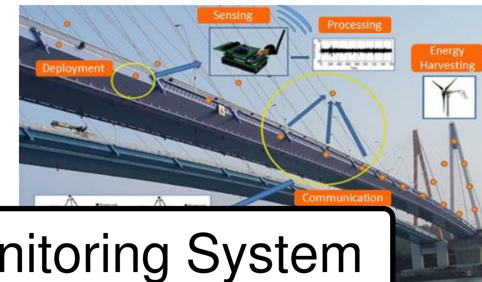


Public Expectations

BACKGROUND

Visual Inspection

NDT Testing



Monitoring System

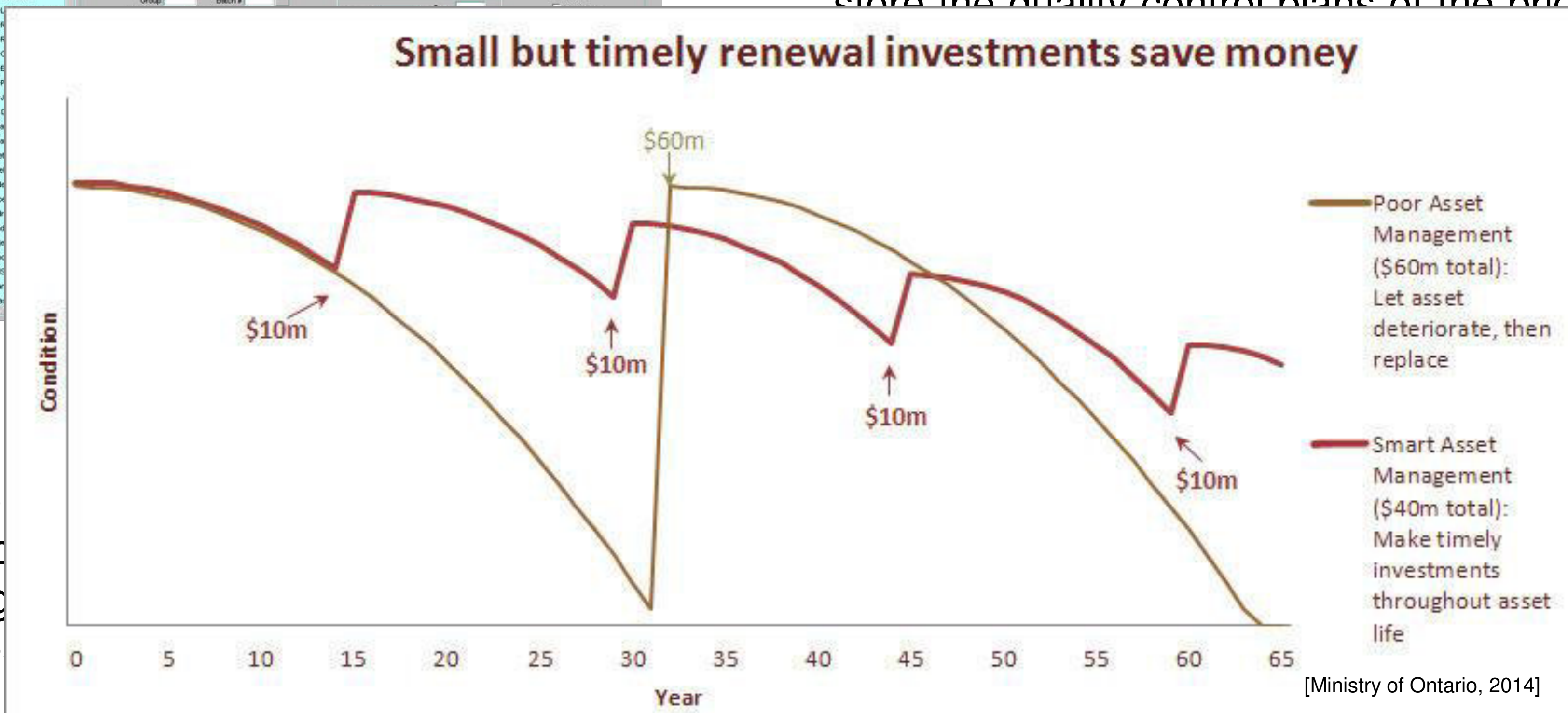
Performance Indicator

Performance Goal

Quality Control Plan

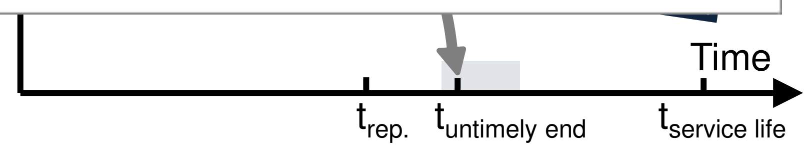
1. BACKGROUND

A Bridge Management System is used to store the quality control plans of the bridge ... he ... nd



[Ministry of Ontario, 2014]

In pe mo alg be



2. REASONS FOR THE ACTION

- **Denmark**
  - DANBRO (DANish Bridges and Roads)
- **Finland**
  - FinnRABMS (Finnish National Roads Administration Bridge Management System)
- **France**
  - Advitam
- **Italy**
  - SAMOA (Surveillance, Auscultation and Maintenance of Structures)
- **Netherlands**
  - DISC
- **Norway**
  - BRUTUS
- **Sweden**
  - BMS
- **Switzerland**
  - KUBA
- **United Kingdom**
  - STEG (Structures REGister);
  - HiSMIS (Highway Structures Management Information System)
  - SMIS (Structures Management Information System)
  - BRIDGEMAN (BRIDGE MANagement system)
  - COSMOS (Computerized System for the Management Of Structures)
- **United States America**
  - Pontis
  - BRIDGIT

2. REASONS FOR THE ACTION

Main Functions of BMS	D	[illegible]	E	F	UK	NO	FIN	SI	CA	NY (state
Name	S[illegible] Bau[illegible]			Edouard and OA	NATS	Brutus				
Time of operation (years)	new				15	2	3	5		4
Number of bridges managed	34 600	[illegible]	[illegible]	22 000	9 500	17 000	15 000	1760	25 000	10 000
Inventory of existing stock	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Schedule of inspection	Yes	Yes		Yes	Yes	Yes	Yes		Yes	Yes
Condition of structures (rating, ...)	Yes	[illegible]		[illegible]	Yes	Yes	Yes	Yes	Yes	Yes
Bid for maintenance funds	No	Yes			Yes	Yes	?		Yes	Yes
Prioritising of maintenance work	No	Yes			Yes	Yes	?	Yes	Yes	Yes
Budget planning (long term)	No	Yes			Yes	Yes	Yes			Yes
Registering detailed cost information for actions	Yes	Yes								Yes
Safety assessments	No				Yes					Yes
Taking into account alternative maintenance strategies	No			[illegible]	[illegible]					Yes
Application of whole-life costing	No			No	[illegible]					Yes
Road user delays	No			No	[illegible]					
Deterioration prediction	No	No	No	No	No	No	Yes	No	Yes	Yes

Other sources: IABMAS 2014 technical report

REASONS FOR THE ACTION

There is a **REAL NEED** to standardize the quality assessment of roadway bridges at an European Level

REASONS FOR THE ACTION

CSO Approval: 13-11-2014

Start of the Action: 16-04-2015

End of Action: 15-04-2019

Total Number of COST countries accepting MoU: **37**

Total Number of COST countries intending to accept MoU: 0

AIM & OBJECTIVES

The overall intention of the Action is to

develop a guideline for the establishment of Quality Control (QC) plans in roadway bridges

reachable by pursuing the following 5 objectives:

(i) Systematize knowledge on QC plans for bridges, which will help to achieve a state-of-art report that includes performance indicators and respective goals;

(ii) Collect and contribute to up-to-date knowledge on performance indicators, including technical, environmental, economic and social indicators;

(iii) Establish a wide set of quality specifications through the definition of performance goals, aiming to assure an expected performance level;

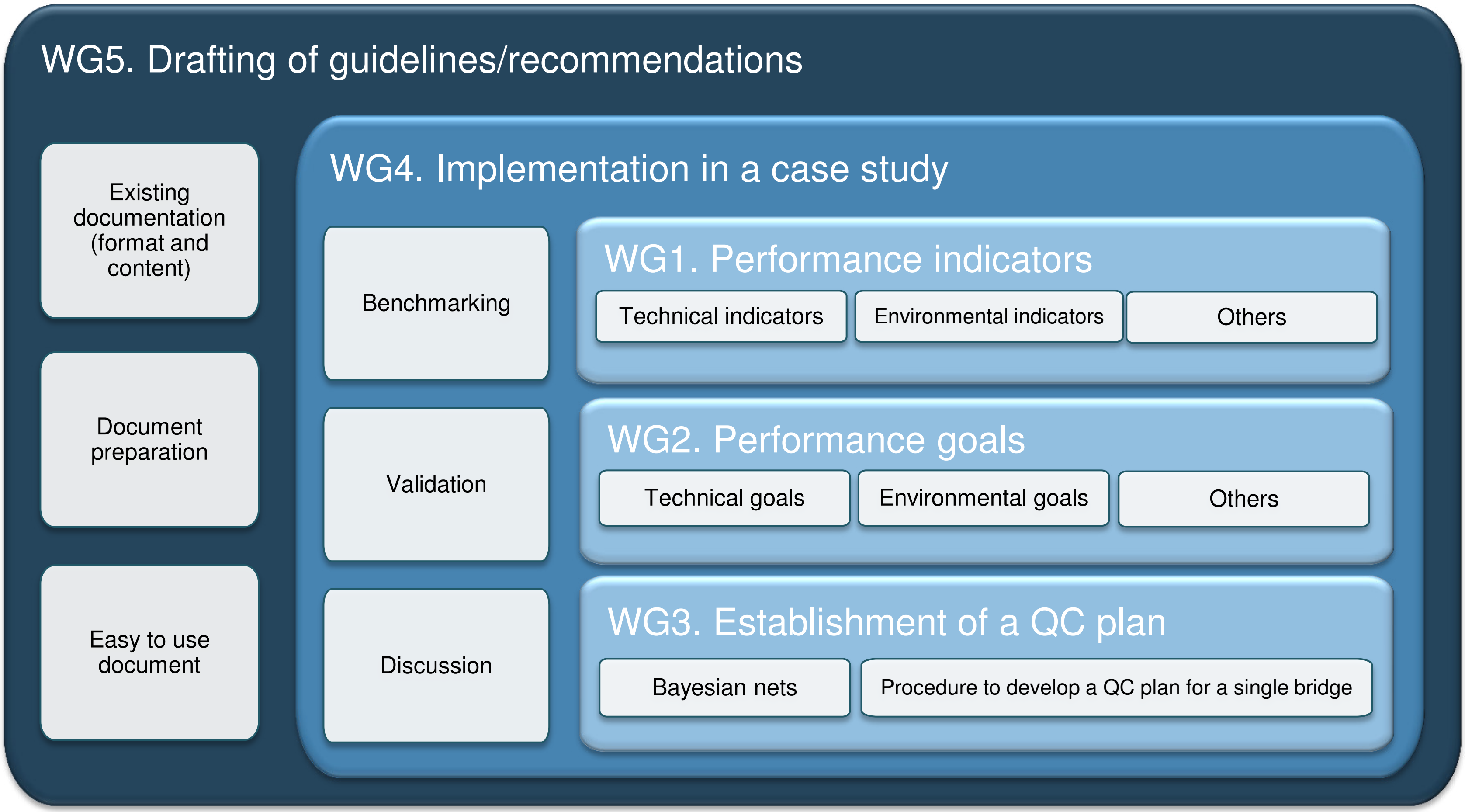
(iv) Develop detailed examples for practicing engineers on the assessment of performance indicators as well as in the establishment of performance goals, to be integrated in the developed guideline;

(v) Create a database from COST countries with performance indicator values and respective goals, that can be useful for future purposes.

4. WORKING GROUPS

Position	Name
WG1: Performance Indicators	Leader: Alfred Strauss (AT) Vice Leader: Ana Mandic (HR)
WG2: Performance Goals	Leader: Irina Stipanovic (NL) Vice Leader: Lojze Bevc (SL)
WG3: Quality Control Plan	Leader: Rade Hajdin (SB) Vice Leader: Matej Kusar (SL)
WG4: Case Study	Leader: Amir Kedar (IL) Vice Leader: Sander Sein (EE)
WG5: Standardization	Leader: Vikram Pakrashi (IR) Vice Leader: Helmut Wenzel (AT)
WG6: Dissemination	Leader: Gudmundur Gudmundsson (IS) Vice Leader: Stavroula Pantazopoulou (CY)
CHAIR:	Jose Matos
VICE-CHAIR:	Joan Casas
TECHNICAL SECRETARIAT:	Eleni Chatzi

SCIENTIFIC PROGRAM



OUTCOMES FROM THE ACTION

Deliverables

WG1 : Performance indicators

- Report of Performance Indicators (incorporating new indicators)

WG2: Performance goals

- Report of Performance Goals (incorporating new indicators)

WG3: Establishment of a QC plan

- Recommendations for the Establishment of a QC plan (with detailed examples for practicing engineers)

WG4: Implementation in a Case Study

- Database from Benchmarking (from COST countries)

WG5: Drafting of guideline / recommendations

- Guideline for the Establishment of a QC plan

ORGANIZATION

Management Committee

Including:
- MC Chair
- MC Vice-Chair
- WG's Leaders and Vice-Leaders
- General Secretariat
- STSM Leader and Vice-Leader
- M&E Leader and Vice-Leader
- Innovation Leader and Vice-Leader
- R&D Leader and Vice-Leader

Core Group

- MC Chair
- MC Vice-Chair
- WG's Leaders
- General Secretariat
- STSM Leader
- M&E Leader *
- Innovation Leader *
- R&D Leader *

Advisory Board

- Industry/Owners/ Operators
- External Advisors (MC Observers)

MC Observers

- Australia
- Chile
- Japan
- South Africa
- United States of America

An MC Observer per Continent

* under an "ad-hoc" basis

STATUS OF THE ACTION

Activity/Months	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Milestone				M1				M2		M3				M4		M5

M1: WG1 – Performance indicators
Elaborate a report of performance indicators

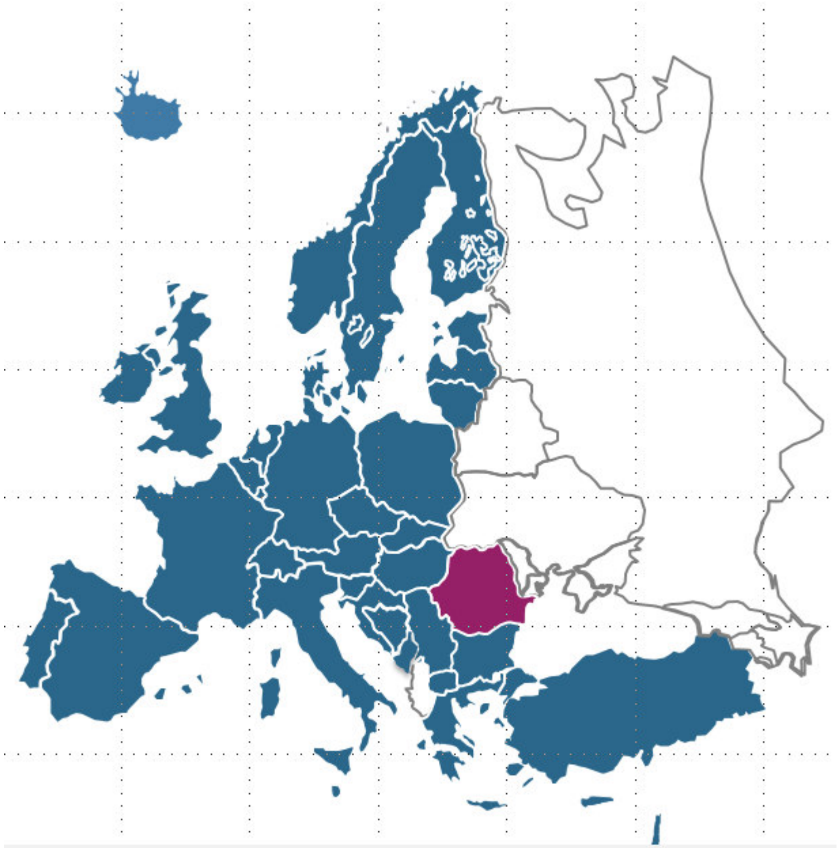
M2: WG2 – Performance goals
Elaborate a report of performance goals

M3: WG3 – Establishment of a QC plan
Prepare recommendations for the establishment of Quality Control plan

M4: WG4 – Implementation in a Case Study
Prepare database from benchmarking

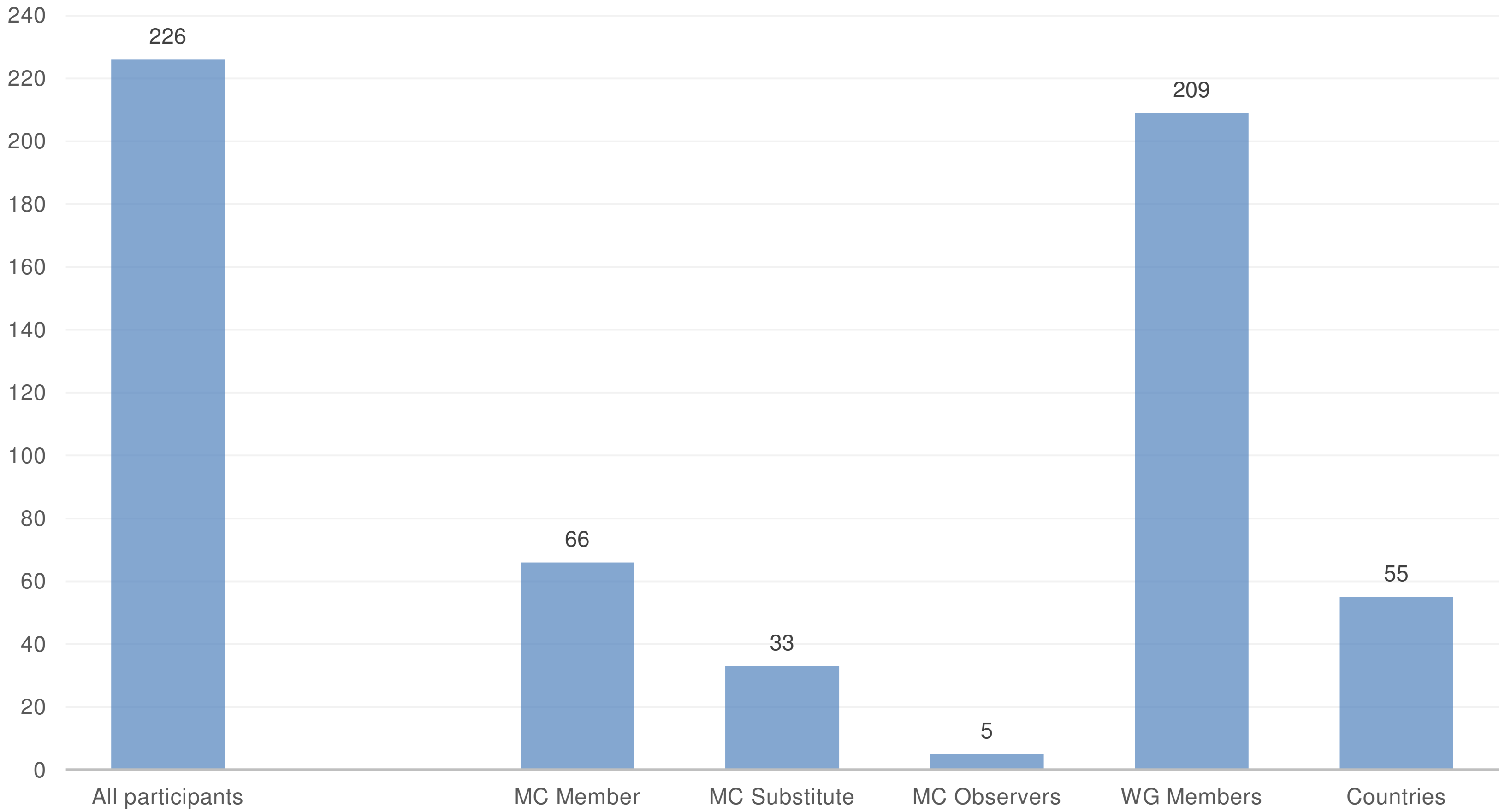
M5: WG5 – Drafting of guideline/recommendations
Prepare guideline/recommendations for the establishment of QC plan

MEMBERS

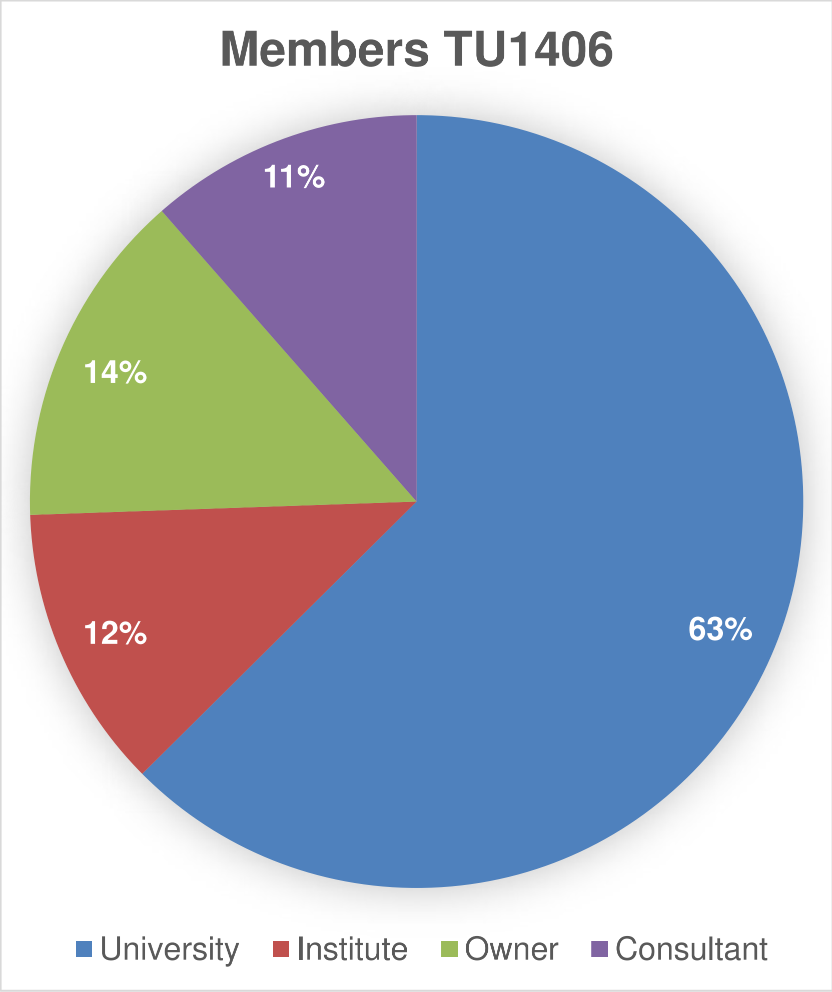


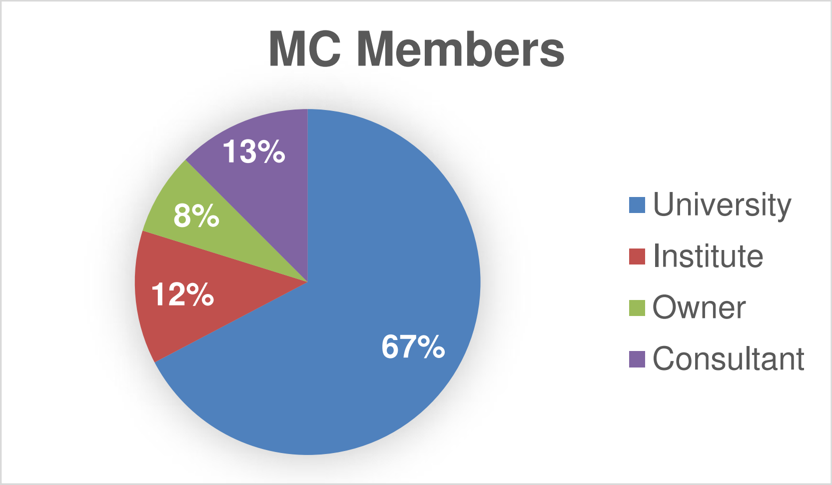
- **Action represented countries**
- **Missing Countries** **(only registered as WG member)**
  - Romania

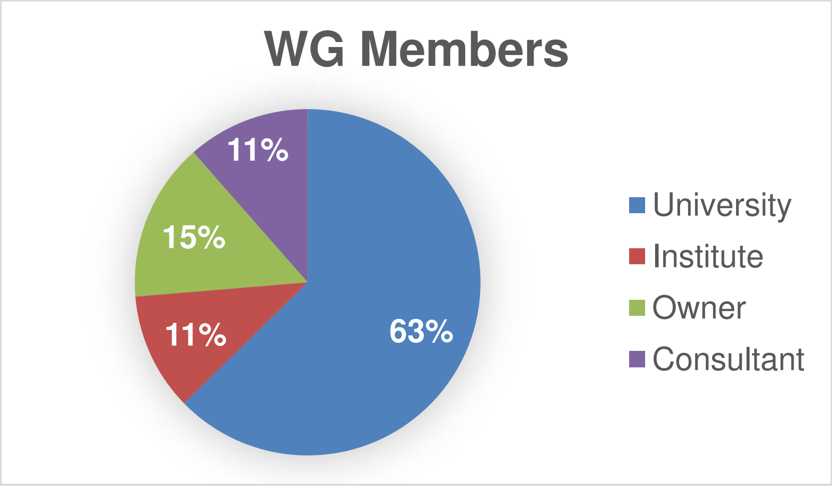
MEMBERS


240
220
200
180
160
140
120
100
80
60
40
20
0
226
209
66
33
5
55
All participants
MC Member
MC Substitute
MC Observers
WG Members
Countries

MEMBERS


Members TU1406
11%
14%
12%
63%
University
Institute
Owner
Consultant


MC Members
13%
8%
12%
67%
University
Institute
Owner
Consultant


WG Members
11%
15%
11%
63%
University
Institute
Owner
Consultant

NON-RESEARCH PARTNERS

Government of the Netherlands

Statens vegvesen

SKANSKA

ATKINS

VEGAGERÐIN

VCE Vienna Consulting Engineers ZT GmbH

LATVIJAS VALSTS CEĻI · LATVIAN STATE ROADS

EP Estradas de Portugal. S.A.

LUSOPONTE LISBOA

ANSER, Lda. Arquitectura e Engenharias

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PROJEKTOVÁ, INŽENÝRSKÁ A KONZULTAČNÍ ORGANIZACE
DESIGN, ENGINEERING AND CONSULTING ORGANIZATION

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Teede Tehnokeskus

KEDMOR ENGINEERS LTD.

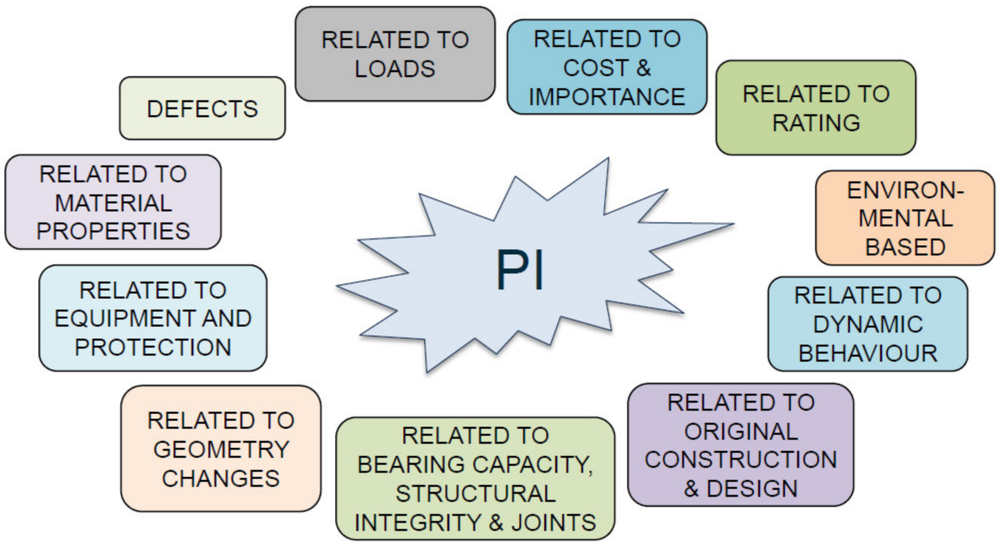
ČERVENKA CONSULTING

Str o N GER

WG1: Performance Indicators

What is an "Indicator"?

- Something measurable, quantifiable?
- For which there is a target value, a goal, available?
- Which is valid for ranking / decision purposes?
- And what is a performance indicator?



Performance Indicators

Performance Indicator is a

Measurable and **quantifiable** parameter, related to the bridge performance, that can be directly compared with a **target measure** of a **performance goal** (absolute measure of performance) or can be used for **ranking** purposes, among a bridge population (relative measure of performance), in the framework of a **Quality Control Plan** or life-cycle management (**decisions, actions involving economic resources**)

Performance Indicators

In order to have relevant indicators, there are important steps:

- Collection and homogenization of data = database

- Types of indicators:
  - Technical indicators
  - Sustainable indicators
  - Other indicators

- Indicators can be found at different levels:
  - Element level
  - System level
  - Network level

Process of definition of operational PI

- Data base of performance indicators used in 31 European countries

- A total of 724 “Performance indicators” were recorded. Clustering and homogenisation reduced the number to 385 PI related terms in 8 categories

- From PI related terms to KPI (in WG2)

Research-based indicators

Ranking	(PRL) Parameter Readiness Level	Definition
1	basic principles observed	The **principles underlying** the parameter are known
2	**parameter** concept formulated	The parameter is applied in **analytical studies**
3	experimental proof of concept	**Analytical and experimental studies (indoor)** performed on a **laboratory scale on a component level** to validate analytical predictions
4	**parameter** validated in laboratory	**Experimental studies are** performed in laboratory on **a reduced scale model** of the structure/asset to produce a database for which estimate the parameter
5	**parameter** validated in laboratory in simulated environment	**Experimental studies** performed in controlled laboratory (or outdoor) on **a large model** of the structure/asset **reproducing real environmental condition**s to produce a database for which estimate the parameter
6	**parame**ter demonstrated in relevant environment	Experimental studies performed **on a real structure/asset**
7	**paramete**r demonstrated in operational environment	**Performance goals** are defined
8	system complete and qualified	**Testing protocols** are defined
9	Actual system proven in operational environment	**Decisions** on possible interventions in a bridge (repair, maintenance,...) are made

WG1. MILESTONE: *Report*

WG1

Technical Report

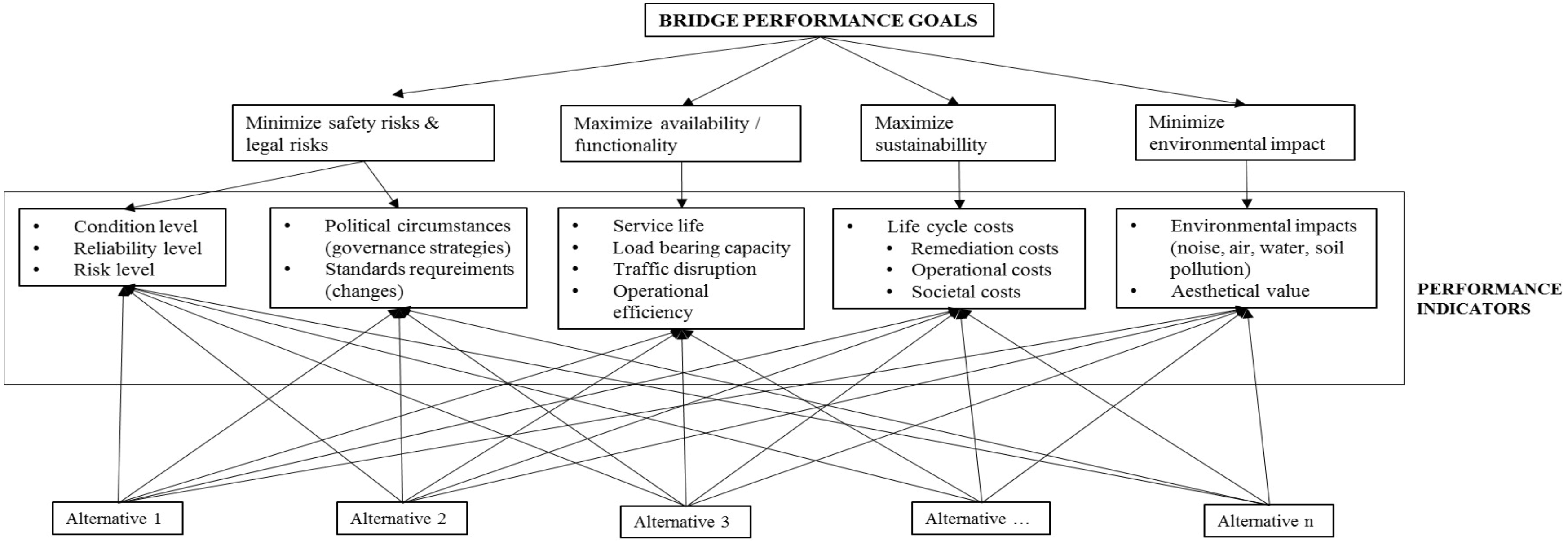
Performance Indicators for Roadway Bridges of Cost Action TU 1406

available on website: www.tu1406.eu

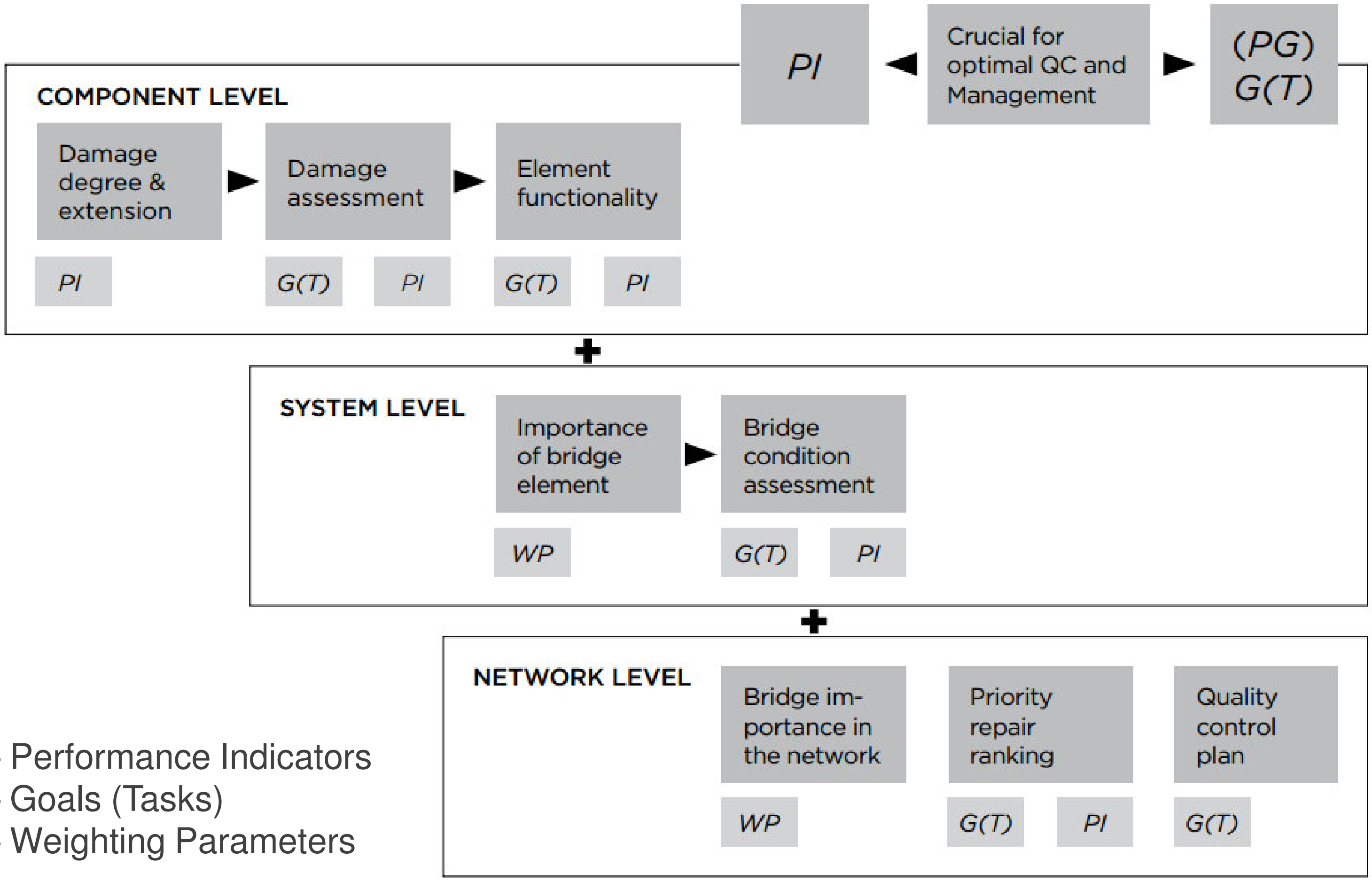
WG2. WHAT ARE THE PERFORMANCE GOALS?

In case of bridges, what are the public desires (Performance Goals "or" Key Performance Indicators)?

- Safety;
- Serviceability;
- Availability (related to maintainability and, therefore, including durability issues);
- Economy (referred to life-cycle cost and, therefore, including durability issues);
- Environmentally friendly (including visual appearance).



Interaction of Indicators with Goals



PI – Performance Indicators
G(T) – Goals (Tasks)
WP – Weighting Parameters

(Strauss et al, 2016)

Key Performance Indicators

Safety, Reliability, Security		
PI	**rating (1-5)**	**weighting**
crack width	2	0,8
corrosion	3	0,5
lack of bolts	5	0,3
support damage	2	1
drainage system	2	0,8
fungus appereance (wooden elements)	3	0,5
bugs attack (wooden elements)	5	0,3
rotting (wooden elements)	2	1
overweight traffic	1	1
sediment accumulation	2	0,8
vandalism	3	0,8
	total rating	**2,33**

Availability, Maintainability		
PI	**rating (1-5)**	**weighting**
concrete eflorescence	3	0,2
lack of bolts	5	0,3
support damage	3	1
drainage system	2	0,8
fungus appereance (wooden elements)	5	0,5
bugs attack (wooden elements)	1	0,3
rotting (wooden elements)	3	1
sediment accumulation	1	1
vandalism	3	0,8
	total rating	**2,69**

Costs		
PI	**rating (1-5)**	**weighting**
concrete eflorescence	3	0,5
lack of bolts	4	0,3
support damage	3	0,3
drainage system	3	1
detour distance	3	0,8
	total rating	**3,10**

Environment		
PI	**rating (1-5)**	**weighting**
concrete eflorescence	4	0,3
fungus appereance (wooden elements)	4	1
bugs attack (wooden elements)	3	0,8
rotting (wooden elements)	4	0,3
sediment accumulation	4	0,3
	total rating	**3,70**

Health, Politics		
PI	**rating (1-5)**	**weighting**
	total rating	**#DIV/0!**

KPI	total rating
Safety, Reliability, Security	2,33
Availability, Maintainability	2,69
Costs	3,10
Environment	3,70
Health, Politics	#DIV/0!

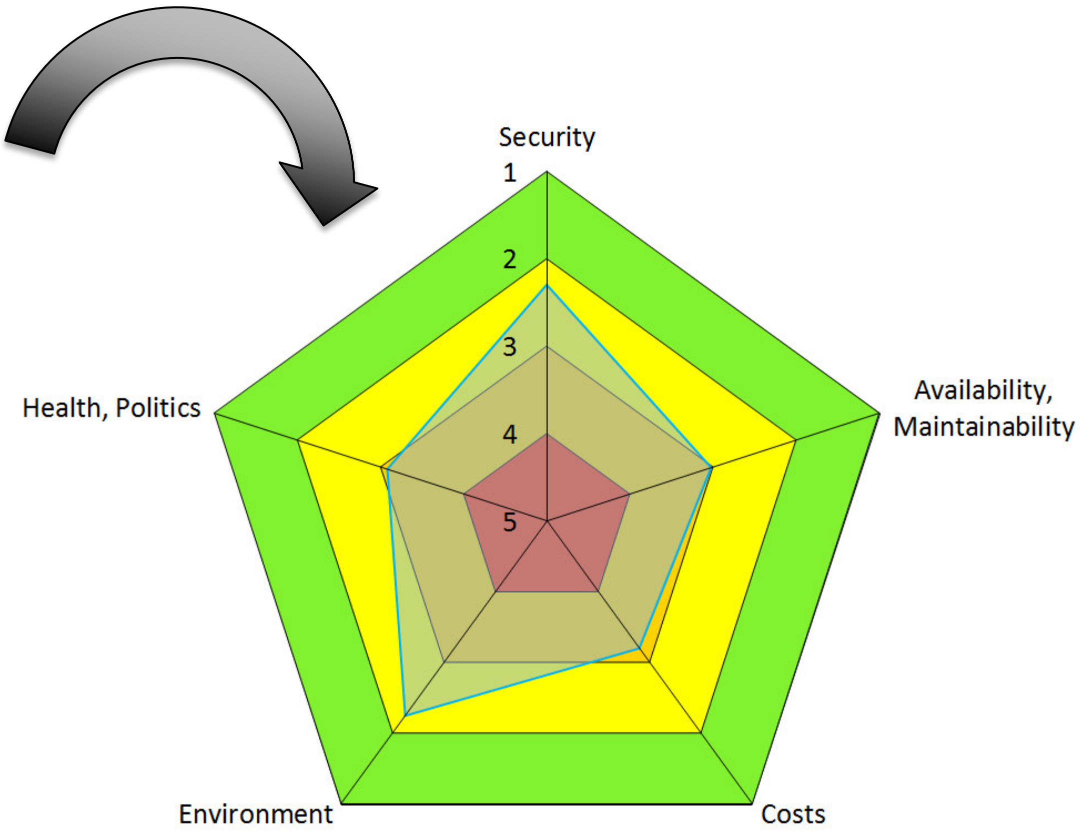
Indicators can be grouped into Key Performance Indicators

Safety, Reliability, Security		
PI	**rating (1-5)**	**weighting**
crack width	2	0,8
corrosion	3	0,5
lack of bolts	5	0,3
support damage	2	1
drainage system	2	0,8
fungus appereance (wooden elements)	3	0,5
bugs attack (wooden elements)	5	0,3
rotting (wooden elements)	2	1
overweight traffic	1	1
sediment accumulation	2	0,8
vandalism	3	0,8
	total rating	**2,33**

KPI	total rating
Safety, Reliability, Security	2,33
Availability, Maintainability	2,69
Costs	3,10
Environment	3,70
Health, Politics	#DIV/0!

WG2. FROM PI TO KPI

KPI	total rating
Safety, Reliability, Security	2,30
Availability, Maintainability	3,02
Costs	3,20
Environment	2,25
Health, Politics	3,08



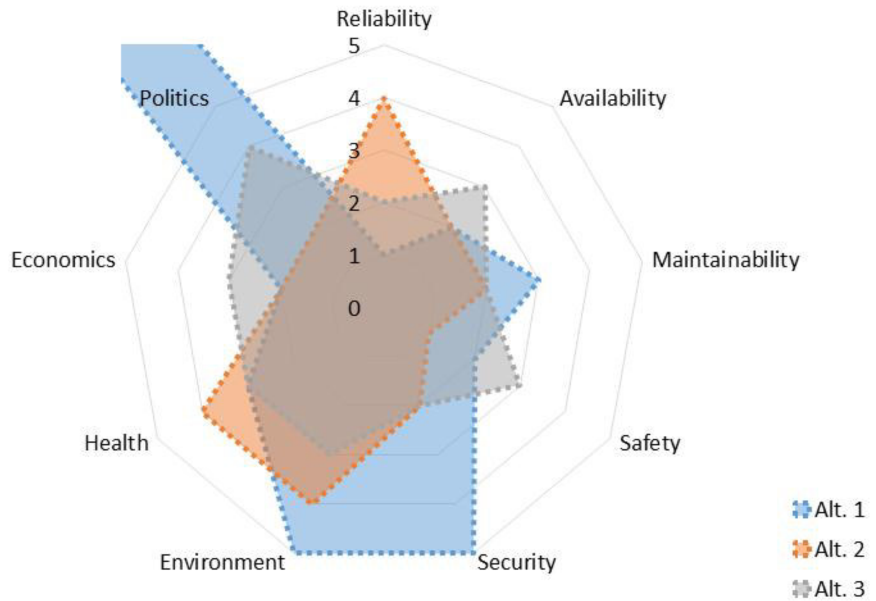
Intervention management: bridge network

- It is necessary to identify a set of goals and a set of performance indicators for each goal.
- The decision has to be made implicitly, so that alternatives can be ranked and best alternative selected.
- The ranking can be based on temporal alternatives or on a cost-minimization rule, where preference order is adequately represented.
- If there are several criterions, then multi-criteria decision-making (MCDM) should be considered.

Connecting KPIs to PGs at Network Level

- Possible result of multi-objective assessment of different bridge maintenance alternatives against different performance aspects

- Can be used for decision making to reach an optimal maintenance or design alternative.



MULTI-ATTRIBUTE UTILITY THEORY (MAUT)

- Utility theory provides a measure of preferences of a decision maker over a group of alternatives (Ishizaka & Nemery, 2013).
- Multi-attribute utility theory (MAUT) provides an approach to reduce the qualitative values of various attributes (i.e. performance indicators) into utility functions.
- In other words, MAUT assigns the relative importance of performance indicators (e.g. condition, cost, etc.), while comparing number of bridges. These bridges are often referred as alternatives in MAUT.
- The application of MAUT provides a systematic approach to improve the decision making of maintenance planning by making use of available data only, accommodating multiple performance goals, their uncertainty, and preferences of infrastructure managers.

WG2. MILESTONE: *Report*

WG2

Technical Report

Performance Goals for Roadway Bridges of Cost Action TU 1406

First draft recently finished

In process of editing

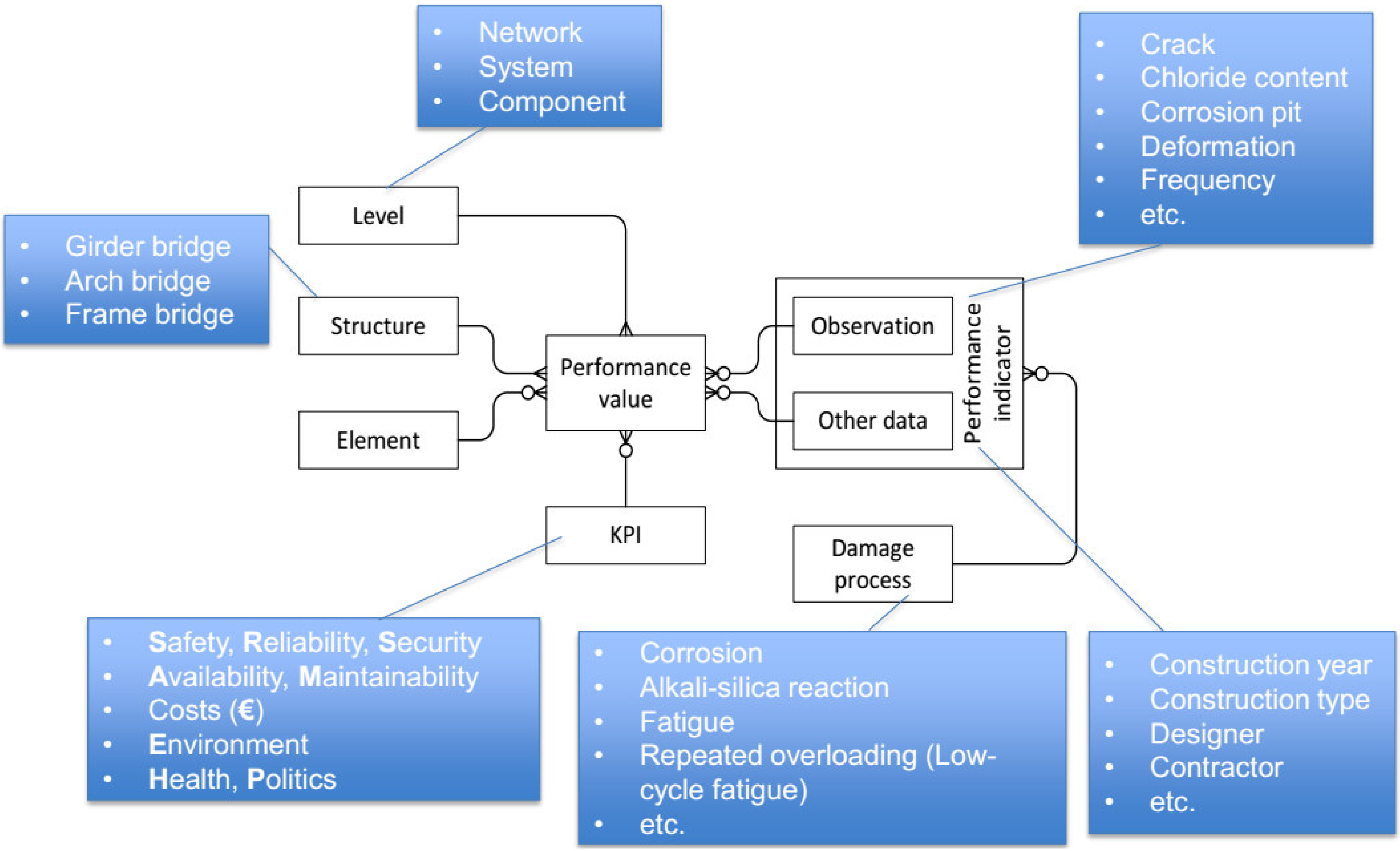
WG3. QUALITY CONTROL FRAMEWORK

- Based on results from previous WGs, as well as on a survey of existing approaches in practice, the objective of this WG is to provide a methodology with a detailed step-by-step explanations, for the establishment of QC plans for different bridge types;

- The QC plan has to relate to Performance Goals "or" Key Performance Indicators, which are user/society related, e.g.
  - Traveling time;
  - Weight allowance and clearance;
  - Safety level;
  - Comfort / Serviceability.

- Implementation of common methodology across Europe, with flexibility to accommodate country-specific requirements, is mandatory.

WG3. QUALITY CONTROL FRAMEWORK



WG4. CASE STUDIES

Girder Bridge
Strimonas River Bridge
Greece

Arch Bridge
Carinski most, Mostar Bridge
Bosnia and Herzegovina

Frame Bridge
Unterführung SBB Bridge
Switzerland

PERFORMANCE-BASED BRIDGE ASSESSMENT

- Definition of quality: Degree to which a set of inherent characteristics of a product or service fulfills requirements (ISO 9000)

- Quality control:
  - Are the requirements fulfilled ?
  - **Is the required performance achieved ?**

- Decisions and actions (involving money) will result from the answer to those questions

What we do refer when talking about performance requirements or goals ?

- In the case of bridges: What public desires ?
  - Safety
  - Serviceability
  - Availability
  - Economy (referred to life-cycle cost, and therefore including durability issues)
  - Environtmentally friendly (including visual appearance)

How do we measure performance and answer to the question: Is required performance achieved ?

- By defining the so-called “performance indicators”
- By **measuring** and **monitoring** them
- By comparing their actual value with defined “target values”
- Target values are defined in the **Quality Control plans**

Which are the performance indicators to be monitored ?

- **Related to safety**:
  - Load factor
  - Safety factor
  - Reliability index (ULS)
  - Risk

- **Related to serviceability**:
  - Condition rating, condition index
  - Crack width
  - Deflection
  - Vibration intensity
  - Natural frequencies
  - Modal shapes

Which are the performance indicators to be monitored ?

- **Related to availability**:
  - robustness
  - redundancy
  - resilience

- **Related to economy**:
  - Life-cycle cost
  - Difussivity coefficient of chlorides
  - Permeability
  - Concrete cover
  - Crack width
  - Remaining service life

Which are the performance indicators to be monitored ?

- **Related to environment (including aesthetics)**:
  - Crack pattern
  - CO_2 equivalent
  - resilience

MOTIVATION OF THE TRAINING SCHOOL

- INTRODUCTION TO PERFORMANCE-BASED ASSESSMENT
- PRESENTATION OF QUALITY CONTROL FRAMEWORK
- IMPLEMENTATION INTO CASE STUDIES
- CAPABILITIES ASSOCIATED WITH BACKGROUND FOR NDT TECHNIQUES
- CAPABILITIES TO PERFORM AND DESIGN THE INSPECTION AND DIAGNOSTICS
- APPLICATION OF THE QUALITY CONTROL FRAMEWORK

COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control
25th – 29th September, 2017
Faculty of Civil Engineering CTU in Prague
Prague, Czech Republic

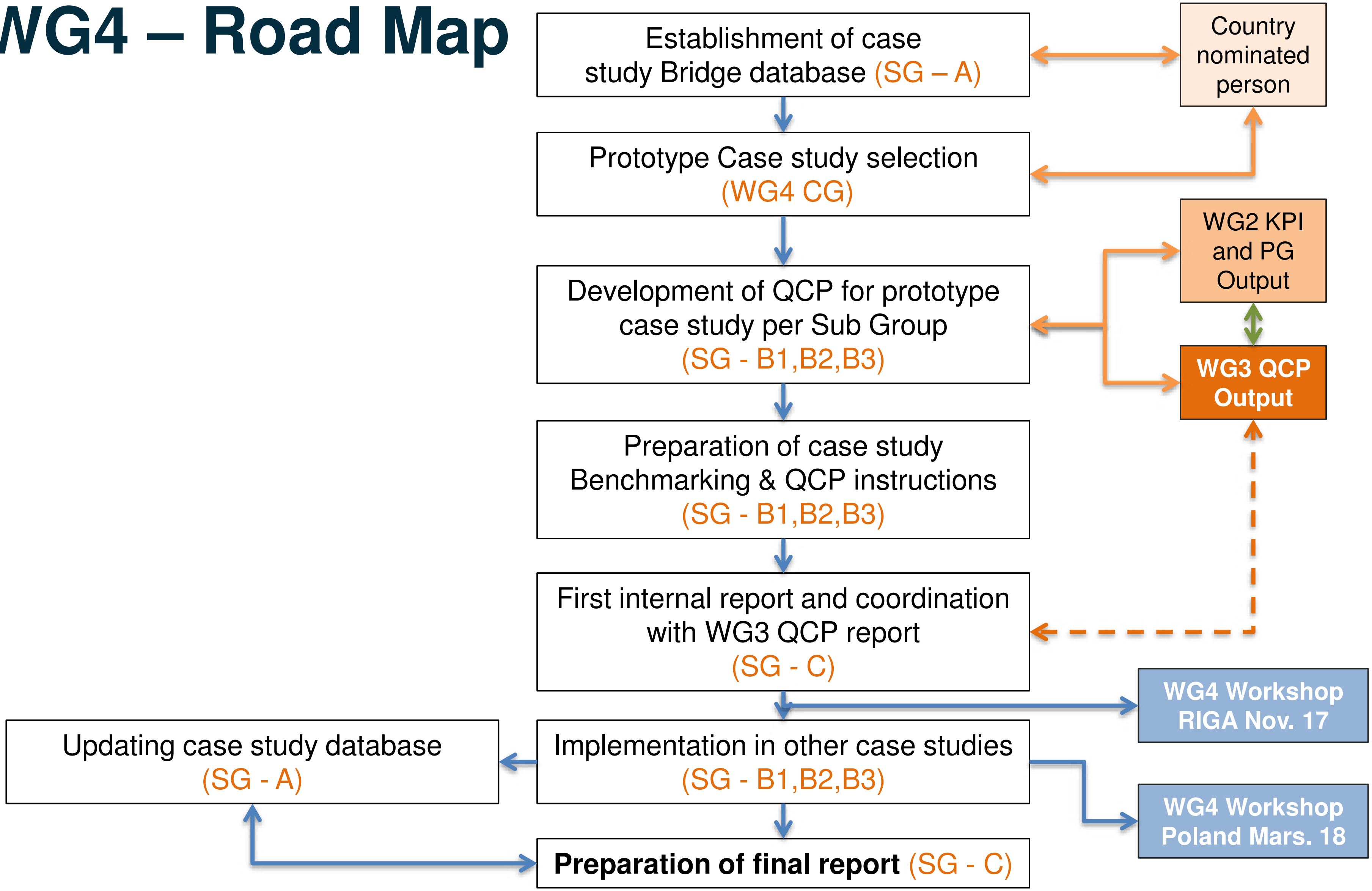
Developing Case studies

Amir Kedar - Kedmor Engineers Ltd, Israel
Naida Ademovic - Faculty of Civil Engineering, University of Sarajevo, Bosnia and Herzegovina
Marija Kuster Maric - Faculty of Civil Engineering, University of Zagreb, Croatia
Panagiotis Panetsos - Egnatia Odos, Greece

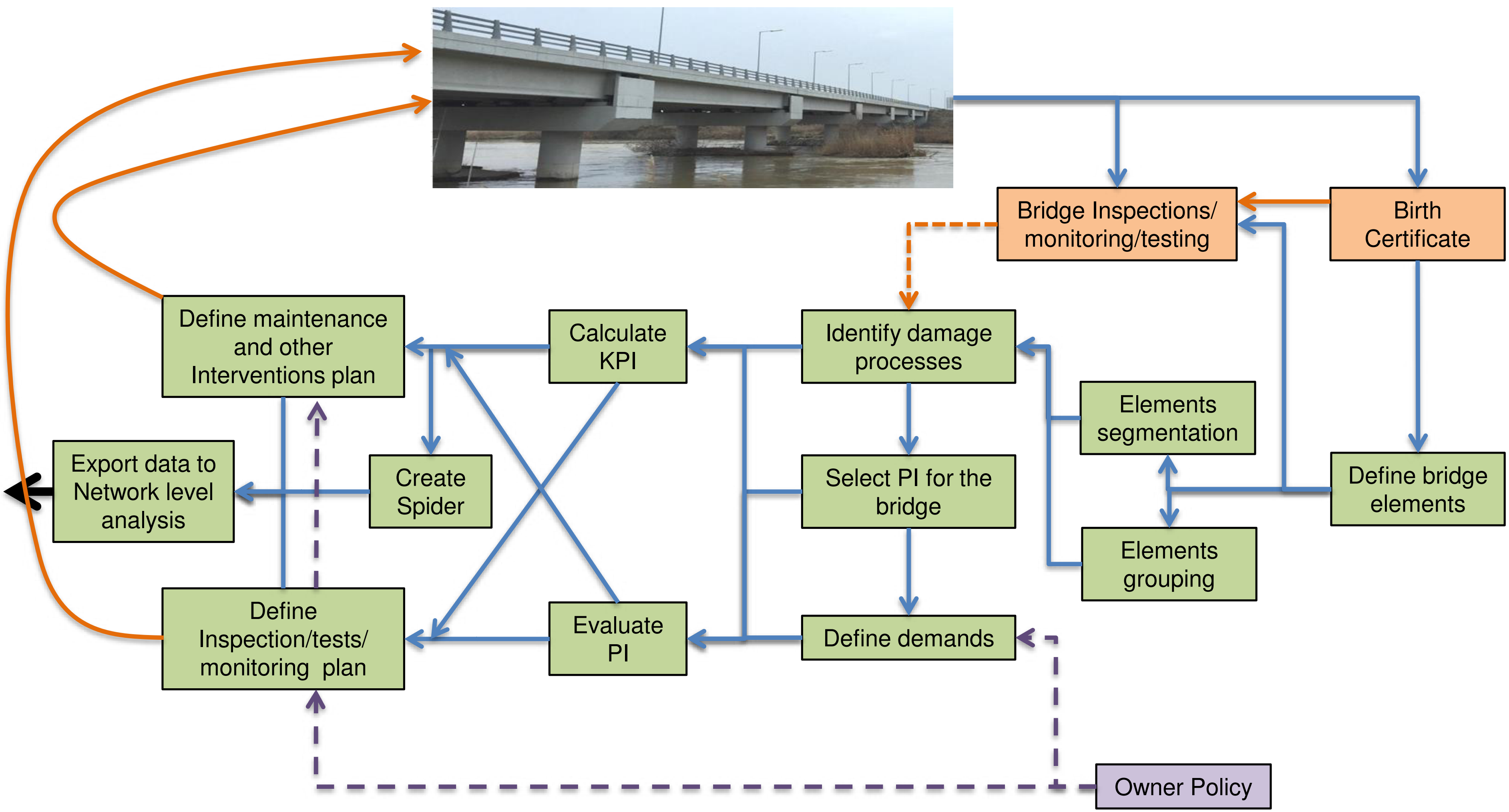
ESF provides the COST Office through a European Commission contract
COST is supported by the EU Framework Programme

Content:

WG4 – Road Map


Establishment of case study Bridge database (SG – A)
Country nominated person
Prototype Case study selection (WG4 CG)
WG2 KPI and PG Output
Development of QCP for prototype case study per Sub Group (SG - B1,B2,B3)
WG3 QCP Output
Preparation of case study Benchmarking & QCP instructions (SG - B1,B2,B3)
First internal report and coordination with WG3 QCP report (SG - C)
WG4 Workshop RIGA Nov. 17
Updating case study database (SG - A)
Implementation in other case studies (SG - B1,B2,B3)
WG4 Workshop Poland Mars. 18
Preparation of final report (SG - C)

SUGGESTED PROCESS PER BRIDGE



Implementing PI/KPI approach in a bridge – possible steps

1. Prepare bridge 'Birth Certificate' (all available data).
2. Identify Bridge Elements (per bridge prototype).
3. Classify element importance based on:

   3.1 System level (bridge)
   3.2 Structure safety
   3.3 Durability
   3.4 User safety
   3.5 …..

4. Perform Bridge Elements Segmentation

   Identify areas with high vulnerability based on relevant criteria:

   4.1 Scheme
   4.2 Exposure
   4.3 Safety
   4.4 Serviceability
   4.5 ……

Implementing PI/KPI approach in a bridge – possible steps

5. Perform grouping of Bridge elements based on :
   5.1 Exposure
   5.2 Material properties
   5.3 Geometry
   5.4 Functionality (Purpose)
   5.5 ………
6. Select relevant PI per bridge prototype (pre-defined)
7. Identify existing or developing damage processes in the bridge (based on historical data, inspection results etc.) and decide if more detailed investigation/assessment is needed ? (based on triggering criteria). Use those later for inspection scheduling and maintenance/interventions planning.

Implementing PI/KPI approach in a bridge – possible steps

8. Define the relevant demands (Min./Max.) and their triggering criteria for PI

8.1 Operational:

Traffic volume, Traffic loading, Traffic geometry, Maintainability, LCC, Visual appearance.

8.2 User:

Reliability, Availability, Safety, Affordable travel, Travel time.

8.3 General: regulation by law or other measures

Human Health, Environmental protection, Climate change, Noise, Waste.

Implementing PI/KPI approach in a bridge – possible steps

9. Select KPI for use (WG2/3 recommendations)
10. Evaluate performance of the bridge (PI).
    10.1 Based on updated Inspection/NDT/other
    10.2 Use suggested WG3 formats (excel) or other relevant format (develop?)
11. Calculate/Assess the selected KPI for the bridge. Check if the bridge meets performance goals for road users (Bridge level). If previous KPI already exist, compare values.
12. Create Spider Diagram (WG2)
    Normalize values and define axis

Implementing PI/KPI approach in a bridge – possible steps

13. Define inspection and monitoring types and schedule (Intervals)
    12.1 Inspection type correlated with Demands
    12.2 Determine the need for Complementary NDT and semi-destructive test
    12.3 Define specific point/element/areas of interest (CW)
    12.4 Inspection schedule (routinely? Risk based ? Etc.)
14. Define maintenance and other intervention type and schedule.
    13.1 Aggregate the existing faults in organized tables
    13.2 Correlate with the identified damage processes
    13.3 Correlate with estimated future state (deterioration curves, other)
    13.4 Prepare list of specific treatment per faults
    13.5 Aggregate treatments into groups based on elements segmentation (previously identified see 4)
    13.6 Aggregate treatments into time zones
    13.7 Create suggested intervention plan.

Additional stages, Missing items ?

Implementing PI/KPI approach in a bridge – possible steps

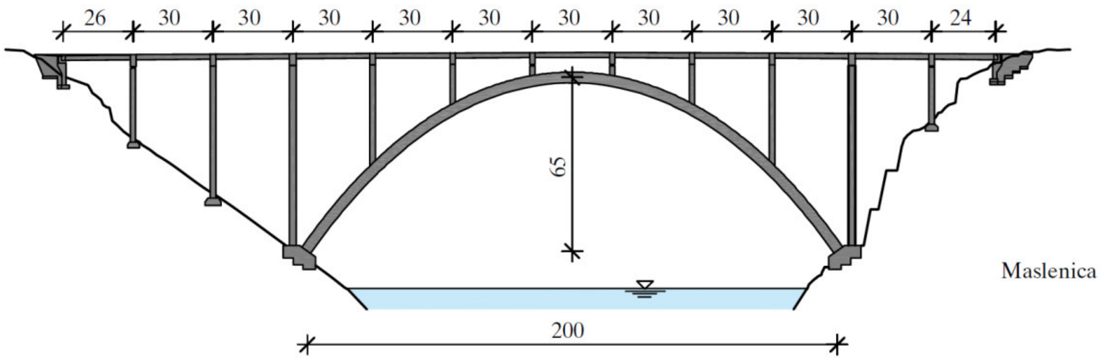
15. Export bridge data to Network level
    - 15.1 Performance values
    - 15.2 Candidate projects and costs

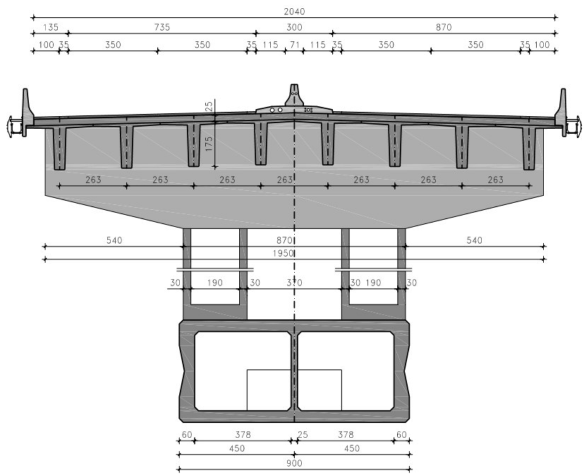
16. Compare results with existing QCP

CASE STUDY:

Maslenica Bridge-Republic of Croatia-constructed 1993-1997

Maslenica Bridge-Republic of Croatia-constructed 1993-1997

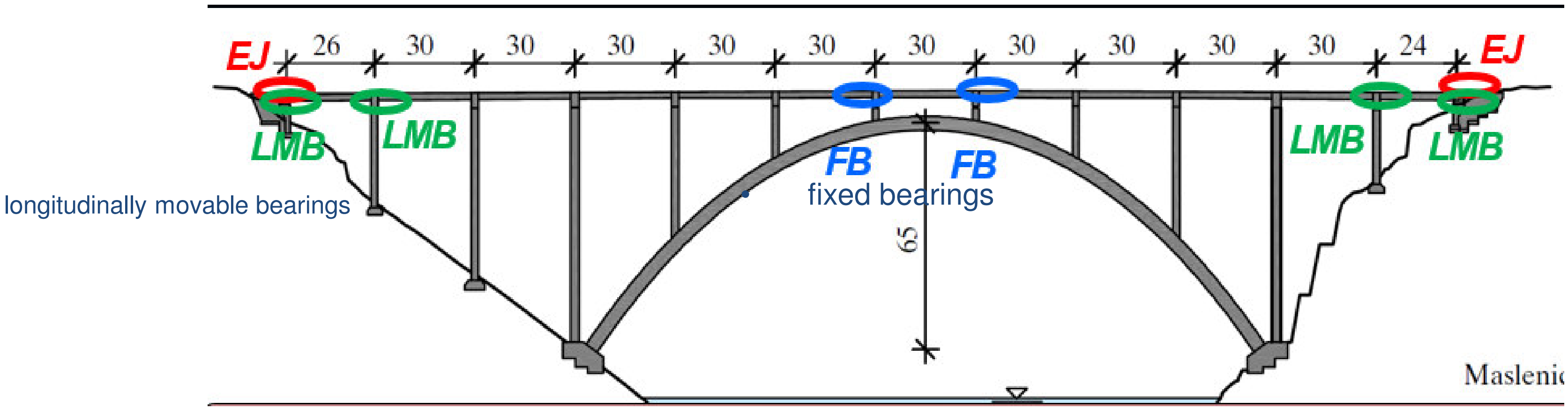




- Arch span: 200 m, f/L=65/200=1/3.08
- Arch is fixed of double cell box cross-section
- Structural system = rigid arch and rigid superstructure
- Superstructure is continuous over 12 spans L=26+10*30+24 = 350 m
- Superstructure consists of 8 simple-span precast prestressed girders (H=1.75 m), interconnected by concrete deck slab (H=0.25 m) cast in situ

- 4 lanes (4x3.50 m)
- 1 median strip (3.0 m)
- 4 safety strips (4x0.35 m)
- 2 additional safety strips (2x1.0 m) next to concrete safety barriers

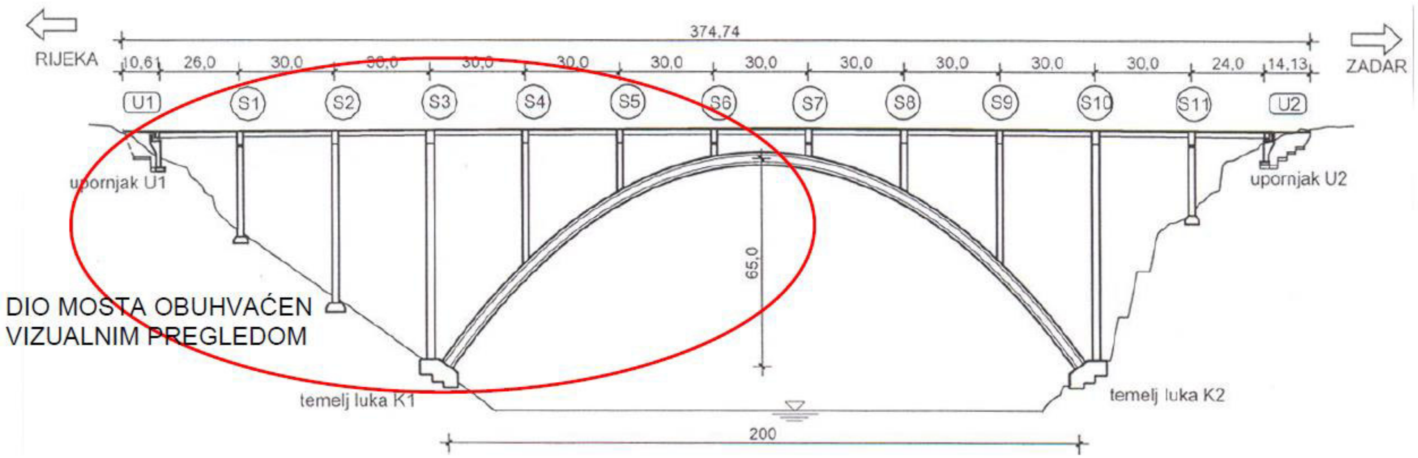
Maslenica Bridge-Republic of Croatia



- 2 expansion joints (displacement= ± 20 cm) at the abutments only- never replaced
- The bridge is exposed to extremely aggressive maritime environment, thus very thick concrete cover was specified in the bridge design.
- Defects during construction!

Maslenica Bridge-Republic of Croatia

- **Investigation works 2006**

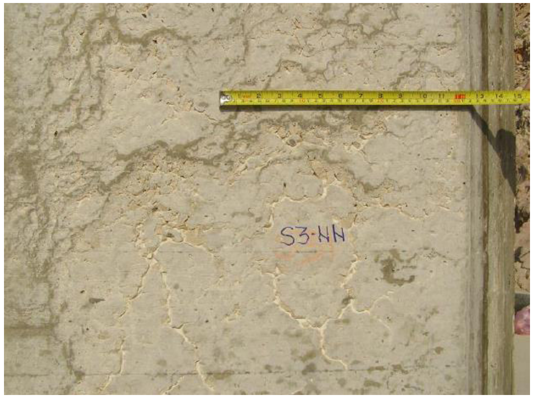


- **In-situ measurement of concrete cover depth**
- **In-situ tests of homogeneity and mechanical properties of concrete**
- **compressive strength-destructive and ND tests, modulus of elasticity**
- **Chloride content determination**
- **Gas permeability determination**

Maslenica Bridge-Republic of Croatia

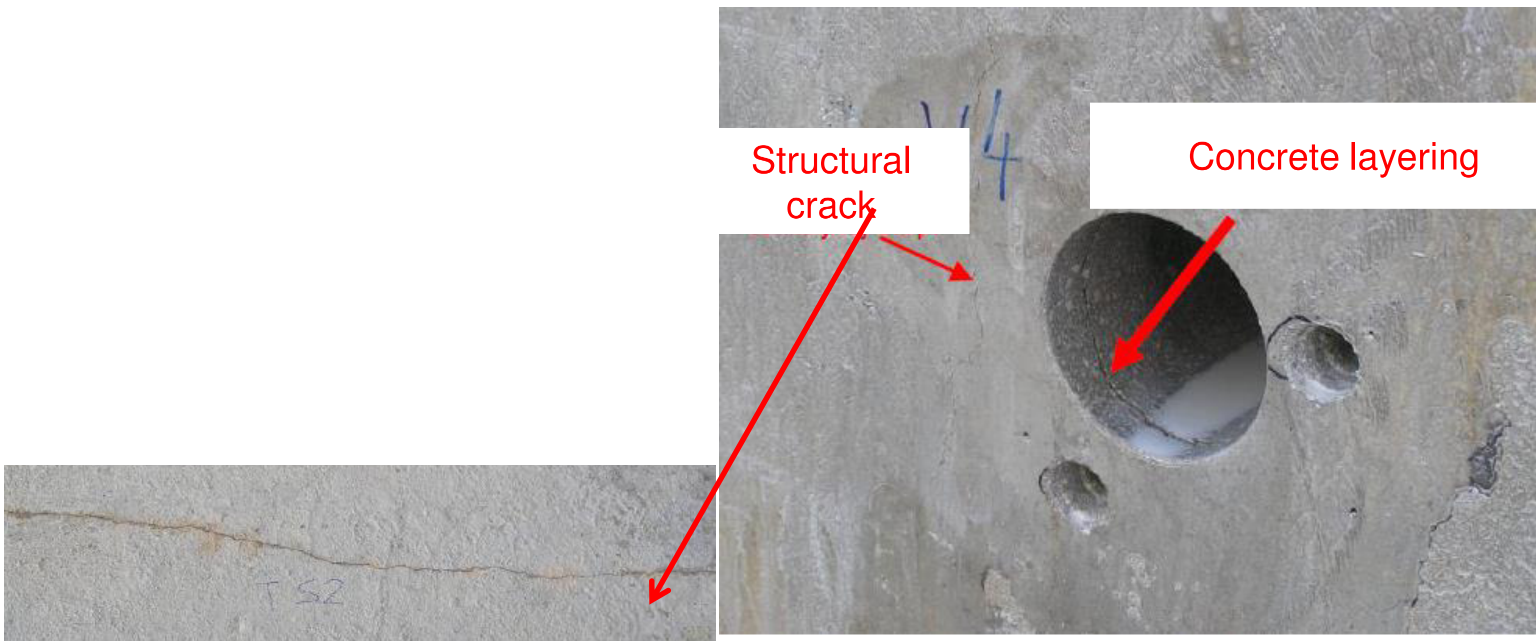
RESULTS

- Corrosion indused damages on piers, piers foundations, arch and arch abutments caused by:
    - Insufficient concrete cover
    - Irregularities during construction (poor quality execution of construction joints, steel components remained on the concrete surface, concrete segregation)
    - Lack of maintenance



Maslenica Bridge-Republic of Croatia

- **Cracks and defects in concrete cover**
  - **Surface cracks** caused by poor quality of construction
  - **Structural cracks** – at the foundation of the pier S2
  - **Concrete layering** at the depth of 1 cm from concrete surface



Maslenica Bridge-Republic of Croatia

- **Delamination and spalling of concrete cover**
  - **Pier S3 –** surface exposed to the bora wind

- **Water leakage** through the expansion joint

Maslenica Bridge-Republic of Croatia

- **Concrete compression strength – OK**
- **Modulus of elasticity – OK**
- Concrete cover: 31-79 mm
- Gas permeability: 1,4 – 4,2 x 10^{-16} m^2 high → low quality concrete
- Chloride content measurements- above or around the threshold value!!!!

Structural part	Design	Laboratory, f_{ck} [MPa]	In situ, f_{ck} [MPa]	Modulus of elasticity, E_b [MPa]
Piers foundations	C20/25	56,47	58,17	3,327 x 10^4
Columns	C30/37	42,51	55,03	
Arch	C30/37	-	60,91	

Maslenica Bridge-Republic of Croatia

Investigation works 2010

- – visual inspection of all structural members, recording defects and registering cracks, together with identifying locations for taking specimens;
- – taking concrete specimens for measuring chloride content in concrete.

- Defects during construction (poor quality execution of construction joints, concrete segregation, cracks)
- Water leakage through the expansion joint

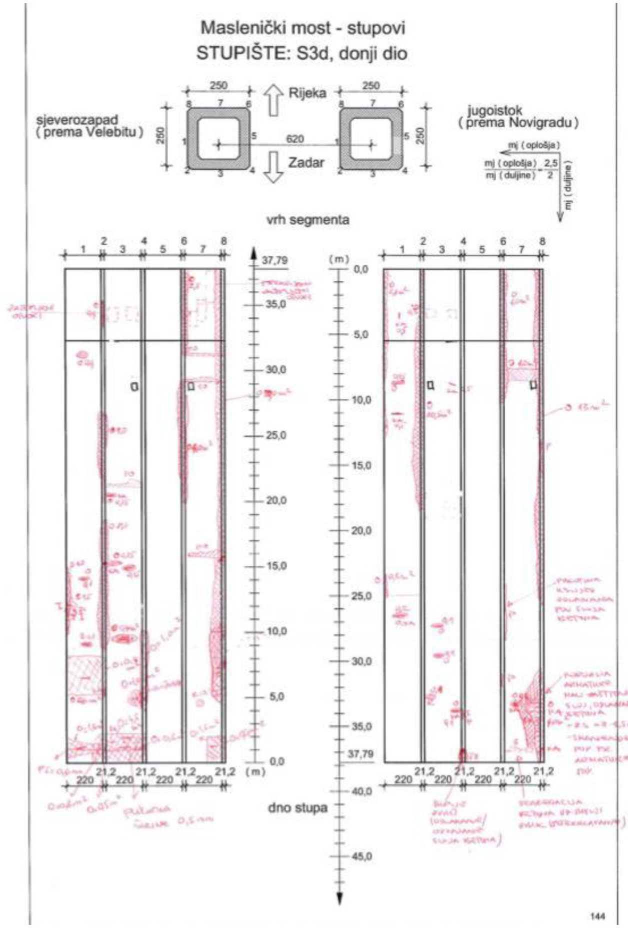
ABUTMENTS

Maslenica Bridge-Republic of Croatia

PIERS



- Defects during construction (poor quality execution of construction joints, concrete segregation, cracks)
- Cracks
- Defects and delamination of concrete cover
- Localized damage are more frequent on the columns S3 and S10 – **repair works**



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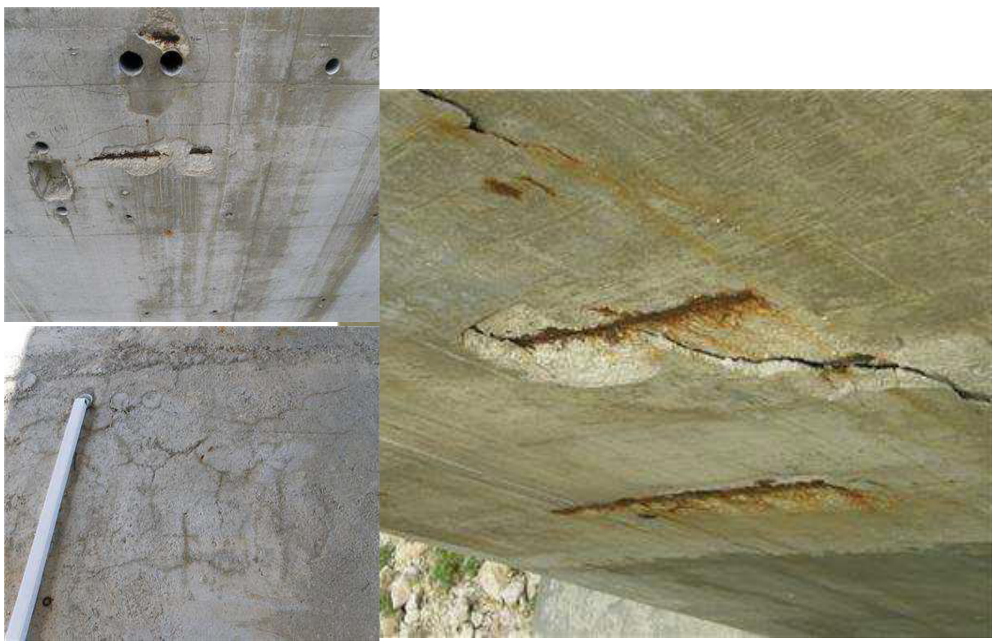
ARCH

OUTER SURFACE

- Defects during construction
- Cracks
- Defects and delamination of concrete cover
- Insuficient concrete cover - corrosion



INNER SURFACE

- Rainwater leaks through built-in openings (d=100 mm)
- Cracks on the upper and external lateral surface
- Concrete segregation
- Insufficient concrete cover – corrosion
- Stairs inside the arch – completely damaged !

Maslenica Bridge-Republic of Croatia

GIRDERS

- Insuficient concrete cover - corrosion

HEAD BEAMS, CROSS BEAMS, BEARINGS

- Deep cracks on the head beams above piers S3, S5, S6
- Insuficient concrete cover - Corrosion

Maslenica Bridge-Republic of Croatia

CARRIAGEWAY

- pavement cracking
- Asphalt pavement wearing and tearing
- Insuficient concrete cover – corrosion
- Minor damage on the concrete safety barrier

Maslenica Bridge-Republic of Croatia

EXPANSION JOINTS

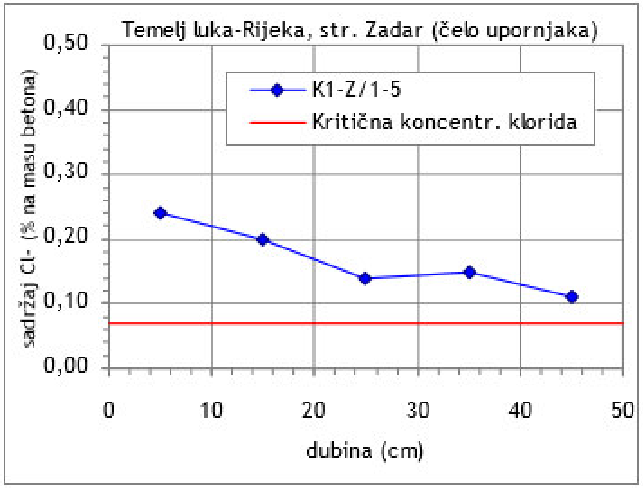

- Water leakage through the expansion joints
- Deterioration of protective coatings

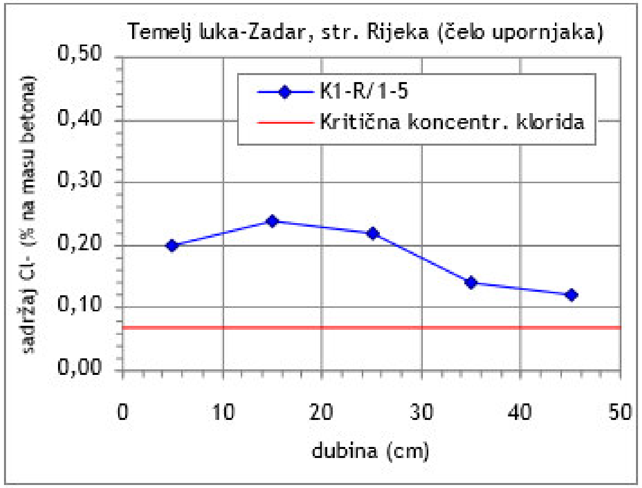
BRIDGE CORNICE

- Deterioration of protective coatings

Maslenica Bridge-Republic of Croatia

- Determination of the Chloride content
- Chloride penetration in concrete cover is uneven, and depends on location.
- **The content is higher** and penetration deeper in concrete members facing Velebit (north).





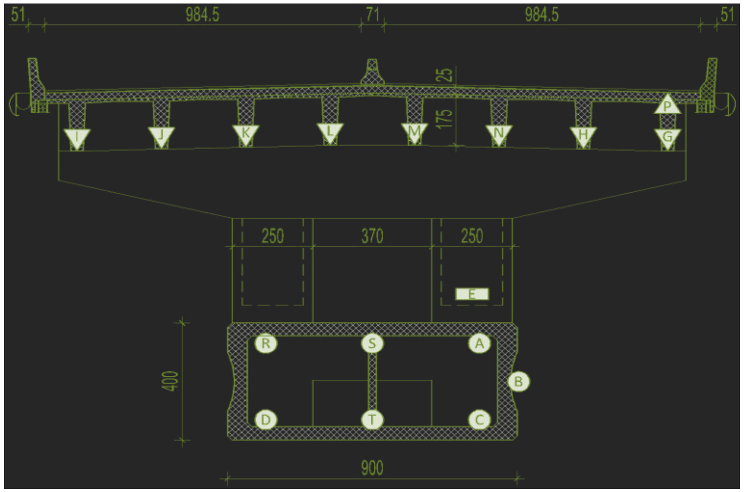
Maslenica Bridge-Republic of Croatia

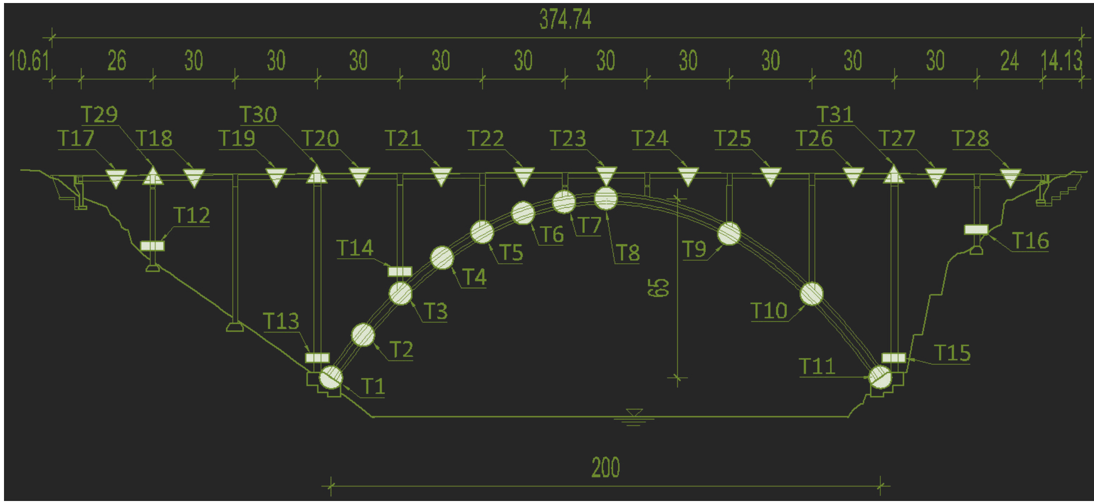
Monitoring

- The monitoring system was used to record the stresses and strains at various construction stages and under load-testing prior to opening the bridge to the service.
- The system consists of 92 strain-gauges, 40 temperature sensors and 21 corrosion sensors (anode-ladder) mounted at carefully chosen spots on the arch and girders of the superstructure. - the monitoring project was stopped soon afterwards!!!!!

Maslenica Bridge-Republic of Croatia

Monitoring





Maslenica Bridge-Republic of Croatia

Case study PI and KPI calculations and interpretations prepared by:

Marija Kuster Maric,
Ana Mandic Ibankovic,

Faculty of Civil Engineering, University of Zagreb, Croatia

Maslenica Bridge-Republic of Croatia

Performance Indicators (PI) and Key Performance Indicators (KPI)

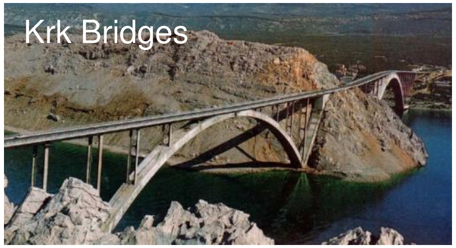
- **Based on COST TU1406 WG1**
- **Include the results od the Croatian Arch bridges assessment project**

Basic categories for KPI taken from the Arch bridges project are:

- Structural
- Environmental
- Economic

Categories for KPI based on WG1 are:

- Safety, Reliability, Security (with rating factor r_{SRS})
- Availability, Maintainability (with rating factor r_{AM})
- Costs (with rating factor r_C)
- Environment (with rating factor r_E)
- Health, Politics (with rating factor r_{HP})



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Performance Indicators (PI), based on WG1 report

Approximately 60 PIs are further related with one or more Key Performance Indicators (KPI):

Each **PI** is determined by **rate (R=1-5)** and **weight (W=0-1).**
Rate represents the degree of performance indicators, where:

Rate	Description
1	means no damage, good condition or observation favorable for the bridge
2	means smaller defects, condition or observation that is slightly disrupted
3	means defects, condition or observation that in long term (approximately 20-30 years) decrease KPIs
4	means defects, condition or observation that in foreseeable future (approximately 10 years) can decrease KPI
5	means defects, condition or observation in the worst stage presenting serious danger to KPI and intervention on the bridge is needed immediately or within 5 years at least.

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Rates of PI in this Case study are based on :

- Project design data
- Results of SHM during construction and in service (limited)
- Load testing prior to the bridge opening
- Results of the last two visual inspections (2006,2010)
- Destructive and NDT
- Bridge assessment on seismic
- Bridge assessment on Wind
- Bridge assessment on traffic loading
- Numerical analysis don for service life prediction

Maslenica Bridge-Republic of Croatia

From PI to KPI

Weights represent the impact of each **PI** on the relevant **KPI**

0 = No impact of the **PI** on the **KPI**
1 = Particular **PI** is significantly influencing the relevant **KPI**

In this case study the weight were determined based on expert knowledge and experience

Maslenica Bridge-Republic of Croatia

From PI to KPI

Rating of each KPI in this case sturdy is based on simple calculation

$$r_{KPI} = \frac{\sum_{i=1}^{n} R_i * W_i}{\sum_{i=1}^{n} W_i}$$

Ri = Rate of the PI_i
Wi = Weight of the PI_i for the certain group of the KPI.

r_{KPI}	Description
$0 \leq r_{KPI} \leq 1$	Good condition - no intervention needed.
$1 < r_{KPI} \leq 2$	In general good condition – maintenance is required.
$2 < r_{KPI} \leq 3$	Marginal condition - minor rehabilitation is required.
$3 < r_{KPI} \leq 4$	Poor condition - repair or rehabilitation is required.
$4 < r_{KPI} \leq 5$	Critical condition - repair or rehabilitation is urgent.

(Kušter Marić & Mandić Ivanković, 2017)

Arch Bridge Case study: Maslenica Motorway Bridge (Marija Kušter Marić, marijak@grad.hr - last changed 11 September 2017)

Assessment of PIs for first KPI – Safety, Reliability, Security

	Safety, Reliability, Security				
	PI	Level Component Level (CL) System Level (SL) Network Level (NL)	rating (1-5)	weighting	Basis for assessment
defects in concrete cover	cracks generated during or immediatly after construction	CL,SL	3	0,9	Visual inspection, measurement
	cracks due to temperature changes	CL, SL	2	0,9	Visual inspection
	corrosion induced cracks	CL	4	1	Visual inspection, measurements
	crumbling of concrete cover (at safety barrier)	CL	3	0,4	Visual inspection
	delamination / detachment of concrete cover	CL	4	1	Visual inspection; NDT
	insufficient concrete cover	CL, SL	4	1	Visual inspection, measurements, NDT
	layering (concrete)	CL, SL	3	0,8	NDT
	concrete segregation	CL, SL	3	0,8	Visual inspection, NDT
material parameters	concrete strength deficiency: arch	CL, SL	1	0,7	Concrete parameters testing
	concrete strength deficiency:superstructure	CL, SL	1	0,7	Concrete parameters testing
	concrete strength deficiency: piers	CL, SL	1	0,7	Concrete parameters testing
	concrete strength deficiency: abutments	CL, SL	1	0,7	Concrete parameters testing
	concrete strength deficiency: foundations	CL, SL	2	0,7	Concrete parameters testing
	modulus of elasticity: arch	CL, SL	1	0,7	Concrete parameters testing
	modulus of elasticity:superstructure	CL, SL	1	0,7	Concrete parameters testing
	modulus of elasticity: piers	CL, SL	1	0,7	Concrete parameters testing
	modulus of elasticity: abutments	CL, SL	1	0,7	Concrete parameters testing
	modulus of elasticity: foundations	CL, SL	2	0,7	Concrete parameters testing
	gas permeability:arch	CL, SL	4	1	Concrete parameters testing
	gas permeability:piers	CL, SL	5	1	Concrete parameters testing
structural performance	arch displacement (reatification needed)	CL	1	0,7	Visual inspection, measurements
	sag / deformation / denivelation /differential displacement	CL, SL	1	1	Visual inspection, measurements
	absent (missing) structural component	CL, SL	1	0,8	Visual inspection
	presstresing cable failure: superstructure	CL, SL	1	0,8	Visual inspection
	carrying capacity factor	SL	1	0,8	Design project, assessment
	stiffness	CL, SL	1	0,5	Design project, assessment, numerical analysis
	damping	SL	1	1	Load-testing prior to the bridge opening, numerical analysis
	frequency	SL	1	1	Load-testing prior to the bridge opening, numerical analysis
	vibrations/oscillations	SL	1	0,8	Load-testing prior to the bridge opening, numerical analysis
	reliability index	SL	1	0,5	Design project, assessment, numerical analysis

	safety index	SL	1	0,3	Design project, assessment, numerical analysis
	element functionality level	CL	1	1	Visual inspection, Design project, assessment
	importance of bridge element	SL	4	0,8	Design project, assessment, Visual inspection
equipment	asphalt pavement cracking	CL, SL	4	0,5	Visual inspection
	deterioration of equipment component-stairs in arch	CL, SL	5	0.2	Visual inspection
	approach slab settlement	CL, SL	1	0,2	Visual inspection
	asphalt pavement wearing and tearing (rutting, ravelling)	CL, SL	4	0,3	Visual inspection
	asphalt pavement wheel tracking and wrinkling and undulation	CL, SL	4	0,4	Visual inspection
	blistering of protective coating	CL, SL	3	0,8	Visual inspection
	cornicles and curbs defects	CL, NL	3	0,3	Visual inspection
	corrosion related to equipment made of steel	CL, SL	4	0,9	Visual inspection
	deterioration of protective coatings (e.g. corrosion protection, impregnate…)	CL, SL	4	0,8	Visual inspection
	waterproofing deterioration/loss	CL, SL	2	0,5	Visual inspection
	drainage	CL, SL	2	0,3	Visual inspection
	bearings displacement/deformations /defects	CL	3	0,5	Visual inspection
	insufficient height of railing (safety barrier)	CL, NL	1	0,3	Visual inspection
	expansion joint (waterproof, damage)	CL, NL	4	0,7	Visual inspection
Loads (EC1)	Assessment on trafic load	CL, SL	1	0,7	Assessment
	Assessment on wind load	SL, NL	1	0,7	Assessment
	Assessment on seismic load	SL, NL	1	0,7	Assessment
	seismic activity of the area	SL, NL	4	0,8	Assessment
	Extreme traffic load	SL	2	0,5	Assessment
	Extreme wind	SL	4	0,5	Assessment
Environmental influence	inadequate clearance	NL	1	0,3	Environmental conditions, Design project
	Erosion	SL	1	0,1	Environmental conditions, Design project
	settlement	CL, SL	1	0,5	Environmental conditions, Design project
	wetting - drying	CL, SL	4	0,9	Environmental conditions, Meteorological monitoring
	carbonation depth	CL	2	0,8	measurements
	pitting corrosion (chlorides)	CL	3	1	measurements, SHM
	chloride content		5	0,9	measurements
	Corrosion rate (electrical potential, current density)	CL	4	0,9	SHM
	Impact (e.g. of vehicles or ships)	CL, SL	1	0,3	Environmental conditions, Design project
	Rock fall	NL	1	0,5	Environmental conditions, Design project
	Scour	SL	1	0,5	Environmental conditions, Design project
			total rating	**2,98**	

Maslenica Bridge-Republic of Croatia

Calculation PI

Example 1 –

- **Cracks generated during or immediately after construction** are most widespread on the structural elements, especially on the pier P3. According to their length, density and deterioration degree, their **rate is 3**, as average grade of damage.
- **Cracks due to temperature changes** are less often and localized, hence their **rate is 2**
- **Corrosion induced cracks** are localized and accompanied by brown spots, on the most deteriorated elements , the piers P3 and P10, they indicates advanced corrosion process which is not allowable condition for service life of 20 years, and their **rate is 4**.

Cracks significantly influence on the corrosion of reinforcement, especially those with width larger than 0.2 mm and depth up to the reinforcement level. Hence, the weight for the corrosion induced cracks is **1.0,** while for more shallow cracks the weight is assumed to be **0.9**.

Maslenica Bridge-Republic of Croatia

Calculation PI

Example 2 –

- **Crumbling of concrete cover** at concrete safety barrier is noticed during visual inspections and is **rated 3**, but its effect on the KPI is minor (**weight 0.4**), because it will not present the danger for traffic safety in foreseeable future and has no influence on the structural capacity.

Example 3 –

- **Delamination and detachment of concrete cover** is discovered by the NDT on most of the structural elements, where affected area is approximately 1m^2 and density of defects is relatively high, resulting in **rate of 4**. Since the quality and integrity of concrete cover is essential to provide protection against chloride penetration to the reinforcement level, but also to ensure the transfer of force, stress and strain in structure, the PI weight is **1.0**.

Maslenica Bridge-Republic of Croatia

Calculation PI

Example 4 –

- **Concrete layering and segregation** are detected on some spots on the piers and foundations with lower damage degree (**rate 3**), since the depth of the defects is not large, the weight is assumed to be **0.8**.

Example 5 –

- **Concrete cover** measured at piers P3 and P10 is 3.1cm, while designed concrete cover was 5 cm, and for the most exposed surfaces 10 cm of concrete cover was specified in the bridge design: Due to its importance for the structure durability in aggressive maritime environment, the **rate is 4**, and weigh is **1.0**.

Maslenica Bridge-Republic of Croatia

Calculation PI

Example 6 –

- **Testing results** showed that **concrete strength** and **modulus of elasticity** are above the value specified in the design, hence rate of the PI concrete strength deficiency is **1** for all elements, expect for pier P2 foundation where the **rate is 2** due to slightly lower measured values. The **weight** for concrete strength and modulus of elasticity is set on **0.7**, taking into account additional reserves covered by a partial safety factors.

Example 7 –

- **Gas permeability** is higher than expected which is unfavourable because accelerates chloride penetration and active corrosion. The designed service life of 100 years was planned to be achieved with much lower permeability, hence the **rate is 4 and 5**, for arch and piers, respectively, while the **weight is 1.0** and due to aggressive environment protective coating is needed immediately.

Maslenica Bridge-Republic of Croatia

Calculation PI

Example 8 –

The assessment of the bridge on the **traffic, wind and seismic loads** according to the EC showed that the ultimate and serviceability limit states are satisfying, hence the **rate is 1**, and the **weight is 0,7** , taking into account additional reserves covered by a partial safety factors.

	Availability, Maintainability				
	PI	Level Component	rating (1-5)	weighting	Basis for assessment
defects in concrete cover	cracks generated during or immediatly after construction	CL, SL	3	0,9	Visual inspection, measurement
	insufficient concrete cover	CL, SL	4	1	Visual inspection, measurements, NDT
	concrete segregation	CL, SL	3	0,8	Visual inspection, NDT
	gas permeability /: arch	CL, SL	4	1	Concrete parameters testing
	gas permeability /: piers	CL, SL	5	1	Concrete parameters testing
	honeycomb (bed concrete compaction)	CL, SL	3	0,8	Visual inspection, measurement
structural performance	arch displacement (reatification needed)	CL	1	0,7	Visual inspection, measurement
equipment	asphalt pavement cracking	CL, SL	4	0,5	Visual inspection
	deterioration of equipment component-stairs in arch	CL, SL	5	1	Visual inspection
	asphalt pavement wearing and tearing (rutting, ravelling)	CL, SL	4	0,6	Visual inspection
	asphalt pavement wheel tracking and wrinkling and undulation	CL, SL	4	0,4	Visual inspection
	blistering of protective coating	CL, SL	3	0,8	Visual inspection
	cornicles and curbs defects	CL, NL	3	0,3	Visual inspection
	corrosion related to equipment made of steel	CL, SL	4	0,4	Visual inspection
	deterioration of protective coatings (e.g. corrosion protection, impr	CL, SL	4	0,8	Visual inspection
	waterproofing deterioration/loss	CL, SL	2	0,5	Visual inspection
	drainage	CL, SL	2	0,3	Visual inspection
	bearings displacement/deformations /defects	CL	3	0,8	Visual inspection
	expansion joint (waterproof, damage)	CL, NL	4	0,8	Visual inspection
global parameters	damage degree/extension	CL	5	0,8	Visual inspection, numerical analysis
	deterioration index	CL	4	0,8	Visual inspection, numerical analysis
	importance of the bridge in the network	NL	5	1	Location, traffic conditions, meteorological monitoring
	Extreme traffic load - summer (tourist) season	SL, NL	5	1	Location, traffic conditions
	Extreme wind - winter season	SL	5	1	Location, traffic conditions, meteorological monitoring
			total rating	3,87	

Costs				
PI	Level Component	rating (1-5)	weighting	Basis for assessment
crack and concrete cover repair	CL, SL	5	0,5	Visual inspection, measurement
Replacement of asphalt	SL, NL	4	0,2	Visual inspection
Application of protective coating	CL, SL	5	0,5	Visual inspection, measurement, numerical analysis
replacement of bearings	CL	3	0,3	Visual inspection
replacement of expansion joints	NL	4	0,4	Visual inspection
deterioration of equipment component-stairs in arch	CL, SL	5	0,3	Visual inspection
reliability index	SL	1	0,5	Visual inspection, measurement, numerical analysis
remaining service life	SL, NL	4	0,7	Visual inspection, measurement, numerical analysis
traffic restrictions	NL	3	0,5	Location, traffic conditions, meteorological monitoring
traffic volume (anual avarage daily traffic)	SL, NL	3	0,3	Location, traffic conditions, meteorological monitoring
importance of the bridge in the network	NL	5	1	Location, traffic conditions, meteorological monitoring
road category (roadway width)	NL	5	0,8	Traffic conditions
detour distance	NL	2	0,3	Location, traffic conditions, meteorological monitoring
bridge span	SL	4	0,5	Design project
bridge lenght	SL	4	0,5	Design project
seismic activity of the area	SL, NL	4	0,5	Design project
Aggressive maritime environment	SL, NL	5	1	Location, SHM,numerical analysis
		total rating	**4,10**	

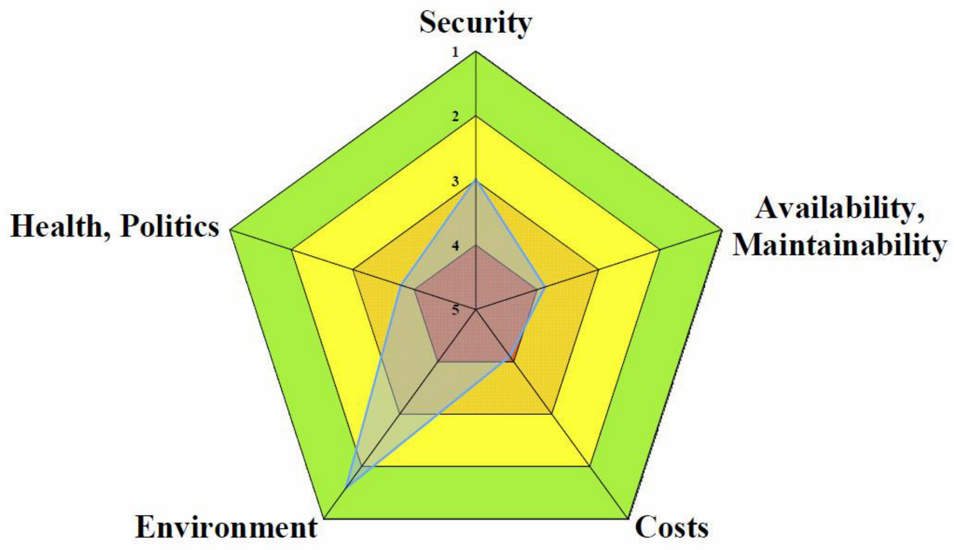
Environment				
PI	Level Component Level (CL)	rating (1-5)	weighting	Basis for assessment
Emissions to Air	NL	2	0,5	Location, traffic conditions, design
Emissions to Sea/Water	NL	2	0,3	Location, traffic conditions, design
Emissions to Soil	CL, SL	2	0,3	Location, traffic conditions, design
Impact (e.g. of vehicles or ships)	CL, SL	1	0,8	Location, traffic conditions, design
		total rating	**1,58**	

Health, Politics				
PI	Level Component Level (CL)	rating (1-5)	weighting	Basis for assessment
deterioration index	CL	4	0,8	Visual inspection, numerical analysis
importance of the bridge in the network	NL	5	1	Location, traffic conditions, meteorological monitoring
noise	NL	1	0,5	Location, traffic conditions, environment
		total rating	**3,78**	

Weights or impacts 0-1 are assumed based on knowledge and experience with arch bridges in general, and particularly those built on the Adriatic coast.

Rates from 1-5 are based on the project design, results of SHM during construction and in service, Load-testing prior to the bridge opening, results of last two visual inspections, destructive and non-destructive testing, bridges assessment on seismic, wind and traffic loads, numerical analysis on service life prediction. The most important results are listed in the presentation from Paris.

KPI	total rating
Safety, Reliability, Security	2,98
Availability, Maintainability	3,87
Costs	4,10
Environment	1,58
Health, Politics	3,78



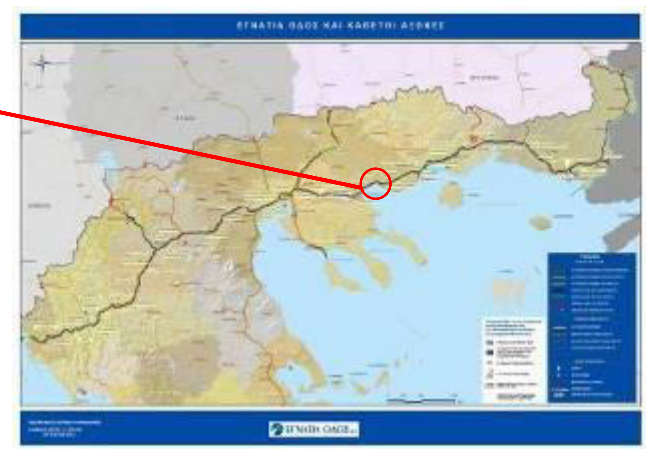
Maslenica Bridge-Republic of Croatia

Intermediate conclusions for Maslenica bridge case study:

1. PI selection is controlling the aggregation process and scoring of the different KPI. Different PI selection will give different KPI score!
2. Currently no unified method yet. (WG2 + WG3)
3. Can we use the same aggregation method for different KPI ? $r_{KPI} = \frac{\sum_{i=1}^{n} R_i * W_i}{\sum_{i=1}^{n} W_i}$
4. Weight is highly subjective (Expert opinion)
5. This bridge has a lot of data and is not a typical case of highway bridge data

STRYMONAS RIVER BRIDGE
SELECTED FOR GIRDER BEAM USE CASE

Year of construction: 1987
Deck: 5 prestressed concrete beams
Bridge length: 237.60m
Span no: 8 (×30.00m long)
Joint type: Elastomeric expansion joint (anchored) T50
Bearing type: Elastomeric orthogonal Type NB1



Modelling of the older Branch of Strymonas Bridge

Deck scheme: Simply supported spans
Computerized calculation FEM : 3-d model using SAP2000.v14 nonlinear analysis program.

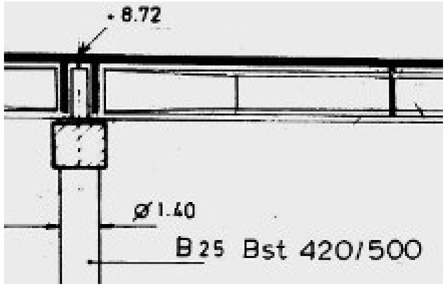
Concrete and steel at the older Branch of Strymonas Bridge

Concrete's compress strength assigned to 20MPa according to the design study and the laboratory strength from concrete drilling and Schmidt Hammer testing.

The yield stress of steel bars, needed for the assessment calculations, assigned to 420MPa according again to the design study and tensile stress test.

Δοκίμιο	Μήκος L_o (mm)	Διάμετρος d_o (mm)	Διατομή f (mm^2)	Φορτίο διαρροής $P_δ$ (kg)	Φορτίο θραύσης $P_θ$ (kg)	Τάση διαρροής $σ_δ$ (MPa)	Τάση θραύσης $σ_θ$ (MPa)
1	60	12,1	114,990	5000	8250	434,8	717,5
2	60	12	113,097	5000	8100	442,1	716,2
M.O.						**438,5**	**716,8**

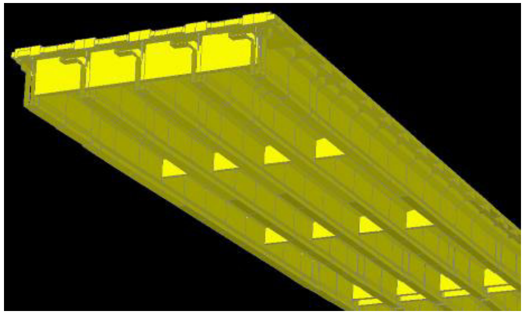
Yield stress of steel bars

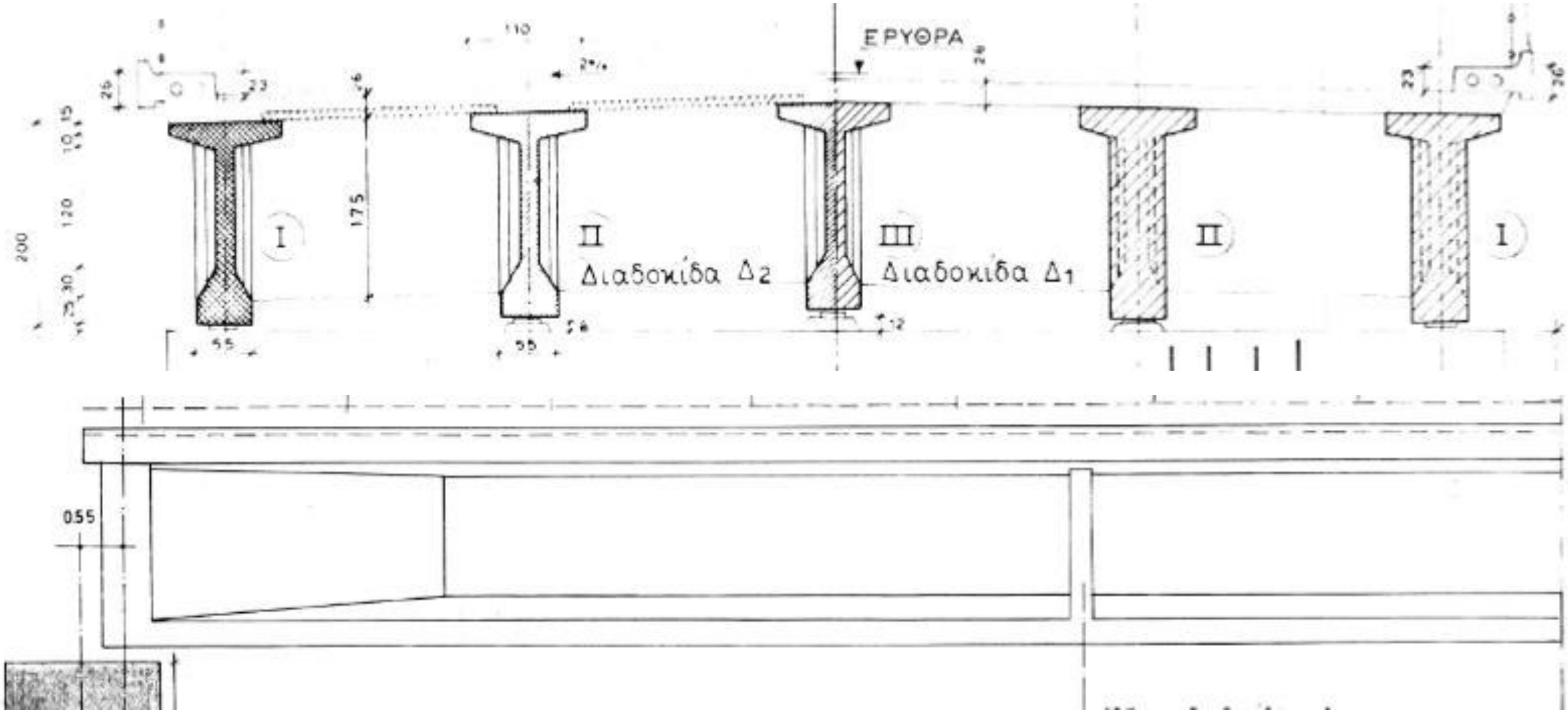


Δοκίμιο	Φορτίο (kN)	**Αντοχή πυρήνα** (MPa)	L1	L2	L4	**Ισ.αντοχή κυλίνδρου** (MPa)	L3	**Ισ.αντοχή κύβου** (MPa)
K1	182,5	24,29	0,852	0,958	1,03	20,4	1,208	24,7
K2	119,3	15,88	0,855	0,958	[illegible]	[illegible]	1,246	16,7
K3	134,6	17,92	0,855	0,958	1,03	15,[illegible]	1,238	18,7
K4	96,8	16,11	0,857	0,958	1,03	13,6	1,246	17,0
K5	120,6	16,05	0,857	0,958	1,03	13,6	1,246	16,9
K6	142,8	19,01	0,855	0,958	1,03	16,0	1,233	19,8
M.O.		**17,0**				**14,3**		**17,8**

Compress strength from drilling cores

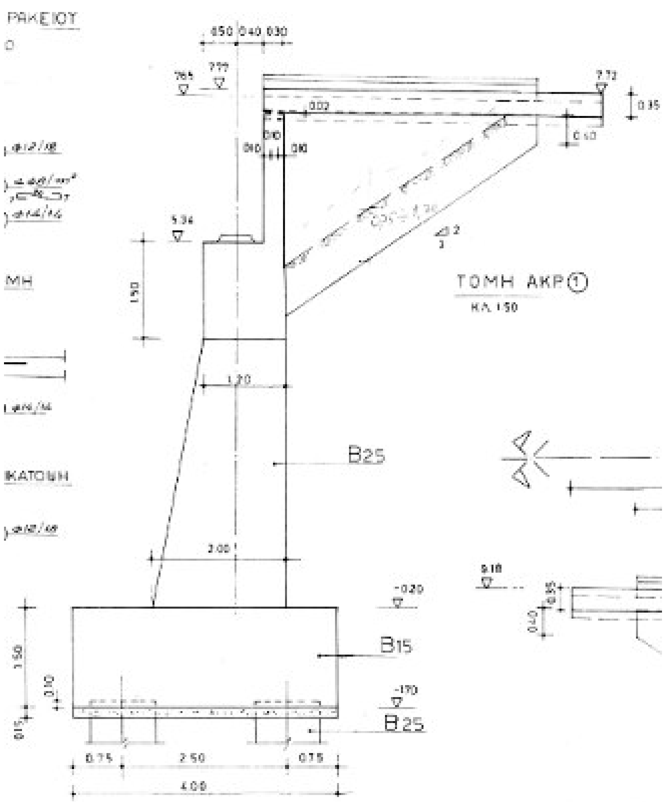
- **Superstructure – Deck:**
- **8 spans**
- **5 precast pre-stressed concrete beams with different width at supports and middle span (each span)**
- **4 diaphragm beams (each span) also post-tensioned**
- **Cast in situ concrete deck slab 26cm thick**

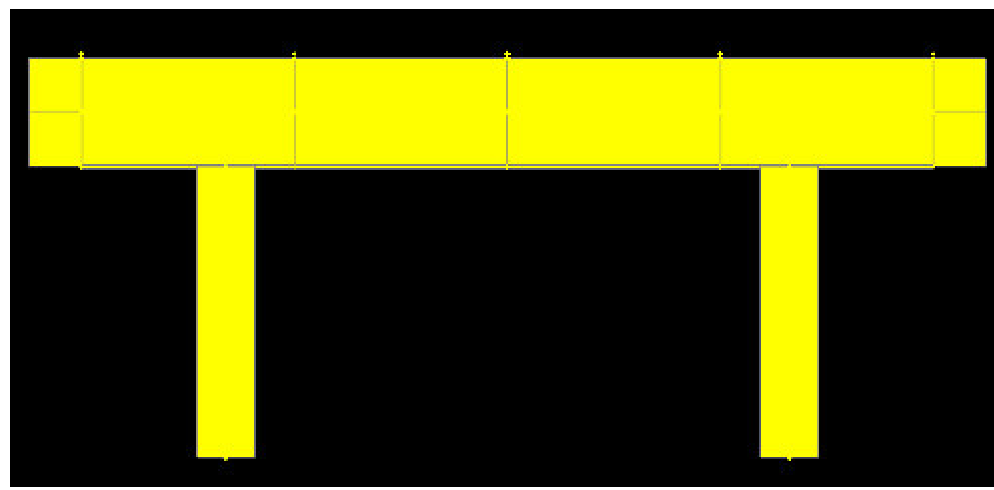




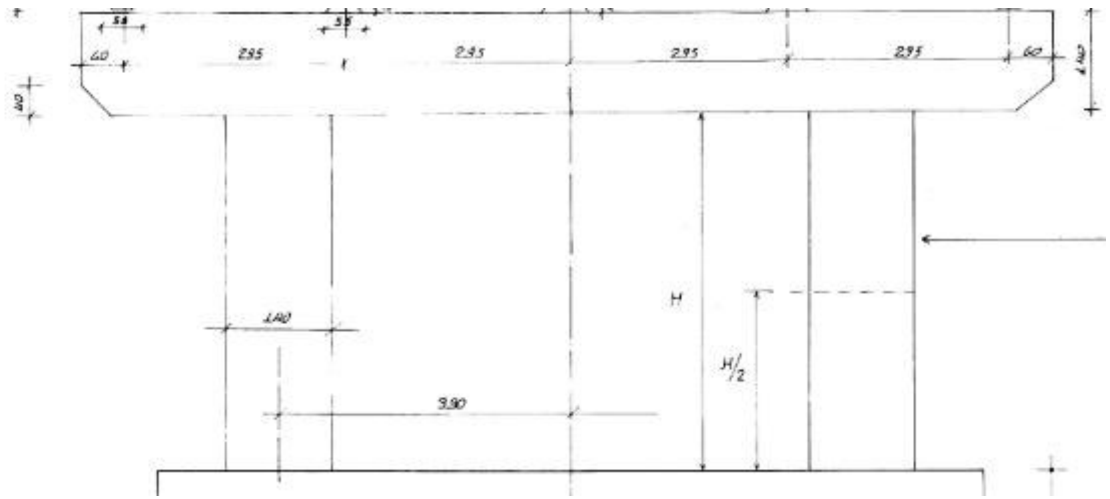
❑ Substructure – Abutments:

- Abutments, open type with 2 columns of changing section and head cap



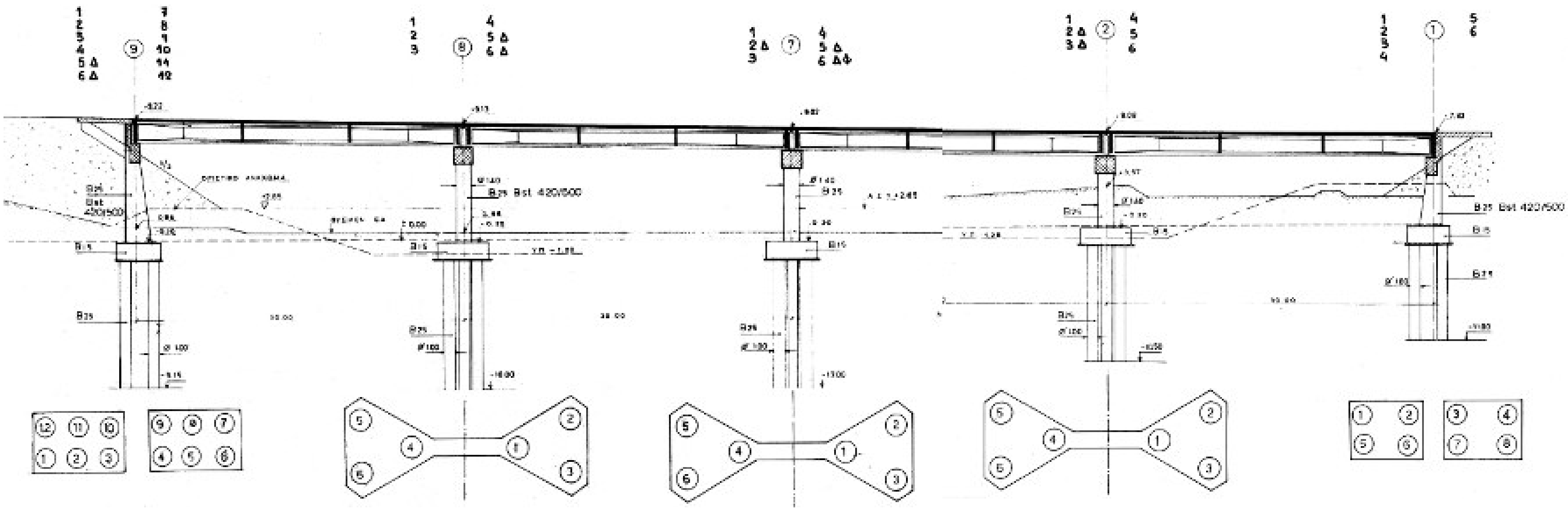


- ❑ **Substructure – Piers:**
- **Piers, with 2 columns of circular section (1,4m) and head cap**



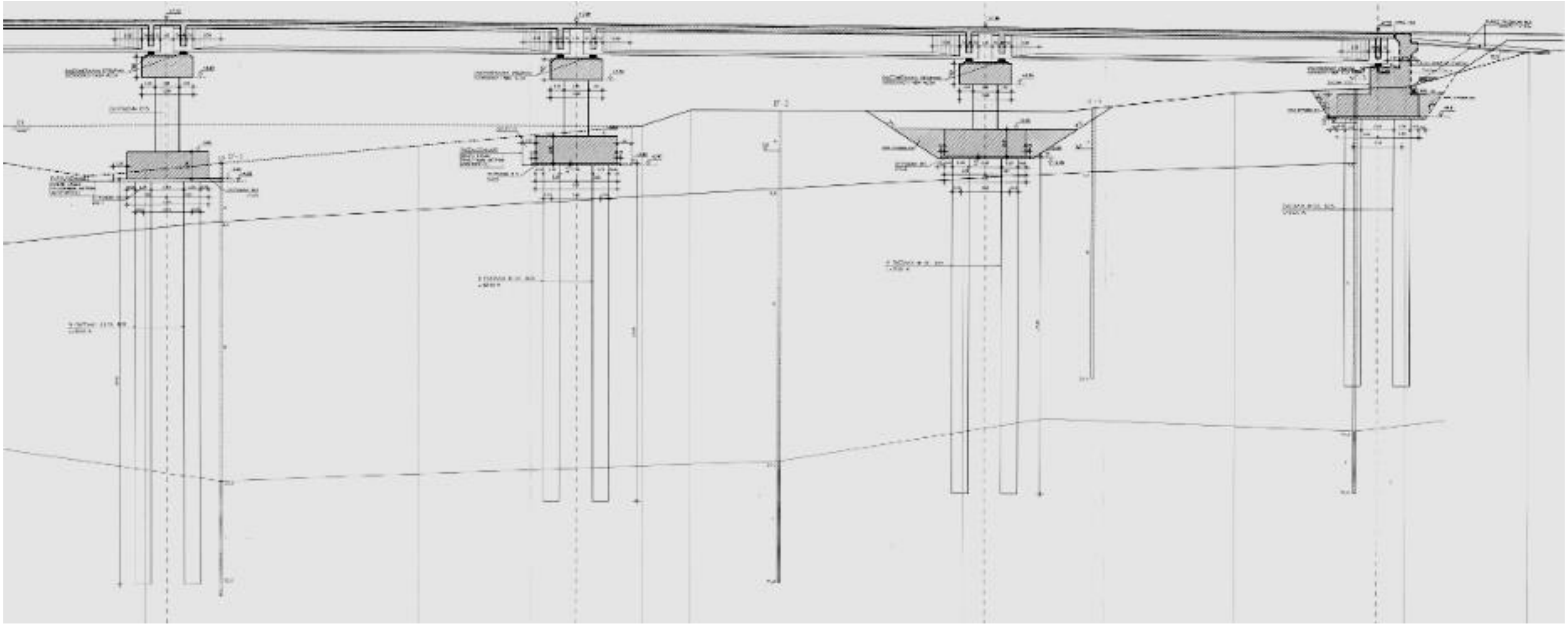
Foundations :

- **Deep foundation with piles (d=1,00m) and pile-head both at abutments and peers**
- **Different type of pile system between abutment AA0,AA1 and piers according to design drawings. Also different pile depth at each pier.**



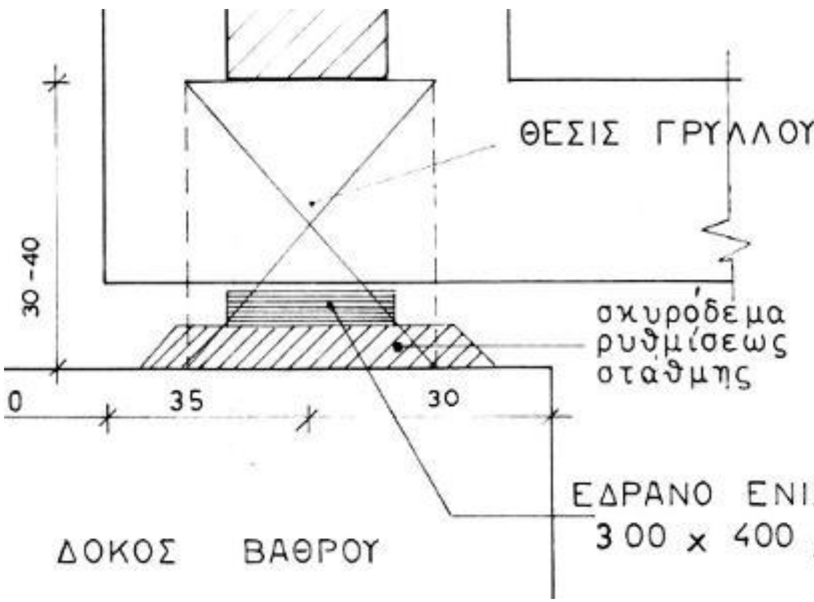
❑ Foundations (cont.) :

- **Information for the soil of the foundations from the design drawings of the newest right branch of the bridge (type and depth of the layers) assuming that similar state for the older branch. Top loose layer of clay and gravel (around 5m depth) and then medium density sand. According to the above the whole of the foundation is constructed into loose weak soil.**



❑ Bearings :

- **Rectangular section-elastomeric type-1 bearings at the supports of the beams on the piers and abutments.**



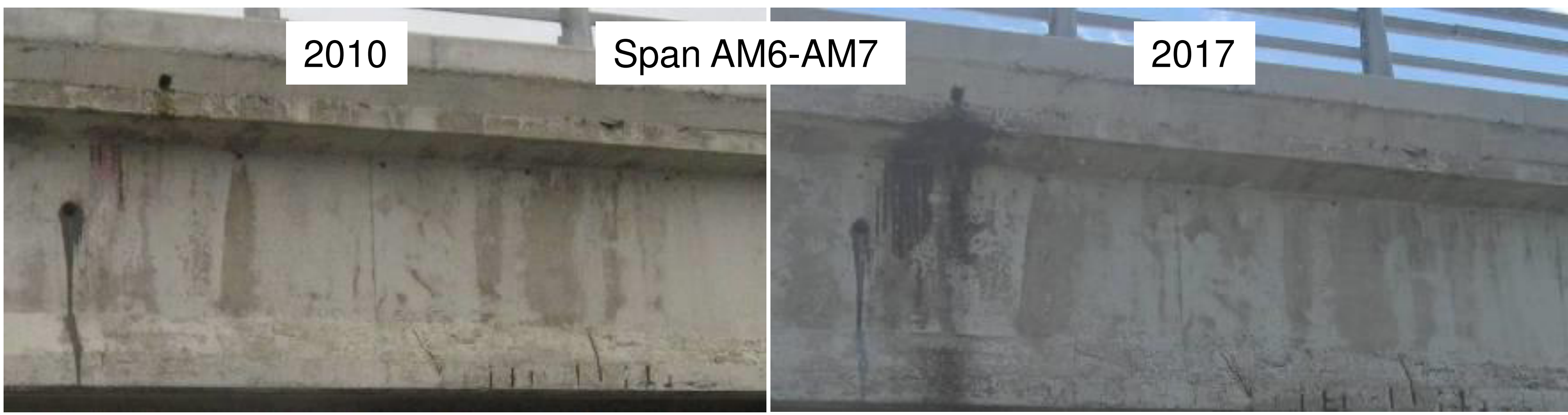
Analysis in SAP2000

•Pier M4 Seismic Load Rating for some piers is very poor as the bridge was designed following old much more favorable seismic codes

	column of pier M4 (51Φ26-base,34Φ26-head)											
Combination	*1,35G+1,5Q*		*seismic x*		*seismic y*		*seismic z*		*G+0,2Q+Ex*		*G+0,2Q+Ey*	
Position	base	head	base	head	base	head	base	head	base	head	base	head
N	-6674	-6354	-2753	-2516	-784	-547	-2039	-1802	-4097	-3859	-1284	-1046
ν	**-0,33**	**-0,31**	**-0,13**	**-0,12**	**-0,04**	**-0,03**	**-0,10**	**-0,09**	**-0,20**	**-0,19**	**-0,06**	**-0,05**
M3	0	0	13840	2899	4415	1109	4356	1149	13714	2761	250	204
M2	69	40	1981	1883	6476	6180	1983	1882	50	35	6474	6177
$M_{o\lambda}$	69	40	13981	3457	7838	6279	4786	2205	13714	2761	6479	6180
μ	**0,00**	**0,00**	**0,49**	**0,12**	**0,27**	**0,22**	**0,17**	**0,08**	**0,48**	**0,10**	**0,23**	**0,22**
V3	17	17	625	625	2022	2022	626	626	14	14	2050	2050
V2	0	0	1819	1819	626	626	623	623	1776	1776	73	73
Voλ	17	17	1923	1923	**2117**	**2117**	883	883	1776	1776	2051	2051
$stirrups_{inst}$	Φ10/20											
$V_{R,stirrups}$	261											
$\omega_{tot,\alpha\pi}$	0	0	1,58	0,22	0,75	0,61	0,44	0,12	1,53	0,2	0,71	0,61
$A_{stot,needed}$ (cm^2)	0,00	0,00	887,93	123,64	421,49	342,81	247,27	67,44	859,83	112,40	399,01	342,81
$A_{stot,inst}$ (cm^2)	270,64	180,42	270,64	180,42	270,64	180,42	270,64	180,42	270,64	180,42	270,64	180,42
$A_{stot,needed-inst}/A_{stot,inst}$ (%)			**228**	**-31**	**56**	**90**	**-9**	**-63**	**218**	**-38**	**47**	**90**

Strymonas Bridge

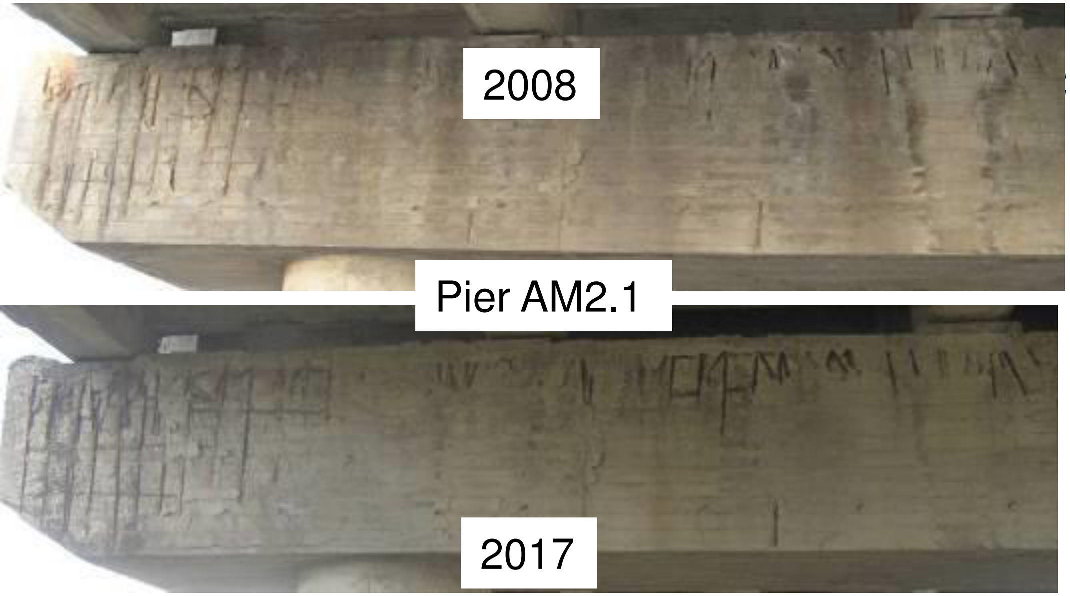

Pier AM7.1
2010
2017

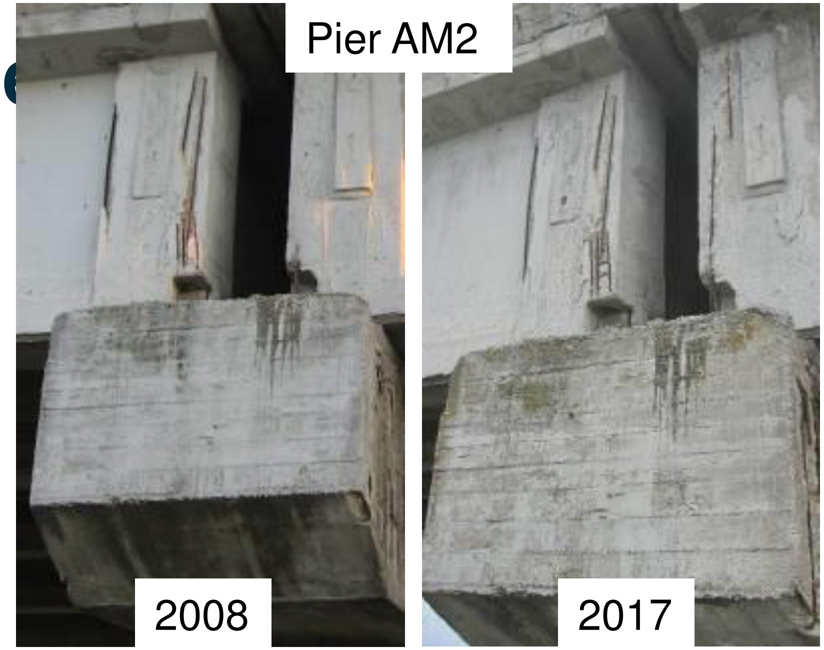

2010
Span AM6-AM7
2017

Span AM6-AM7

Damages evolution

Pier AM7





Damages evolution

Span AA1-AM7

Strymonas Bridge - Greece

Assessing the bridge by using PI and KPI

Panagiotis Panetsos, Egnatia Odos

First attempt using adaptation of the 'Sustainable Building Method'

(SB, Mateus, Braganca, 2011)

- **7 Bridge components are defined: Abutment, Piers, Superstructure, Safety barriers, sidewalks, pavement and drainage**
- **11 KPIs are defined: Reliability, Availability, Maintainability, Safety, Costs, Security, Politics, Environment, Rating/Inspection, Durability**
- **More than 40 PIs are set, common or different for various KPIs**
- **The importance of PIs for each KPI is defined in 0-5 scale for each element**

The **importance for each PIs** relevant to each component are defined (using questionnaire for expert opinion of maintenance , research, and design).

S/N	KPI (BENCHMARK)	PI	Abutments	Piers	Superstructure	Safety railings	Sidewalks	Pavement	Drainage system
			COMPONENTS						
1	Reliability	bearings deformation	2	4	4	0	0	0	0
		bearings displacement	2	4	4	0	0	0	0
		concrete cover (insufficient)	4	4	4	0	0	0	0
		corrosion	0	0	0	5	3	0	4
		corrosion related to prestressing steel	0	0	5	0	0	0	0
		corrosion related to reinforcement steel	5	5	5	0	0	0	0
		crack spacing (due to shrinkage)	2	2	2	0	0	0	0
		crack width (due to shrinkage)	2	3	4	0	0	0	0
		crack width (longitudinal, due to retraction o concrete and reinforcement corrosion)	4	5	5	0	0	0	0
		cracks related to origin (e.g. due to loading, due to settlement, due to crumbling of concrete, shrinkage)	5	5	5	0	0	0	0
		damping	3	5	5	0	0	0	0
		ductility	3	5	5	1	0	0	0
		frequency	2	5	5	0	0	0	0
		grouting deficiency	0	0	4	0	0	0	0
		joint deterioration	2	2	3	0	0	0	0
		loss of section (reduced section, section area absence)	3	4	5	0	0	0	0
		pitted corrosion	5	5	5	0	0	0	0
		probability of failure	5	5	5	5	3	3	3
		settlement	3	4	3	0	0	0	0
		water penetrability	3	5	5	0	0	0	0
			Abutments	Piers	Superstructure	Safety railings	Sidewalks	Pavement	Drainage system
2	Availability	approach slab settlement	3	0	0	0	0	3	0
		asphalt pavement cracking	0	0	0	0	0	5	0
		asphalt pavement wearing and tearing (rutting, ravelling)	0	0	0	0	0	5	0
		asphalt pavement wheel tracking and wrinkling and undulation	0	0	0	0	0	5	0
		bearings deformation	3	3	3	0	0	0	0
		bearings displacement	3	3	3	0	0	0	0
		carbonation depth	5	5	5	0	0	0	0
		chloride content	5	5	5	0	0	0	0
		concrete cover (insufficient)	5	5	5	0	0	0	0
		condition rating	5	5	5	5	5	5	5
		corrosion	0	0	0	5	0	0	4
		corrosion related to prestressing steel	0	0	5	0	0	0	0
		corrosion related to protective coating (corrosion stains)	5	5	5	0	0	0	0
		corrosion related to reinforcement steel	5	5	5	0	0	0	0
		crack length (due to shrinkage)	3	3	3	0	0	0	0
		crack width (due to shrinkage)	4	4	4	0	0	0	0
		crack width (longitudinal, due to retraction o concrete and reinforcement corrosion)	5	5	5	0	0	0	0
		grouting deficiency	0	0	0	0	0	0	0
		joint deterioration	4	4	4	0	0	0	0
		loss of section (reduced section, section area absence)	4	4	4	0	0	0	0
		priority repair ranking	4	4	4	0	0	0	0
		waterproofing deterioration/loss	3	3	5	0	0	0	0

0	Not related to the component
1	Not important
2	Slightly important
3	Moderately important
4	Important
5	Very important

3	**Maintainability**	accessibility	2	5	5	0	0	0	5
		inadequate clearance	0	0	0	0	0	0	0
		priority repair ranking	3	5	5	2	1	3	3
			Abutments	**Piers**	**Superstructure**	**Safety railings**	**Sidewalks**	**Pavement**	**Drainage system**
4	Safety	approach slab settlement	2	0	0	0	0	2	0
		asphalt pavement cracking	0	0	2	0	0	5	0
		asphalt pavement wearing and tearing (rutting, ravelling)	0	0	0	0	0	4	0
		asphalt pavement wheel tracking and wrinkling and undulation	0	0	0	0	0	4	0
		bearings deformation	1	1	3	0	0	0	0
		bearings displacement	1	1	3	0	0	0	0
		carrying capacity factor	1	2	5	0	0	0	0
		concrete cover (insufficient)	4	4	4	0	0	0	0
		condition rating	4	4	4	4	4	4	4
		corrosion	0	0	0	5	0	0	3
		corrosion related to prestressing steel	0	0	5	0	0	0	0
		corrosion related to protective coating (corrosion stains)	3	3	3	3	0	0	0
		corrosion related to reinforcement steel	4	5	5	0	2	0	0
		crack width (due to shrinkage)	3	3	3	0	2	0	0
		crack width (longitudinal, due to retraction o concrete and reinforcement corrosion)	4	5	5	0	3	0	0
		cracks related to origin (e.g. due to loading, due to settlement, due to crumbling of concrete, shrinkage)	5	5	5	0	3	0	0
		damping	2	3	4	0	0	0	0
		ductility	3	5	5	4	0	0	0
		frequency	4	4	4	0	0	0	0
		grouting deficiency	0	0	4	0	0	0	0
		joint deterioration	2	2	2	0	0	0	0
		loss of section (reduced section, section area absence)	4	4	4	4	3	0	3
		misalignment	4	4	4	4	4	0	0
		pitted corrosion	5	5	5	5	0	0	0
		sag / deformation / denivelation	5	5	5	5	0	0	0
		settlement	3	4	3	2	0	0	0
		water penetrability	4	4	4	0	0	0	0
			Abutments	**Piers**	**Superstructure**	**Safety railings**	**Sidewalks**	**Pavement**	**Drainage system**
5	**Security**	approach slab settlement	1	0	0	0	0	2	0
		insufficient height of railing (safety barrier)	0	0	0	5	0	0	0
		misalignment	2	4	3	4	0	0	0
		sag / deformation / denivelation	2	4	3	4	0	0	4
			Abutments	**Piers**	**Superstructure**	**Safety railings**	**Sidewalks**	**Pavement**	**Drainage system**
6	**Environment**	carbonation depth	3	3	3	0	0	0	0
		chloride content	5	5	5	5	0	0	0
		concrete cover (insufficient)	5	5	5	0	4	0	0
			Abutments	**Piers**	**Superstructure**	**Safety railings**	**Sidewalks**	**Pavement**	**Drainage system**
7	Costs	approach slab settlement	2	1	2	1	0	2	0
		asphalt pavement cracking	0	0	0	0	0	5	0
		asphalt pavement wearing and tearing (rutting, ravelling)	0	0	0	0	0	4	0
		asphalt pavement wheel tracking and wrinkling and undulation	0	0	0	0	0	4	0
		bearings deformation	2	2	2	0	0	0	0
		bearings displacement	2	2	2	0	0	0	0
		carbonation depth	3	3	3	0	0	0	0
		chloride content	5	5	5	0	0	0	0
		concrete cover (insufficient)	5	5	5	0	0	0	0
		condition rating	4	4	4	4	4	4	4
		corrosion	0	0	0	4	0	0	3
		corrosion related to prestressing steel	0	0	5	0	0	0	0
		corrosion related to protective coating (corrosion stains)	0	0	5	0	0	0	0
		corrosion related to reinforcement steel	4	4	3	0	0	0	0
		crack length (due to shrinkage)	2	2	2	0	0	0	0
		crack width (due to shrinkage)	2	2	2	0	0	0	0
		crack width (longitudinal, due to retraction o concrete and reinforcement corrosion)	4	4	4	0	0	0	0
		grouting deficiency	0	0	4	0	4	0	0
		insufficient height of railing (safety barrier)	0	0	0	0	0	4	0
		joint deterioration	2	2	2	0	0	0	0
		loss of section (reduced section, section area absence)	5	5	5	0	0	0	0
		priority repair ranking	5	5	5	0	0	0	0
		remaining service life	4	4	4	0	3	3	3

No.	Category	Item	Abutments	Piers	Superstructure	Safety railings	Sidewalks	Pavement	Drainage system
		sum of costs for repair of individual damages	5	5	5	5	5	5	5
		waterproofing deterioration/loss	5	5	3	0	0	0	0
			Abutments	Piers	Superstructure	Safety railings	Sidewalks	Pavement	Drainage system
8	Health	corrosion related to reinforcement steel	5	5	5	0	3	0	0
		corrosion	0	0	0	5	0	0	4
		corrosion related to prestressing steel	0	0	5	0	0	0	0
9	Politics		3	3	3	2	0	2	2
			Abutments	Piers	Superstructure	Safety railings	Sidewalks	Pavement	Drainage system
10	Rating/inspection	approach slab settlement	1	0	0	0	0	2	0
		asphalt pavement cracking	0	0	2	0	0	5	0
		asphalt pavement wearing and tearing (rutting, ravelling)	0	0	0	0	0	5	0
		asphalt pavement wheel tracking and wrinkling and undulation	0	0	0	0	0	5	0
		bearings deformation	1	1	2	0	0	0	0
		bearings displacement	1	1	2	0	0	0	0
		carbonation depth	5	5	5	0	3	0	0
		chloride content	5	5	5	0	3	0	0
		concrete cover (insufficient)	5	5	5	0	3	0	0
		condition rating	5	5	5	5	5	5	5
		corrosion	0	0	0	5	0	0	0
		corrosion related to prestressing steel	0	0	5	0	0	0	0
		corrosion related to protective coating (corrosion stains)	4	4	4	4	4	0	0
		corrosion related to reinforcement steel	5	5	5	0	4	0	0
		crack length (due to shrinkage)	3	3	3	0	3	0	0
		crack orientation (due to shrinkage)	3	3	3	0	3	0	0
		crack spacing (due to shrinkage)	3	3	3	0	3	0	0
		crack width (due to shrinkage)	3	3	3	0	3	0	0
		crack width (longitudinal, due to retraction o concrete and reinforcement corrosion)	4	4	4	0	4	0	0
		cracks related to origin (e.g. due to loading, due to settlement, due to crumbling of concrete, shrinkage)	5	5	5	0	4	0	0
		deterioration of protective coatings (e.g. corrosion protection, impregnate...)	4	4	4	4	4	0	4
		grouting deficiency	0	0	5	0	0	0	0
		insufficient height of railing (safety barrier)	0	0	0	5	0	0	0
		joint deterioration	2	2	1	0	0	0	0
		loss of section (reduced section, section area absence)	5	5	5	0	4	0	0
		misalignment	4	4	4	0	0	0	0
		pitted corrosion	5	5	5	0	3	0	0
		sag / deformation / denivelation	4	4	5	0	0	0	0
		settlement	4	5	3	0	0	0	0
		water penetrability	4	4	3	0	0	0	0
		waterproofing deterioration/loss	4	4	3	0	0	0	0
			Abutments	Piers	Superstructure	Safety railings	Sidewalks	Pavement	Drainage system
11	Durability	carbonation depth	4	4	4	0	0	0	0
		chloride content	5	5	5	0	0	0	0
		concrete cover (insufficient)	5	5	5	0	3	0	0
		corrosion	0	0	0	5	0	0	5
		corrosion related to prestressing steel	0	0	5	0	0	0	0
		corrosion related to protective coating (corrosion stains)	4	4	0	0	4	0	0
		corrosion related to reinforcement steel	5	5	5	0	5	0	0
		crack width (due to shrinkage)	2	2	3	0	2	0	0
		crack width (longitudinal, due to retraction o concrete and reinforcement corrosion)	4	4	4	0	3	0	0
		grouting deficiency	0	0	5	0	0	0	0
		pitted corrosion	5	5	5	0	5	0	0
		remaining service life	5	5	5	5	5	5	5
		water penetrability	5	5	5	0	0	0	0

The weighting factors for PIs contributing to the rating of each KPI are calculated using the AHP method for all bridge components

KPI (BENCHMARK)	KPI NOTIFICATION	PI	PI WEIGHTS	KPI WEIGHTS
Reliability	R	bearings deformation	0.036363636	0.085479
		bearings displacement	0.036363636	
		concrete cover (insufficient)	0.072727273	
		corrosion related to reinforcement steel	0.090909091	
		crack spacing (mesh cracking)	0.036363636	
		crack width (mesh cracking)	0.036363636	
		crack width (longitudinal, due to retraction of con	0.072727273	
		cracks related to origin (e.g. due to loading, due t	0.090909091	
		damping	0.054545455	
		ductility	0.054545455	
		frequency	0.036363636	
		joint deterioration	0.036363636	
		loss of section (reduced section, section area	0.054545455	
		pitted corrosion	0.090909091	
		probability of failure	0.090909091	
		settlement	0.054545455	
		water penetrability	0.054545455	
Availability	A	approach slab settlement	0.045454545	0.090528
		bearings deformation	0.045454545	
		bearings displacement	0.045454545	
		carbonation depth	0.075757576	
		chloride content	0.075757576	
		concrete cover (insufficient)	0.075757576	
		condition rating	0.075757576	
		corrosion related to protective coating	0.075757576	
		corrosion related to reinforcement steel	0.075757576	
		crack spacing (mesh cracking)	0.045454545	
		crack width (mesh cracking)	0.060606061	
		crack width (longitudinal, due to retraction of con	0.075757576	
		joint deterioration	0.060606061	
		loss of section (reduced section, section area	0.060606061	
		priority repair ranking	0.060606061	
		waterproofing deterioration/loss	0.045454545	
Maiontainability	M	accessibility	0.4	0.068111
		priority repair ranking	0.6	
Safety	S	approach slab settlement	0.029411765	0.092253
		bearings deformation	[illegible]	
		bearings displacement	[illegible]	
		carrying capacity factor	[illegible]	
		concrete cover (insufficient)	[illegible]	
		condition rating	[illegible]	
		corrosion related to protective co[illegible]	[illegible]	
		corrosion related to reinforcemen[illegible]	[illegible]	
		crack width (due to shrinkage)	[illegible]	
		crack width (longitudinal, due to retraction o conc	0.058823529	
		cracks related to origin (e.g. due to loading, due t	0.073529412	
		damping	0.029411765	
		ductility	0.044117647	
		frequency	0.058823529	
		joint deterioration	0.029411765	
		loss of section (reduced section, section area abse	0.058823529	
		misalignment	0.058823529	
		pitted corrosion	0.073529412	
		sag / deformation / denivelation	0.073529412	
		settlement	0.044117647	
		water penetrability	0.058823529	
Security	Se	approach slab settlement	0.2	0.062359
		misalignment	0.4	
		sag / deformation / denivelation	0.4	
Environment	E	carbonation depth	0.230769231	0.115826
		chloride content	0.384615385	
		concrete cover (insufficient)	0.384615385	

KPI (BENCHMARK)	KPI NOTIFICATION	PI	PI WEIGHTS	KPI WEIGHTS
Maiontainability	M	accessibility	0.4	0.068111
		priority repair ranking	0.6	
Safety	S	approach slab settlement	0.029411765	0.092253
		bearings deformation	0.014705882	
		bearings displacement	0.014705882	
		carrying capacity factor	0.014705882	
		concrete cover (insufficient)	0.058823529	
		condition rating	0.058823529	
		corrosion related to protective coating (corrosion	0.044117647	
		corrosion related to reinforcement steel	0.058823529	
		crack width (due to shrinkage)	0.044117647	
		crack width (longitudinal, due to retraction o conc	0.058823529	
		cracks related to origin (e.g. due to loading, due t	0.073529412	
		damping	0.029411765	
		ductility	0.044117647	
		frequency	0.058823529	
		joint deterioration	0.029411765	
		loss of section (reduced section, section area abse	0.058823529	
		misalignment	0.058823529	
		pitted corrosion	0.073529412	
		sag / deformation / denivelation	0.073529412	
		settlement	0.044117647	
		water penetrability	0.058823529	
Security	Se	approach slab settlement	0.2	0.062359
		misalignment	0.4	
		sag / deformation / denivelation	0.4	
Environment	E	carbonation depth	0.230769231	0.115826
		chloride content	0.384615385	
		concrete cover (insufficient)	0.384615385	
Costs	C	approach slab settlement	0.032786885	0.093079
		bearings deformation	0.032786885	
		bearings displacement	0.032786885	
		carbonation depth	0.049180328	
		chloride content	0.081967213	
		concrete cover (insufficient)	0.081967213	
		condition rating	0.06557377	
		corrosion related to reinforcement steel	0.06557377	
		crack spacing (mesh cracking)	0.032786885	
		crack width (mesh cracking)	0.032786885	
		[illegible]tudinal, due to retraction of con	0.06557377	
		[illegible]n	0.032786885	
		[illegible]duced section, section area	0.081967213	
		[illegible]king	0.081967213	
		[illegible] life	0.06557377	
		[illegible]epair of individual damages	0.081967213	
		[illegible]terioration/loss	0.081967213	
Health	H	corrosion related to reinforcement steel	1	0.104566
Politics	P	(no PI attributed, KPI treated itself as a PI)	1	0.078894
Rating/inspection	I	approach slab settlement	0.011235955	0.093079
		bearings deformation	0.011235955	
		bearings displacement	0.011235955	
		carbonation depth	0.056179775	
		chloride content	0.056179775	
		concrete cover (insufficient)	0.056179775	
		condition rating	0.056179775	
		corrosion related to protective coating	0.04494382	
		corrosion related to reinforcement steel	0.056179775	
		crack spacing (mesh cracking)	0.033707865	
		crack orientation (mesh cracking)	0.033707865	
		crack spacing (mesh cracking)	0.033707865	
		crack width (mesh cracking)	0.033707865	
		crack width (longitudinal, due to retraction o conc	0.04494382	
		cracks related to origin (e.g. due to loading, due t	0.056179775	

KPI weigths for abutment

KPI : AVAILABILITY

Set the importance of each PI for all elements

S/N	KPI (BENCHMARK)	PI	Abutments	Piers	Superstructure	Safety railings	Sidewalks	Pavement	Drainage system
			COMPONENTS						
2	Availability	approach slab settlement	3	0	0	0	0	3	0
		asphalt pavement cracking	0	0	0	0	0	5	0
		asphalt pavement wearing and tearing (rutting, ravelling)	0	0	0	0	0	5	0
		asphalt pavement wheel tracking and wrinkling and undulation	0	0	0	0	0	5	0
		bearings deformation	3	3	3	0	0	0	0
		bearings displacement	3	3	3	0	0	0	0
		carbonation depth	5	5	5	0	0	0	0
		chloride content	5	5	5	0	0	0	0
		concrete cover (insufficient)	5	5	5	0	0	0	0
		condition rating	5	5	5	5	5	5	5
		corrosion	0	0	0	5	0	0	4
		corrosion related to prestressing steel	0	0	5	0	0	0	0
		corrosion related to protective coating (corrosion stains)	5	5	5	0	0	0	0
		corrosion related to reinforcement steel	5	5	5	0	0	0	0
		crack length (due to shrinkage)	3	3	3	0	0	0	0
		crack width (due to shrinkage)	4	4	4	0	0	0	0
		crack width (longitudinal, due to retraction o concrete and reinforcement corrosion)	5	5	5	0	0	0	0
		grouting deficiency	0	0	0	0	0	0	0
		joint deterioration	4	4	4	0	0	0	0
		loss of section (reduced section, section area absence)	4	4	4	0	0	0	0
		priority repair ranking	4	4	4	0	0	0	0
		waterproofing deterioration/loss	3	3	5	0	0	0	0

With AHP calculate the weighting factor of 4 relative PI for pavement

KPI	WPI
R	1

PI	KPI	PI LIKERT VALUE	MATRIX					W	S					V	λmax	CI	WPI
approach slab settlement	AVAILABILITY	3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.14285714	1	0	0.14285714
asphalt pavement cracking		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	CR	0.23809524
asphalt pavement wearing and tearing (rutting, ra		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	0	0.23809524
asphalt pavement wheel tracking and wrinkling ar		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1		0.23809524
condition rating		3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.14285714	1		0.14285714
								SUM	1	1	1	1	1	1	5		1

S/N	KPI (BENCHMARK)	KPI NOTIFICATION	PI	PI TYPE	PI UNIT	REAL PRACTICE Pjh	STANDARD PRACTICE Pjh*	BEST PRACTICE P*jh	NORMALIZED VALUE	CALIBRATED NORMALIZED VALUE Pnormjh	PI WEIGHTS	AGGREGATED KPI VALUE QKPIh	KPI WEIGHTS
2	Availability	A	approach slab settlement	related to equipment & protectio	T = differential displacement cm)	0	1	0	1	1	0.142857143	0.976190476	0.124688338
			asphalt pavement cracking	related to equipment & protectio	T = crack width (mm)	0	10	5	2	1.2	0.238095238		
			asphalt pavement wearing and tearing	related to equipment & protectio	T = affected area (m^2)	5	10	5	1	1	0.238095238		
			asphalt pavement wheel tracking and	related to equipment & protectio	T = affected area (m^2)	5	10	5	1	1	0.238095238		
			condition rating	rating	T = qualitative scale of values	7	5	9	0.5	0.5	0.142857143		

Calculated values of PI (Triplets of R_Pjh, P_Pjh, BP_Pjh values)

The values of actually measured **R_Pjh,** conventional practice **P_Pjh** , and best practice **BP_Pjh** for each of the *PIs* are obtained.

e.g. Crack width measured: 0,5mm ⇒ **R_Pcrack = 0.5**

Crack width least accepted: 0,2mm for PC ⇒ **P_Pcrack = 0.2**

Crack width best practice (Code) : 0,0mm for PC ⇒ **BP_Pcrack = 0**

Normalized value:(**R_Pcrack - P_Pcrack**) / (**BPcrack - P_Pcrack**) = (0,5 -0,2)/ (0-0,2) = 0,3/-0,2= -1.5

If $P_{normalized} < -0.2 \Rightarrow P = -0{,}2 \Rightarrow P_{\_crack} = -0.2$

KPI (BENCHMARK)	KPI NOTIFICATION	PI	PI TYPE	PI UNIT	REAL PRACTICE Pjh	STANDARD PRACTICE Pjh*	BEST PRACTICE P*jh	NORMALIZED VALUE
Safety	S	asphalt pavement cracking	related to equipment & protection	T = crack width (mm)	0	10	5	2
		bearings deformation	related to bearing capacity, structu	T = number of affected bearings	0	5	0	1
		bearings displacement	related to bearing capacity, structu	T = number of affected bearings	0	5	0	1
		carrying capacity factor	related to original construction and	= loads (KN) (qualitative scale her	1	1.3	1.5	-1.5
		concrete cover (insufficient)	defects, related to original construc	percentage of affected area (m^	20	5	0	-3
		condition rating	rating	T = qualitative scale of values	3	5	9	-0.5
		corrosion related to prestressed steel	related to material properties	=percentage of affected strands	10	1	0	-9
		corrosion related to protective coating	related to material properties	percentage of affected area (m^	5	5	0	0
		corrosion related to reinforcement steel	related to material properties	percentage of affected area (m^	15	1	0	-14
		crack width (due to shrinkage)	defects	T = width (mm)	0.05	0.2	0	0.75
		crack width (longitudinal, due to retraction	defects	T = width (mm)	0.5	0.2	0	-1.5
		cracks related to origin (e.g. due to	defects	T = crach length (cm)	0.3	0.3	0.2	0
		damping	related to dynamic behavior	T = qualitative scale of values	5%	4%	4%	0
		ductility	related to original construction and	length per length unit (qualitativ	5	10	15	-1
		frequency	related to dynamic behavior	frequency (Hz) (qualitative scale h	6	6	9	0
		grouting deficiency	related to bearing capacity, structu	=percentage of affected strands	10	5	0	-1
		joint deterioration	related to bearing capacity, structu	T = qualitative scale of values	8	6	9	0.666666667
		loss of section (reduced section, section	related to bearing capacity, structu	percentage of damaged section (	10	0	0	0
		misalignment	geometry changes	= component misalignment (cm	3	5	3	1
		pitted corrosion	related to material properties	percentage of affected area (m^	15	5	0	-2
		sag / deformation / denivelation	geometry changes	= component misalignment (cm	-10	10	5	4
		settlement	defects	T = differential displacement (cm)	3	5	3	1
		water penetrability	defects	T = penetration depth (mm)	100	10	0	-9

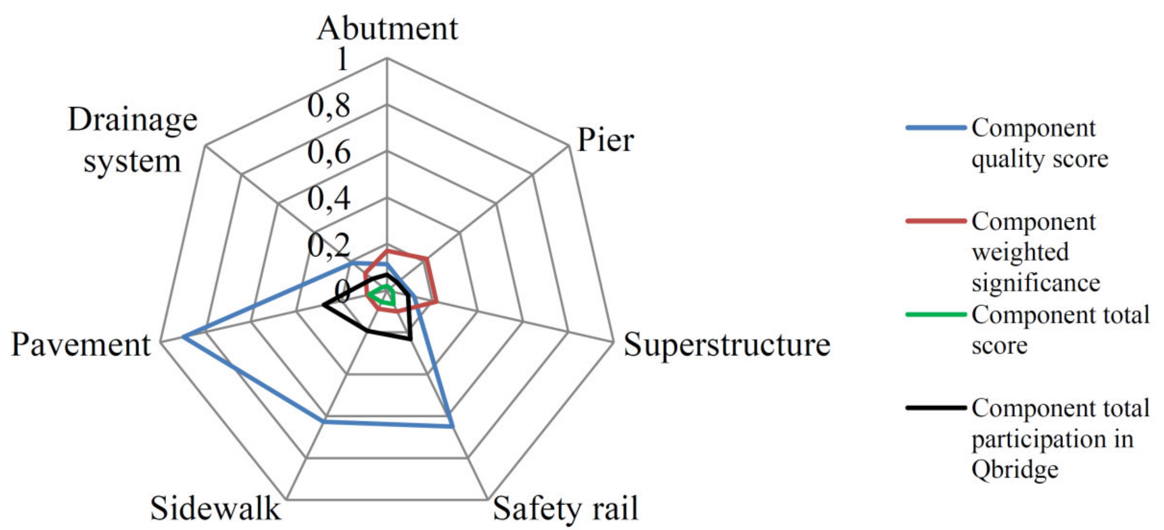
Calculated values of Qcomp values and Final System (bridge) value

ID:	Strimonas Bridge
Type of bridge:	River bridge
Construction year:	1987
Construction cost (€):	Non available
Type of structure:	Continuous span
Number of spans:	8
Total span (m):	240
Width (m):	12
Maximum span (m):	30
Component:	Deck
Inspection date(s):	Ιουλ-17

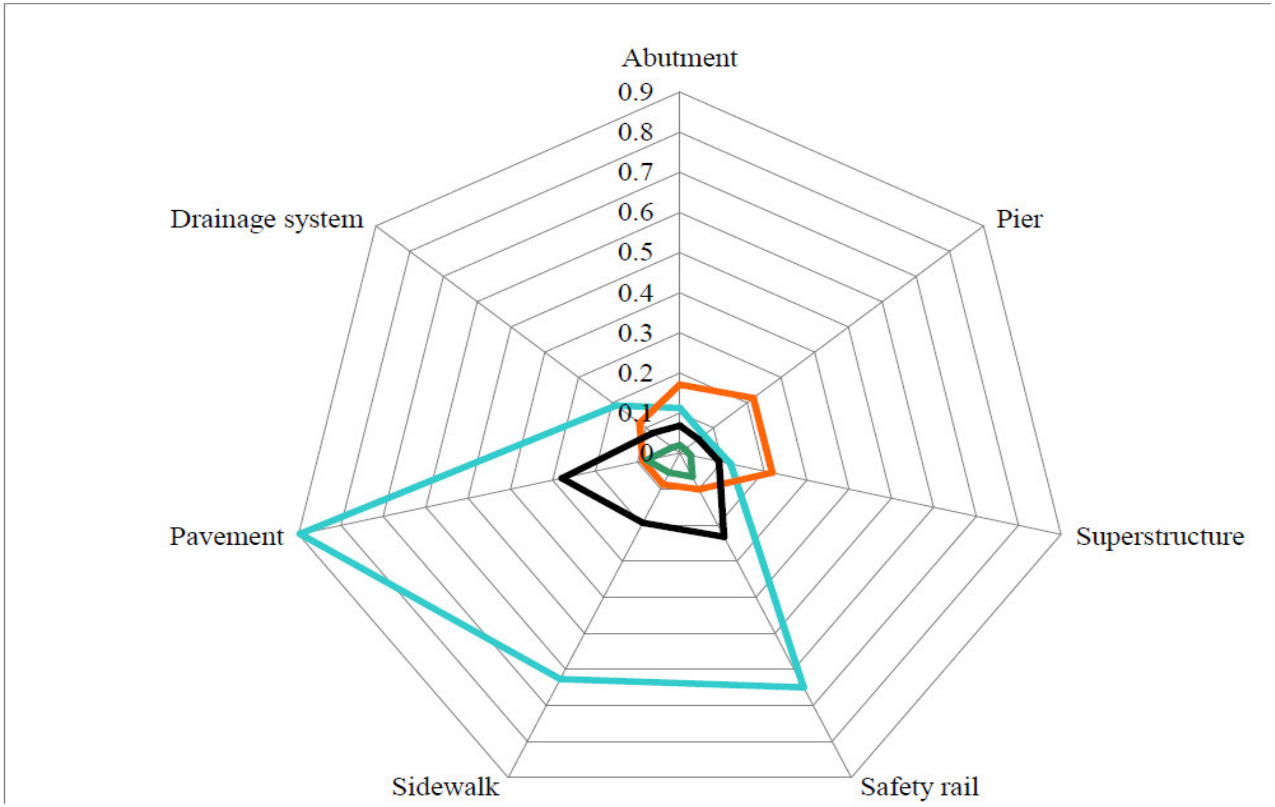
SB QUALITATIVE SCALE	
A+ (Qsystem > 1,00)	
A (0,70 <= Qsystem <= 1,00)	
B (0,40 <= Qsystem < 0,70)	
C (0,10 <= Qsystem < 0,40)	0.239260369
D (0,00 <= Qsystem < 0,10)	
E (Qsystem < 0,00)	

S/N	COMPONENT	Qcomp NOTATION	Qcomp VALUE	WCOMP
1	Abutment	Qabut	0.115802494	0.170580699
2	Pier	Qpier	0.070966281	0.217974296
3	Superstructure	Qsuper	0.120221791	0.217974296
4	Safety rail	Qsrail	0.649707783	0.100606325
5	Sidewalk	Qside	0.627199716	0.086743371
6	Pavement	Qpave	0.896676628	0.087189719
7	Drainage system	Qdrng	-0.169160687	0.118931294
			SUM	1

AGGREGATED DECK QUALITY PERFORMANCE Qdeck
0.239260369



Component	Component quality score	Component weighted significance	Ci*Di Component total score	Ei/ E11 Component total participation in Qbridge
Abutment	0.112185814	0.170580699	0.019136735	0.068055897
Pier	0.070744505	0.217974296	0.015420484	0.054839808
Superstructure	0.120221791	0.217974296	0.02620526	0.093193668
Safety rail	0.649707783	0.100606325	0.065364712	0.232456279
Sidewalk	0.627199716	0.086743371	0.054405418	0.193481783
Pavement	0.896676628	0.087189719	0.078180983	0.278034734
Drainage system	0.188998470	0.118931294	0.022477833	0.079937831
			0.281191424	1



TU1406
COST ACTION

1st matrix:

We divide the 5 values of importance (5 KPi : (3,5,5,5,3) :

In the first column by 3, in the second column by 5, …………

KPI	WPI
R	1

PI	KPI	PI LIKERT VALUE	MATRIX					W	S					V	λmax	CI	WPI
approach slab settlement	AVAILABILITY	3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.14285714	1	0	0.14285714
asphalt pavement cracking		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	CR	0.23809524
asphalt pavement wearing and tearing (rutting, ra		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	0	0.23809524
asphalt pavement wheel tracking and wrinkling ar		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1		0.23809524
condition rating		3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.14285714	1		0.14285714
								SUM	1	1	1	1	1	1	5		1

3/3 3/5 5/5 3/5 3/3

w,i=Sums (of the 1st col : 1+1.666+1.666+1.6666+1=7

of the 2nd col: 0.6+1+1+1+1+-.6= 4.2

,,,,,,,

of the 5th col: +1.6666+1.6666+1.6666+1.6666+1 = 7

KPI	WPI
R	1

PI	KPI	PI LIKERT VALUE	MATRIX					W	S					V	λmax	CI	WPI
approach slab settlement	AVAILABILITY	3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.14285714	1	0	0.14285714
asphalt pavement cracking		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	CR	0.23809524
asphalt pavement wearing and tearing (rutting, ra		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	0	0.23809524
asphalt pavement wheel tracking and wrinkling ar		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1		0.23809524
condition rating		3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.14285714	1		0.14285714
								SUM	1	1	1	1	1	1	5		1

1/7 0.6/4.2

1.6666/7 1/4.2

2nd matrix:

We divide the 5 values of importance (5 KPi : (3,5,5,5,3) :

In the first column by the first sum (w,1=7), in the second column by the second sum (w,2=4.2) ………….

λmax =products of v,i * w,i

V = sums of the 5 elements of each row / 5 (number of columns)

PI	KPI	PI LIKERT VALUE	MATRIX					W	S					V	λmax	CI	WPI
	KPI	WPI															
	R	1															
approach slab settlement	AVAILABILITY	3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.1[illegible]85714	1	0	0.14285714
asphalt pavement cracking		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	CR	0.23809524
asphalt pavement wearing and tearing (rutting, ra		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1	0	0.23809524
asphalt pavement wheel tracking and wrinkling ar		5	1.666666667	1	1	1	1.666666667	4.2	0.238095238	0.238095238	0.238095238	0.23809524	0.238095238	0.23809524	1		0.23809524
condition rating		3	1	0.6	0.6	0.6	1	7	0.142857143	0.142857143	0.142857143	0.14285714	0.142857143	0.14285714	1		0.14285714
								SUM	1	1	1	1	1	1	5		1

CI = (Σι (λmax,i)/(5-1) = (5-5)(5-1) = 0

If CI and CR =0 then wPI,i = v,i

COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control
25th – 29th September, 2017
Faculty of Civil Engineering CTU in Prague
Prague, Czech Republic

DIAGNOSTICS OF STEEL BRIDGES

Pavel Ryjáček – Faculty of Civil Engineering CTU in Prague, Czech republic

ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Steel bridge diagnostics procedure

- Desk study
- Site inspection
- Material testing

Desk study

- Gathering of existing information on the bridge
- Drawings of construction
- Previous design records, calculations
- Maintenance records including records of previous alterations to the structure
- Previous condition examination reports;
- Details of the materials used in the structure.

Site inspection

- Should be carried out to verify:
  - Structural form
  - Loading and construction details
  - Dimensions
  - Condition of the structural parts (corrosion, cracks..)
- Verification, that existing calculations are a true representation of the structure or identify updates
- Get information for a new assessment.

Inspection for Loading

- The Site Inspection should determine and record the material types and dimensions for calculating:
  - the self-weight of the structure;
  - the weight of imposed loads such as ballast and track, asphalt
  - the position of the road and track on the structure, including the possible additional asphalt layers

Inspection for Loading

- The Site Inspection should determine and record the material types and dimensions for calculating:
  - the self-weight of the structure;
  - the weight of imposed loads such as ballast and track, asphalt
  - the position of the road and track on the structure, including the possible additional asphalt layers
- For unballasted tracks the details of:
  - supports to the rail
  - restraint against lateral loads
  - guard rail system

Inspection for structural form, details, dimensions

- Drawings of the bridge should be checked to establish that they are in accordance with reality, any discrepancies corrected for:
  - Structural form
  - Structural details.
  - Location and dimensions of member splices, joints, flange curtailments, changes in plate thicknesses;
  - Section sizes for rolled sections;
  - Dimensions including plate dimensions and thicknesses;
  - Details and dimensions of repair work, strengthening and partial renewal
  - Bridge parameters (for example length, span and spacing of members)
  - Material types
- Arrangements for ensuring the safety of people (handrailing, walkways, decking)

Inspection for condition and structural behaviour

- The behaviour of the bridge should be observed under rail/road loading to check for anomalies.
- The bridge should be checked to record the current condition including:
  - location, extent and depth of corrosion –areas susceptible to corrosion (metal in contact with timber; interface with concrete or brickwork; water traps; dripping water; buried parts);

Inspection for condition and structural behaviour

Inspection for condition and structural behaviour

- The bridge should be checked to record the current condition including:
  - Loosening of joints (e.g. rivets, bolts), fretting between fasteners and plates, black corrosion wear between parts, slippage between plates and movement between components of connections, loss of rivet heads; and bolt failures;

Inspection for condition and structural behaviour

- The bridge should be checked to record the current condition including:
  - Location and extent of defects - fatigue susceptible details:

Inspection for condition and structural behaviour

- The bridge should be checked to record the current condition including:
  - Water leakage and staining.

Inspection for condition and structural behaviour

- The deck should be checked to the cracks, mainly in the connections between members.
- Buckling, out of plane distortion of members subject to compression

Inspection for condition and structural behaviour

- Presence of misaligned parts – possible cracks
- Location and extent of deteriorating materials e.g. delamination in wrought iron
- Location and extent of other damages caused by vehicle impact and deformation;

Inspection for condition and structural behaviour

- Presence of unusual permanent deformation of members
- Measurement of movement of bearings, joints and other expansion devices
- Deterioration affecting the supports and bearings;

Material testing

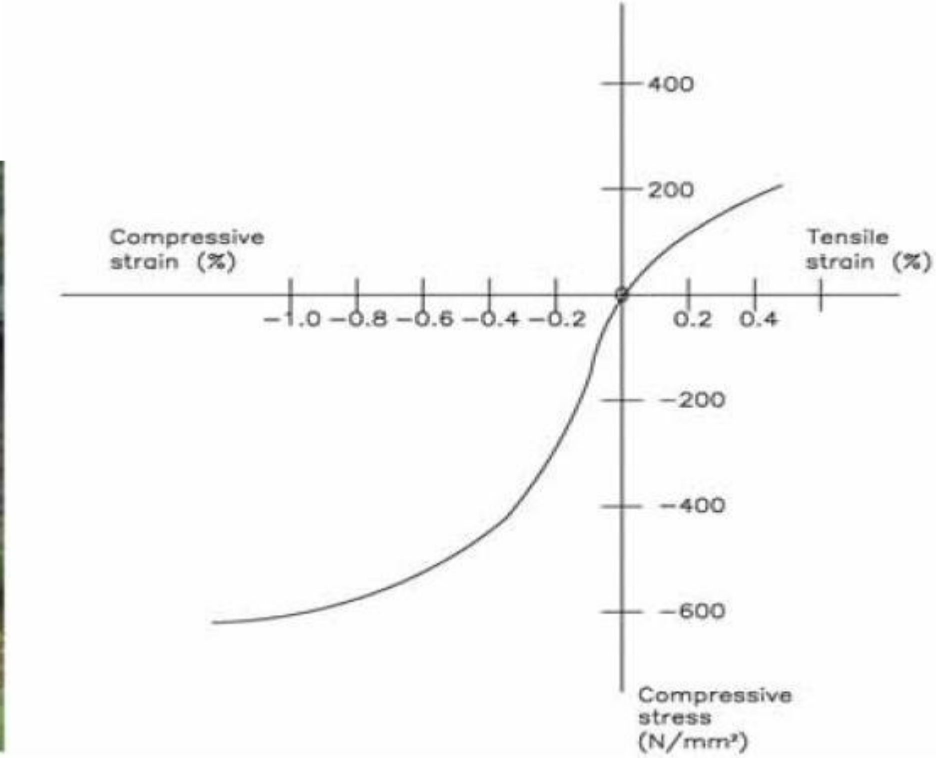
- Especially, when the type of metallic material is not known.
- Cast iron, wrought iron, mild steel and modern steel to be considered
- Yield strength, tensile strength, impact strength, modulus of elasticity, shear modulus, chemical analysis

Location of samples - consider:

- The risk of different parts of the structure being made with different grades or sources of material (plate, profiles)
- The effect on the structure due to removal of material.
- Location over the structure

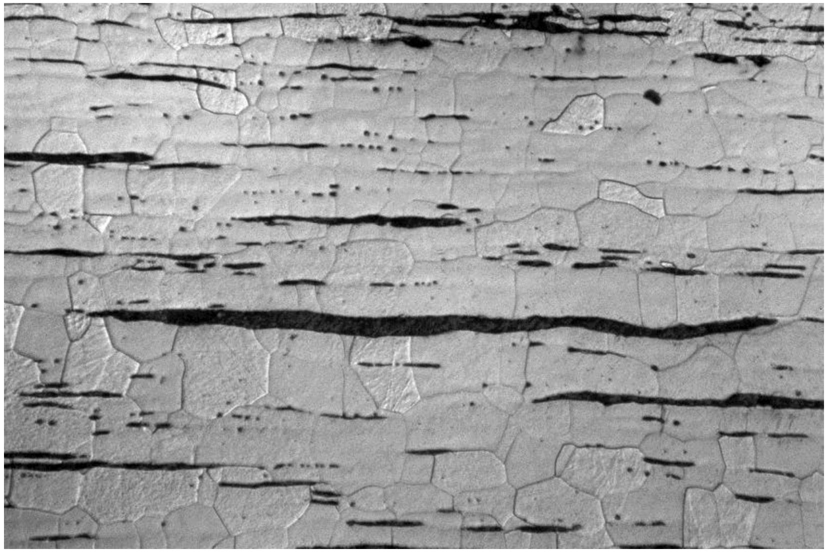
Cast Iron

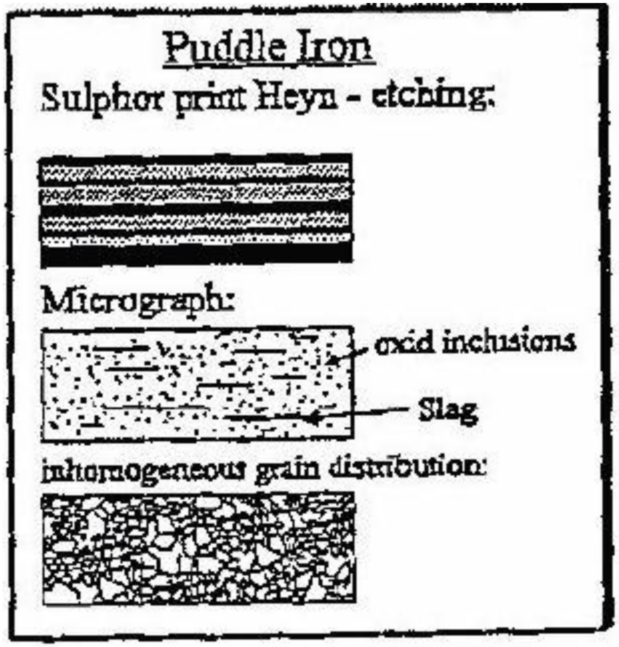
- High strength in compression, very brittle
- Very good resistance against corrosion
- The design strength according to CSN code:
  - Compression – 65-100 Mpa
  - Tension – 30-45 MPa



Wrought Iron

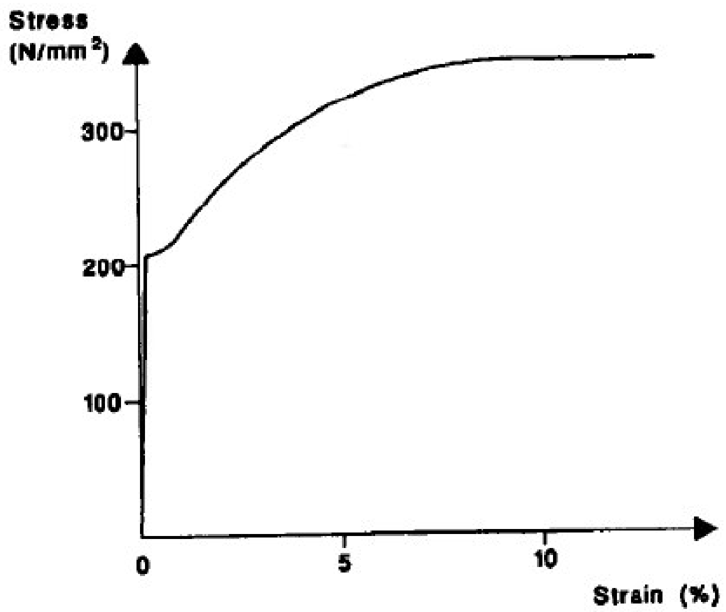
- Manufacturing by puddling at 1300°C
- fy=220 MPa, fu = 320 MPa, elongation 15%, E=190 GPa
- Includes slags and intrusions
- Dificult to weld – because of a small elongation, slags etc.
- Includes about 0,05% of C





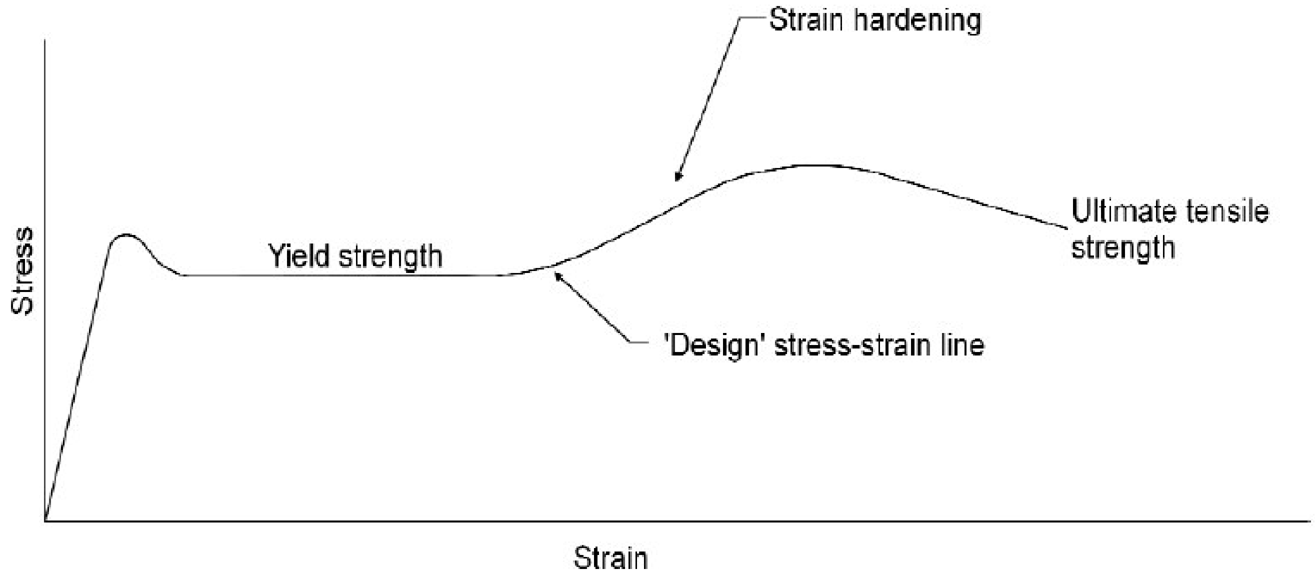
Mild steel

- Manufacturing at 1600-1800°C
- fy=220-235 MPa, fu= 320-335 MPa, elongation 15%, E=200 GPa
- In Czech republic, we consider this steel after 1895 to be possible, after 1905 to be almost sure
- It can be usually welded
- Includes about 0,05% of C



Modern steel

- Variable properties, according to the date of manufacturing
- Many different grades in all countries



Steel testing

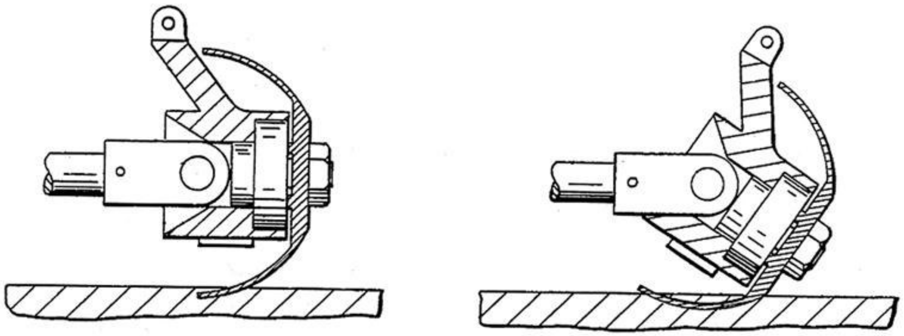
- Nondestructive testing
  - Hardness measurement
  - Small samples method
- Destructive methods – taking samples and standard tests
  - Chemical composition
  - Tensile coupon test (Yield strength, tensile strength, impact strength, modulus of elasticity, shear modulus)
  - Charpy impact test
  - Microstructure

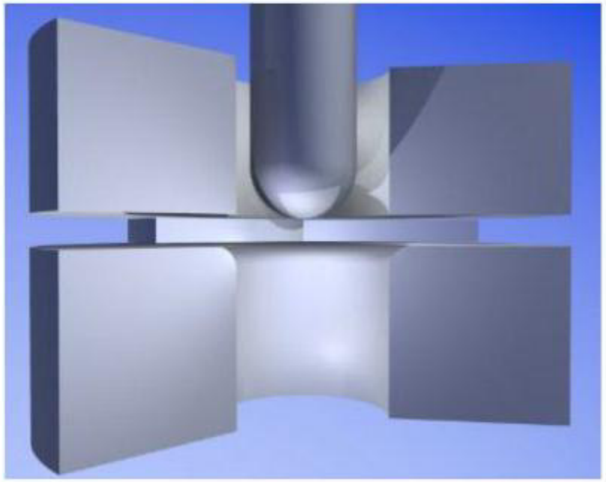
Steel testing - hardness measurement

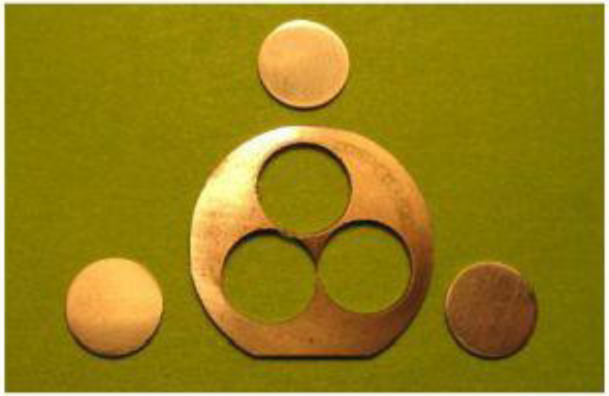
- **Hardness** can be by application of correlation formulas transferred to the **strength** of the material.
- **Traditional methods** - very hard indenters of defined geometries are continuously pressed into the material under a particular force. Deformation parameters, such as the indentation depth in the Rockwell method, are recorded to get hardness.
- **Dynamic Leeb** principle - hardness value is derived from the energy loss of a defined impact body after impacting on a metal sample. The loss is identified based on the velocity, measured by magnetic method. Portable devices are available on the market.

Steel testing - small samples method

- Penetration principle
- Minimal damage to the structure
- Very expensive







Steel testing - chemical composition

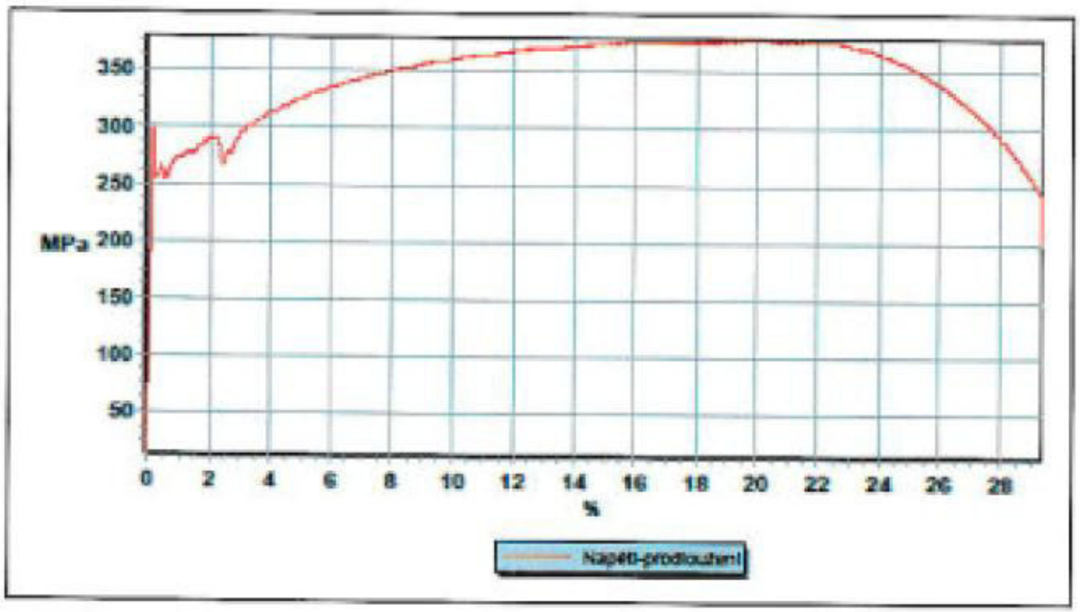
- Chemical composition
- Example from the bridge from 1892:

Číslo objednávky	Číslo vzorku	Značka oceli	Tavba	Výrobek
NO01160116	Z2	- - - -	- - - -	- - - -

Prvek	[%]	Prvek	[%]
C	0,097	Cu	0,03
Si	0,00	Nb	<0,002
Mn	0,19	Ti	0,003
P	0,030	V	0,001
S	0,027	W	<0,005
Cr	0,01	Pb	0,000
Mo	<0,01	Sn	<0,001
Ni	0,02	As	0,032
Al	0,001	Sb	0,001
Co	0,011	B	0,0006

Steel testing - tensile coupon test

- Tensile coupon test (Yield strength, tensile strength, impact strength, modulus of elasticity, shear modulus)
- Example from the bridge from 1892:



Výsledky VPÚ 65 es A:

	ReH [kN/m]	Rp0.2 [MPa]	Rm [MPa]	A* [%]	Z* [%]	E [GPa]
DP1	297	258	378	32.3	73,0	201,964

Steel testing - tensile coupon test

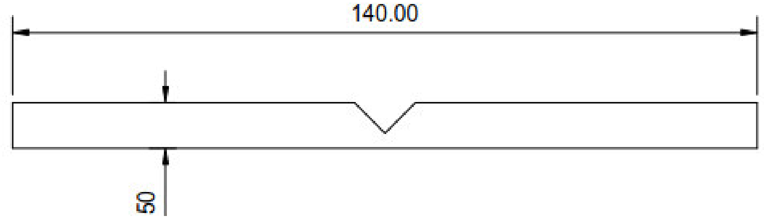
- Tensile coupon test (Yield strength, tensile strength, impact strength, modulus of elasticity, shear modulus)
- Example from the bridge from 1894:

- Sample withouth yield strenght – brittle fracture
- fu = 290 MPa

- Sample with the yield strength
- fy = 280 Mpa, fu = 390 Mpa

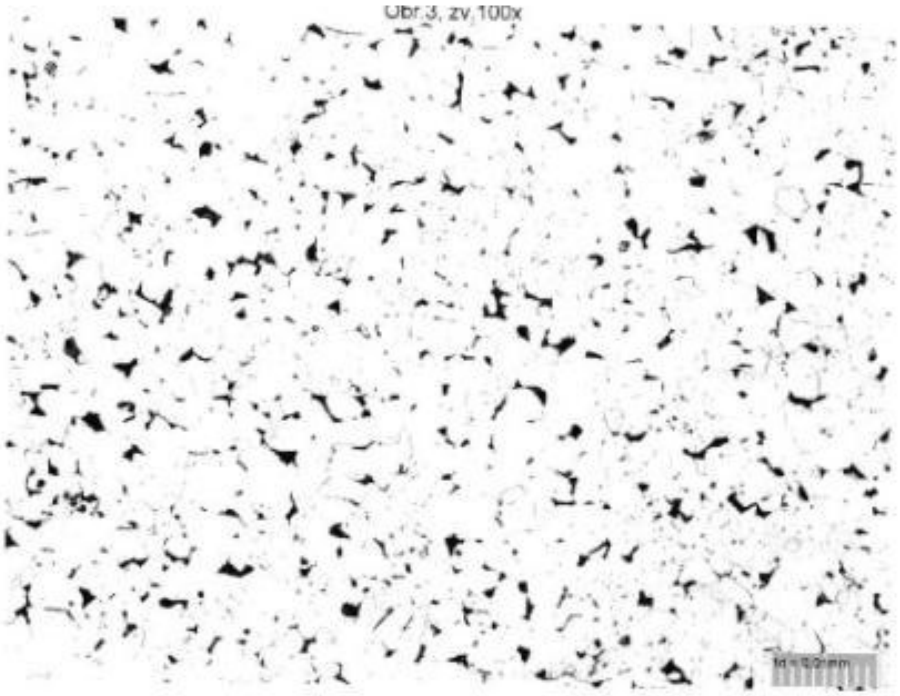
Steel testing - tensile coupon test

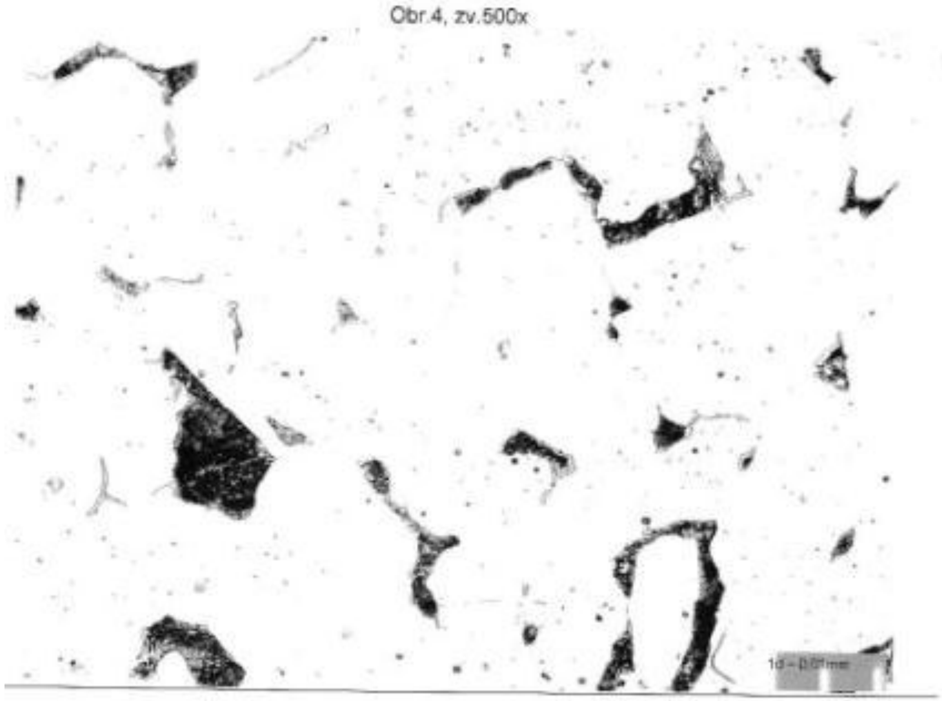
- Weldability test – welding and bending of the sample, if the crack occurs, the test does not satisfy
- Example from the bridge from 1894:



Steel testing - chemical composition

- Microstructure
- Example from the bridge from 1892 – mild steel





COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control
25th – 29th September, 2017
Faculty of Civil Engineering CTU in Prague
Prague, Czech Republic

Diagnostics and NDT techniques for masonry bridges and structures

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Doc. Ing. Jiří Dohnálek, CSc. – BETONCONSULT s.r.o., Czech Republic

ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

OUTLINE

- Available diagnostic techniques for masonry bridges
  - Visual survey of the structure
  - NDT techniques
  - Semidestructive diagnostic techniques

- Typical types of problems in masonry bridges
  - Quick overview
  - Details of each type of problem

AVAILABLE DIAGNOSTIC TECHNIQUES FOR MASONRY BRIDGES

- Visual survey of the structure
  - Bonding pattern of the masonry,
  - Width of joints,
  - Presence of cracks,
  - Orientation of cracks,
  - Width of cracks,
  - Spatial distortion of structural elements,
  - Leaning of structural elements,
  - Partial settlement,
  - Subsiding of supports,
  - Presence of cavities,
  - Localization of areas with material degradation.

AVAILABLE DIAGNOSTIC TECHNIQUES FOR MASONRY BRIDGES

- NDT techniques for masonry structures
  - Schmidt hammer type LB (bricks),
  - Schmidt hammer type PM (mortar),
  - Waitzmann hammer (bricks).

AVAILABLE DIAGNOSTIC TECHNIQUES FOR MASONRY BRIDGES

- Semidestructive diagnostic techniques for masonry structures
  - Cylindrical indentor method (mortar),
  - Drill resistance method – manual „Kučera“ drill (mortar, bricks),
  - Drill resistance method – electric PZZ 01 drill (mortar, bricks),
  - Cutting out of individual bricks by angle grinder (bricks),
  - Drilling 80 mm or 150 mm core samples, for laboratory strength testing, freeze-thaw testing, moisture content, absorption testing, capillary properties. etc.,
  - Cutting into masonry structure to insert two flat presses,
  - Attaching press to the masonry.

CALCULATION OF CHARACTERISTIC STRENGTH OF THE MASONRY – COMBINATION OF ALL MEASURED PROPERTIES

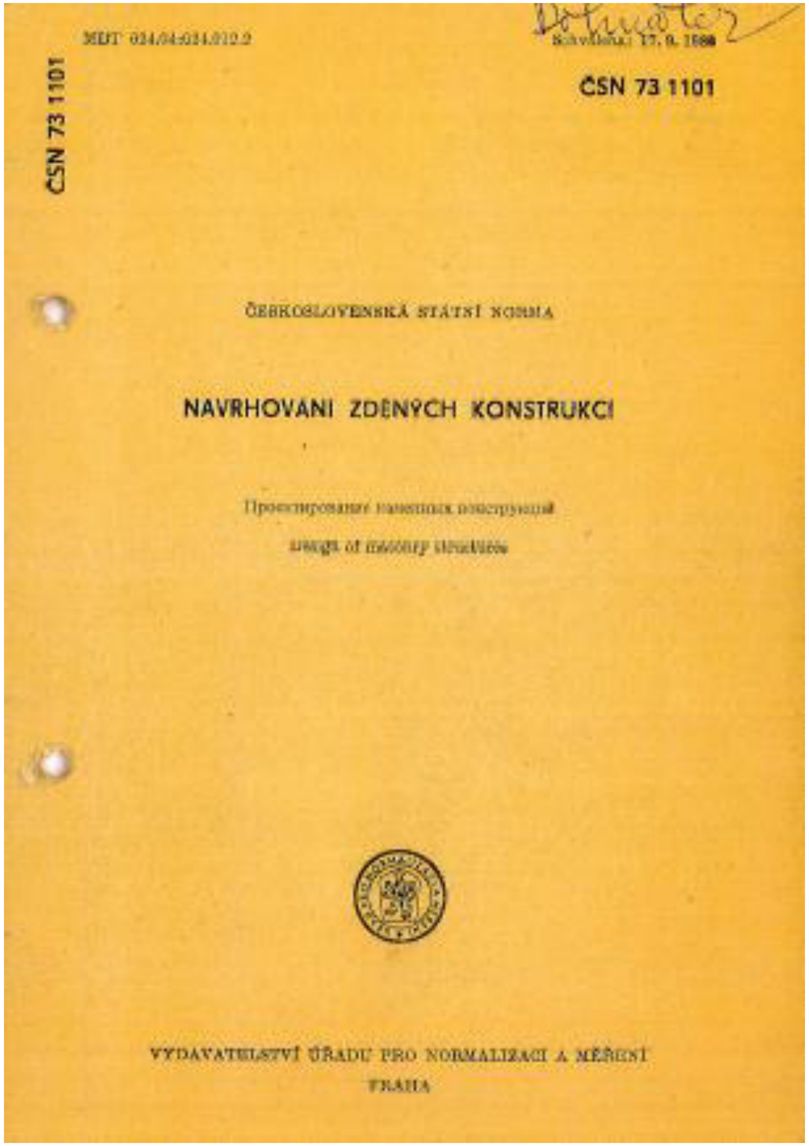
- ČSN ISO 13822 - Bases for design of structures – Assessment of existing structures

$$f_k = K f_b^{\alpha} f_m^{\beta}$$

$$\gamma_m = \gamma_{m1} \times \gamma_{m2} \times \gamma_{m3} \times \gamma_{m4}$$

CALCULATION OF CHARACTERISTIC STRENGTH OF THE MASONRY – COMBINATION OF ALL MEASURED PROPERTIES

- ČSN 73 1101 Design of masonry structures (not valid)



Pokračování tab. 3

	Zdivo	Výška jedné ložné vrstvy h_1 (mm)	Pevnostní značka dílců[1]) (–)	Výpočtové pevnosti zdiva na maltu označenou podle ČSN 72 2430 [2]) 150	100	50	25	10	4	0
				MPa						
betonové	z dílců z lehkého betonu	$1200 < h_1$ $h_1 \leq 2500$	220	5,0				4,5		3,6
			170	4,0				3,6		2,7
			135	3,4				3,0		2,2
			100	2,8				2,5		1,7
			80	2,2				1,8		1,3
			60	1,7				1,3		0,9
		$600 < h_1$ $h_1 \leq 1200$	260	4,8				4,2		3,2
			190	3,7				3,3		2,4
			135	3,1				2,7		2,0
			105	2,5				2,2		1,5
			80	1,9				1,6		1,2
			60	1,5				1,2		0,9
	z dílců z pórobetonu	$h_1 > 2500$	30	0,8				–		0,5
		$1200 \leq h_1$ $h_1 \leq 2500$	30	0,7				–		0,3
		$600 \leq h_1$ $h_1 < 1200$	20	0,5				–		0,2

Pokračování tab. 3

	Zdivo	Výška jedné ložné vrstvy h_1 (mm)	Třída jakosti kamene (–)	Pevnostní značka kamene[1]) (–)	Výpočtové pevnosti zdiva na maltu označenou podle ČSN 72 2430 [2]) 150	100	50	25	10	4	0
					MPa						
kamenné	z čistých kvádrů podle ČSN 73 2310	$h_1 > 400$	I	110	13,8			13,3	12,3	10,9	9,4
			II	80	11,4			10,9	9,9	8,6	7,3
			III	40	6,8			6,2	5,7	5,1	4,4
	řádkové[3]) čisté podle ČSN 73 2310	$h_1 > 150$	I	110	6,3	6,0	6,4	5,1	4,8	4,2	3,9
			II	80	5,1	4,3	4,6	4,2	3,6	3,3	2,9
			III	40	3,2	2,8	2,6	2,4	2,2	2,0	1,7
	řádkové[3]) hrubé podle ČSN 73 2310		I	110	4,7	4,5	4,0	3,8	3,6	3,2	2,9
			II	80	3,8	3,6	3,4	3,2	2,7	2,5	2,3
			III	40	2,3	2,1	1,9	1,8	1,7	1,6	1,3
	lomové a kyklopské podle ČSN 73 2310		I	110	–	2,2	1,6	1,0	0,7	0,5	0,3
			II	80	–	2,0	1,4	0,9	0,6	0,4	0,2
			III	40	–	1,3	1,0	0,7	0,5	0,3	0,1

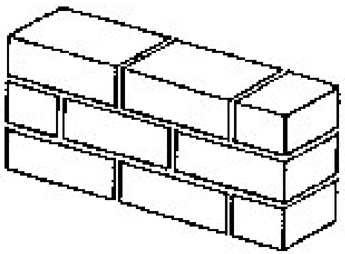
[1]) Viz čl. 11.

[2]) Druhy zdiva příslušející čtverečkům tabulky, ve kterých nejsou uvedeny hodnoty výpočtových pevností zdiva, se neprovádějí.

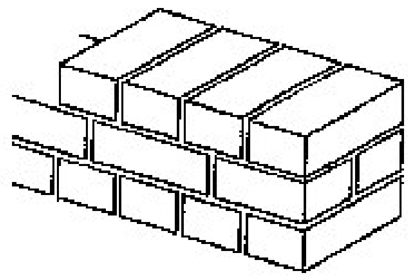
[3]) Též zvlášť provazované řádkové zdivo.

VISUAL INSPECTION OF MASONRY

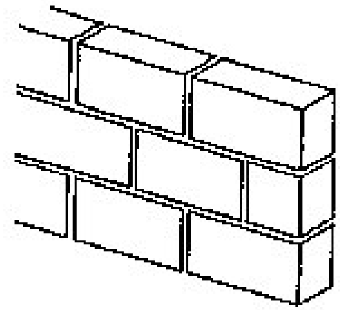
- Bonding patterns of masonry



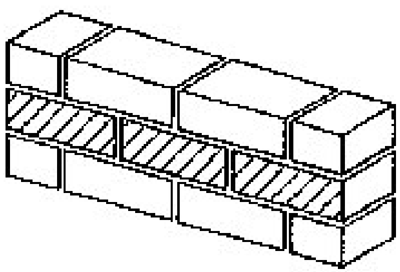
Blocks laid as "stretchers"



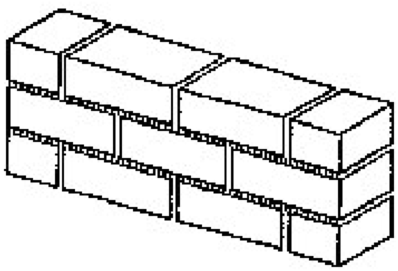
Blocks laid as "headers"



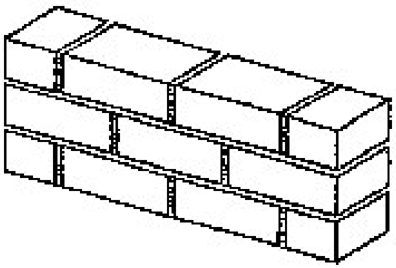
blocks laid as "facers"



A course is a complete horizontal row of bricks



Horizontal joints bond two successive courses of blocks



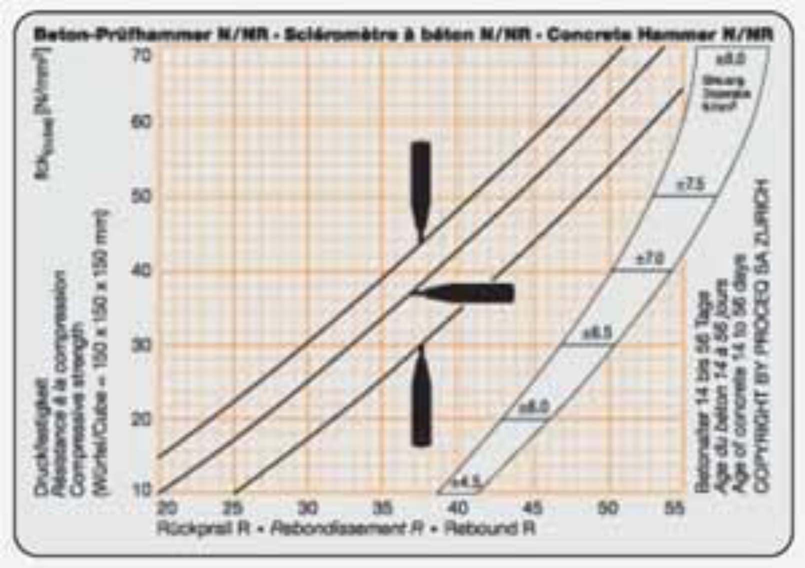
Vertical joints bond the blocks of a single course

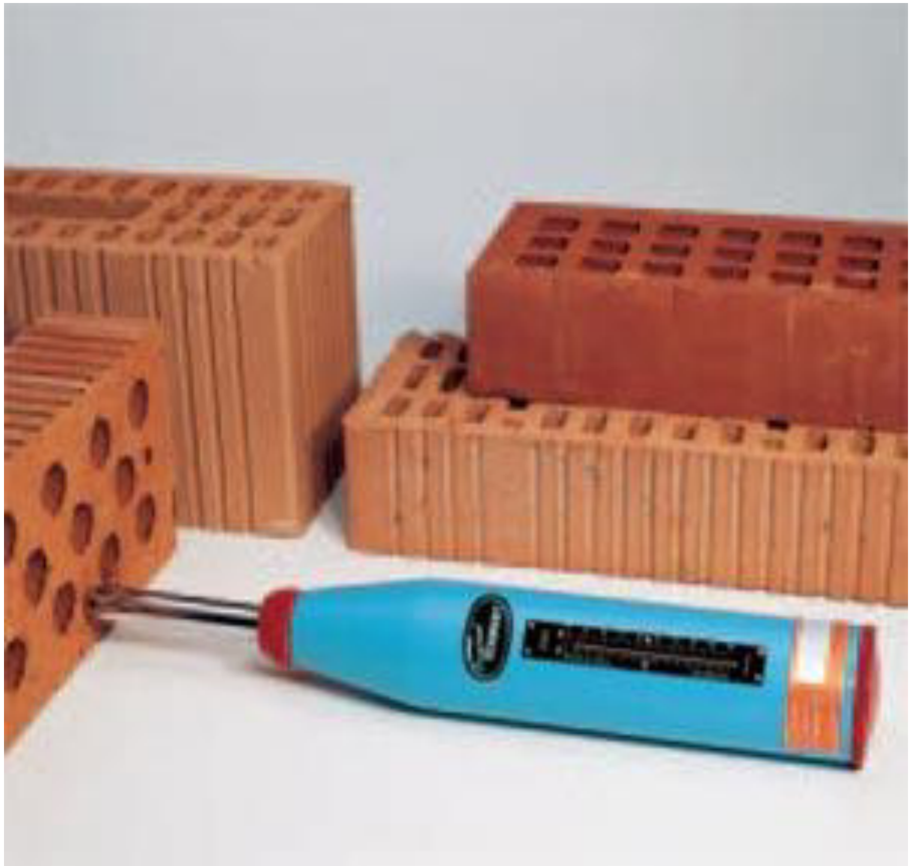
AVAILABLE DIAGNOSTIC TECHNIQUES FOR MASONRY BRIDGES

- NDT techniques for masonry structures
  - Schmidt hammer type LB (bricks),
  - Schmidt hammer type PM (mortar),
  - Waitzmann hammer (bricks).

SCHMIDT HAMMER type LB (bricks)

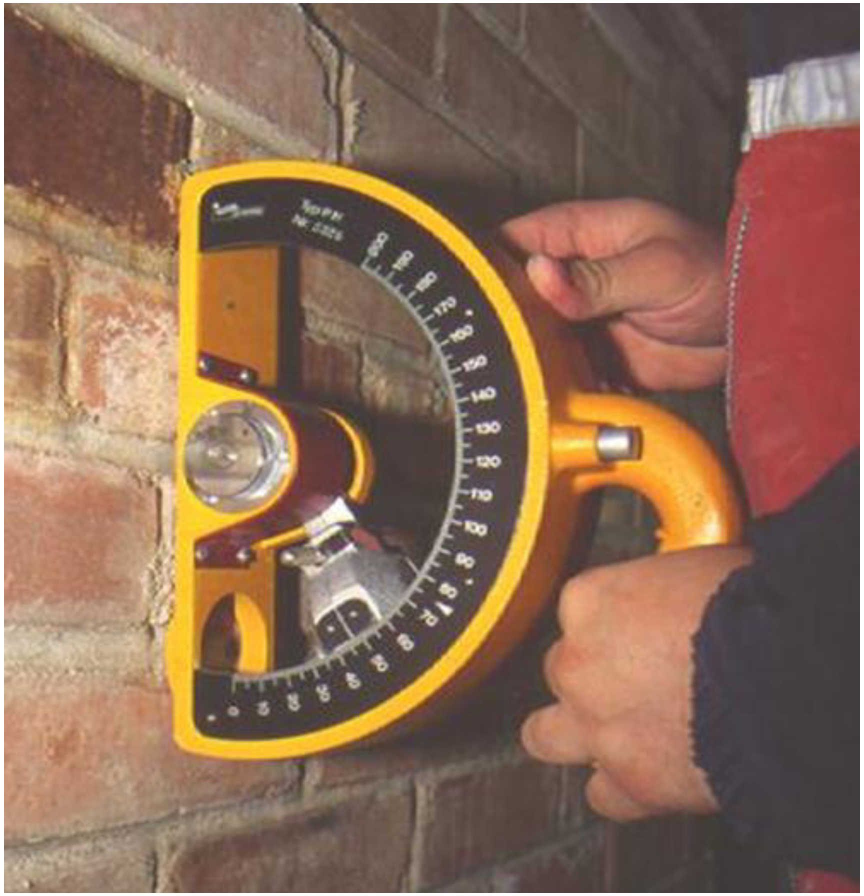
- Type LB for masonry testing has a smaller radius of the testing pin tip and a different calibration





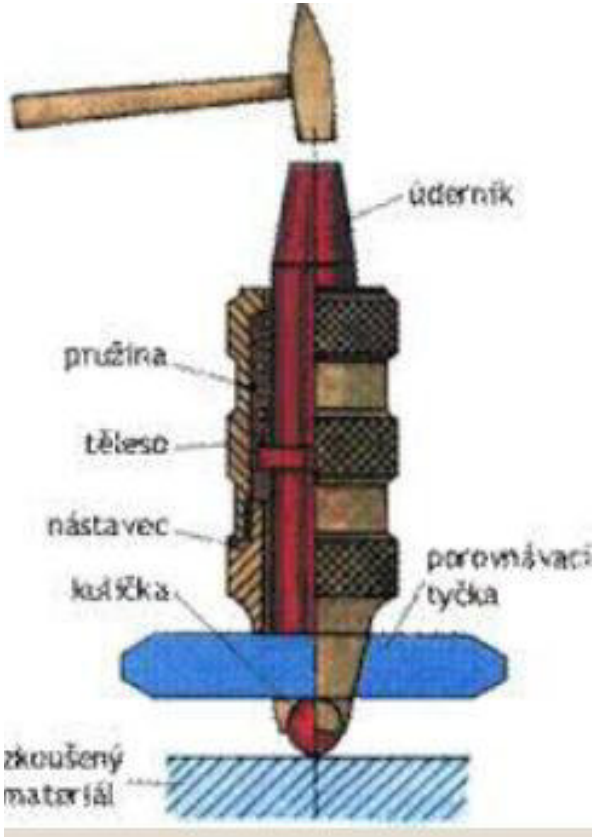
SCHMIDT HAMMER type PM (mortar)

- Type PM has a pendulum striker, working with constant energy of strike,
- Striker with round 8 mm tip rotates on a half-circle track,
- Striker strikes the mortar in the horizontal bed joint of the masonry and rebounds back,
- Based on the value of rebound, the strength of mortar is established from a calibration table.

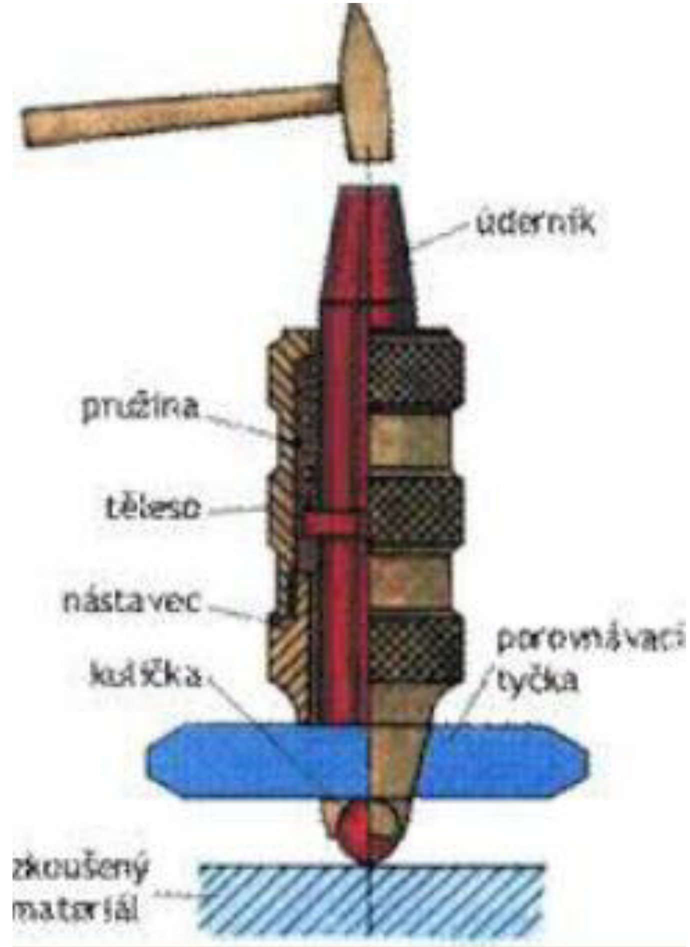


WAITZMANN HAMMER (bricks)

- Waitzmann hammer was created by conversion of Poldi hammer used for steel strength testing (according to Brinell)
- Strength of brick can be established from striking the Waitzmann hammer,
- Striker of Waitzmann hammer conveys the pressure of a steel ball to a comparison stick and also onto the carbon paper on the surface of the brick,
- Based on the diameter of the imprint on the carbon paper and on the comparison stick, we can establish strength of the brick from a calibration table.



WAITZMANN HAMMER (bricks)

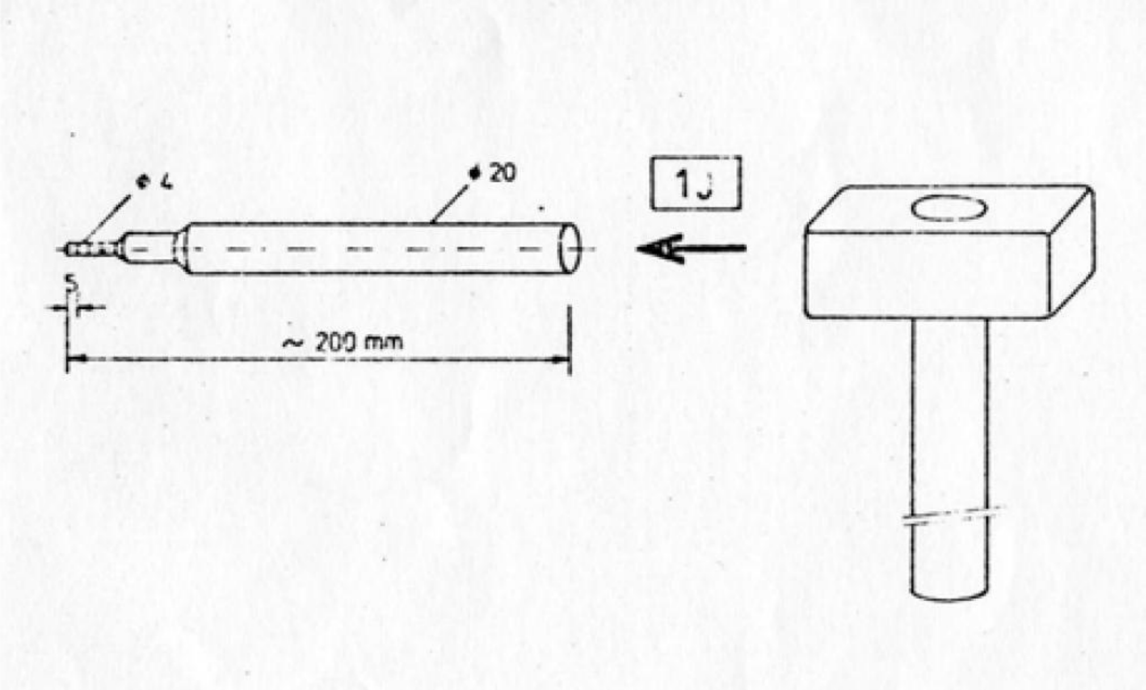


AVAILABLE DIAGNOSTIC TECHNIQUES FOR MASONRY BRIDGES

- Semidestructive diagnostic techniques for masonry structures
  - Cylindrical indentor method (mortar),
  - Drill resistance method – manual „Kučera“ drill (mortar, bricks),
  - Drill resistance method – electric PZZ 01 drill (mortar, bricks),
  - Cutting out of individual bricks by angle grinder (bricks),
  - Drilling 80 mm or 150 mm core samples, for laboratory strength testing, freeze-thaw testing, moisture content, absorption testing, capillary properties. etc.,
  - Cutting into masonry structure to insert two flat presses,
  - Attaching press to the masonry.

CYLINDRICAL INDENTOR METHOD (mortar)

- Indentor of 4 mm tip diameter with 5 mm scale along the length,
- Strikes with 1 kg hammer from 100 mm distance, therefore energy of each strike is 1 J.
- Parameter is the number of strikes to indent the mortar to 5 mm depth,
- Needs a trained and practiced arm to attain repeatability.



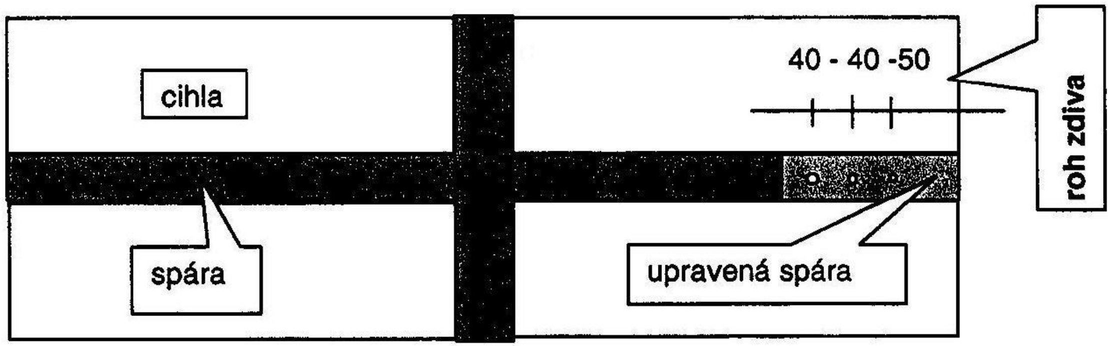
DRILL RESISTANCE METHOD – MANUAL „Kučera“ DRILL (mortar, bricks)

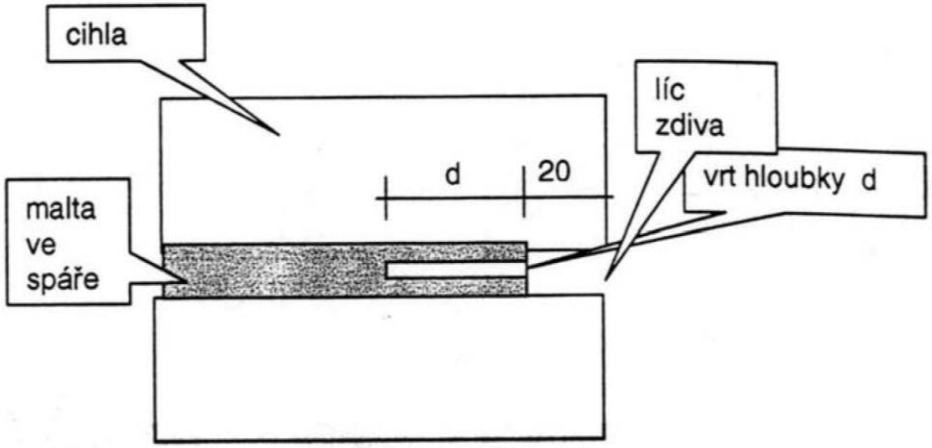
- Pre-set number of 25 revolutions of 8 mm drill bit,
- Drilled depth is measured,
- Strength is established from a calibration table.

DRILL RESISTANCE METHOD – ELECTRIC PZZ 01 DRILL (mortar, bricks)

- Number of revolutions of 6 mm drill bit is set automatically, based on expected strength of the bricks or mortar,
- Drill stops automatically after set number of revolutions,
- Drilled depth is measured,
- Strength is established from a calibration table.

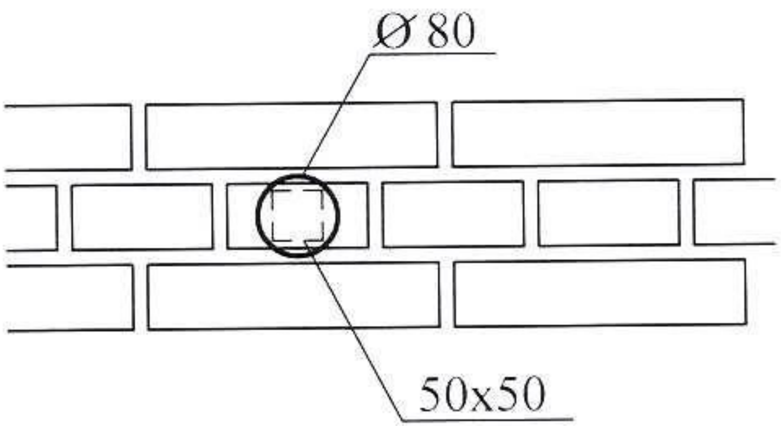
DRILL RESISTANCE METHOD
PRESCRIBED LAYOUT OF DRILLED HOLES





DRILLING 80 mm CORES FOR LABORATORY TESTING (bricks)

- Cores are subsequently used for laboratory strength testing, freeze-thaw testing, absorption testing, capillary properties. etc.



DRILLING 80 mm CORES FOR LABORATORY TESTING (bricks)

- In this size of core sample a specimen of 50x50x290 mm can be cut out,
- This specimen can be used in 3-point bending test,
- The two broken halves can be cut to 4 cube specimens of 50 mm edge for compressive testing,
- In this setup, the direction of compressive test loading is the same as in the original structure.

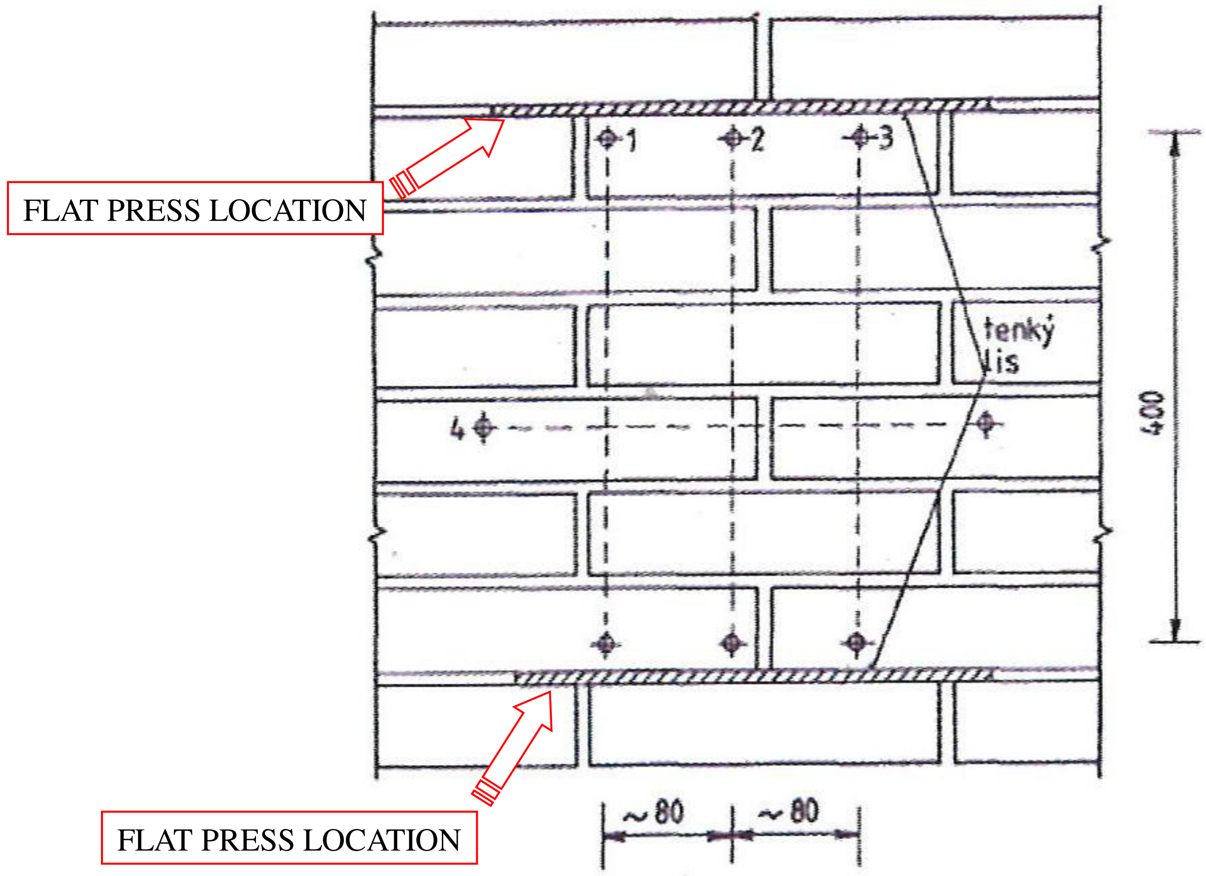
DRILLING 150 mm CORES FOR LABORATORY TESTING (masonry)

- Drilling 150 mm core samples, for compressive strength testing of complete masonry in laboratory,
- Frequently hard or impossible to remove compact cores from structural members (when mortar has low strength).

INSERTING FLAT PRESSES INTO MASONRY

- Inserting two flat presses into bed joints of masonry above each other
- Installing deformation gauges, 3 in vertical plane, 1 in horizontal plane,
- From pressure and deformation readings, we can calculate modulus of deformability and strength of the masonry.

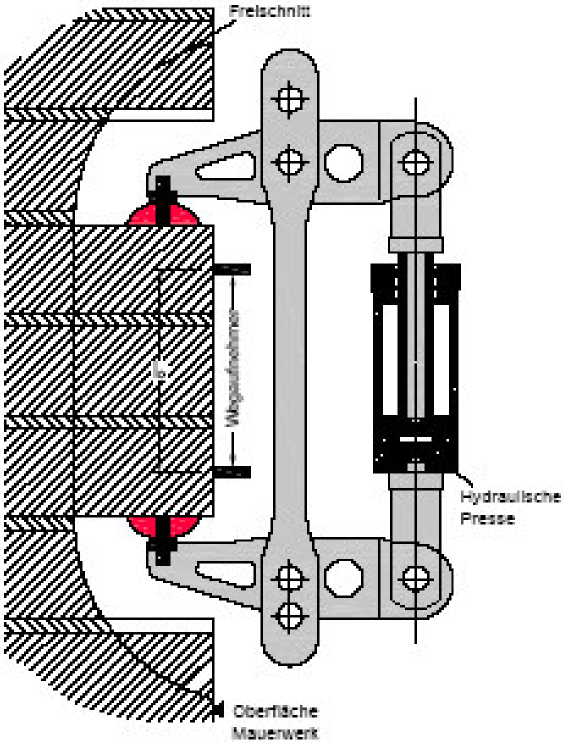
INSERTING FLAT PRESSES INTO MASONRY

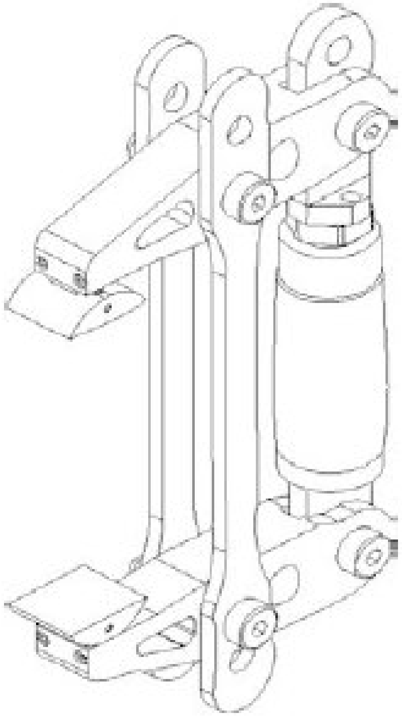


ATTACHING TESTING PRESS TO MASONRY

- Principally similar to method of two flat presses,
- The press outside of masonry surface is much easier to install,
- Tested portion of masonry is number of times smaller,
- Load is much more concentrated,
- Greater number test specimens should be done.

ATTACHING TESTING PRESS TO MASONRY





Catalogue of typical problems in masonry bridges

- Catalogue of typical problems of masonry bridges was prepared by authors Dohnálek, Hromádko, Kůrka, Lorenz,
- Catalogue was prepared to order for Management of Railway network (SŽDC) of the Czech Republic in 2007,
- Catalogue was intended to be used by personnel periodically surveying bridges on the national railway network,
- The contract also included seminars for the personnel,
- The problems of masonry bridges described are in no way limited to railway bridges,
- Problems divided into 26 categories.

List of typical problems in masonry bridges

Catalogue list	Problem
F.5.1.1	Erosion in foundation members
F.5.1.2	Erosion under or wash away of protective members of foundations
F.5.1.3	Subsiding of bridge columns and abutments
F.5.2.1	Longitudinal cracks in arches
F.5.2.2	Longitudinal cracks between frontal arch and vault
F.5.2.3	Diagonal cracks in an arch
F.5.2.4	Transverse cracks in an arch
F.5.2.5	Vertical cracks in columns and abutments
F.5.2.6	Stepwise cracks in columns, abutments, frontal walls and bridge sides (wings)
F.5.2.7	Vertical cracks between breakwater and column
F.5.2.8	Horizontal cracks in bridge supports
F.5.2.9	Vertical cracks between bridge abutment and bridge side (wing)

List of typical problems in masonry bridges

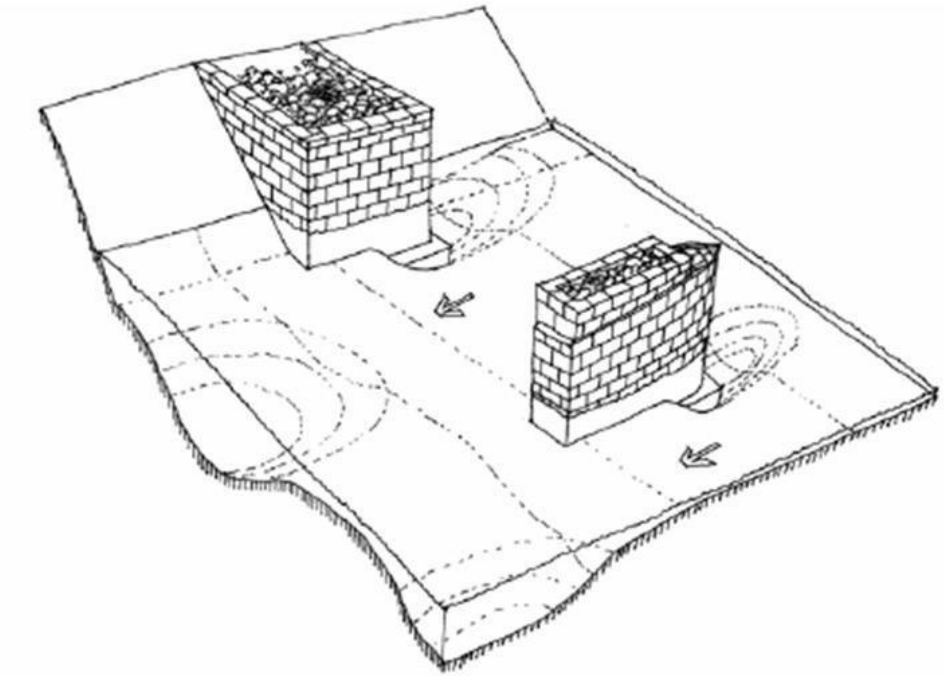
Catalogue list	Problem
F.5.2.10	Cracks in stucco
F.5.3	Water seepage thru masonry arches or lower structure
F.5.4.1	Spatial distortion of frontal wall
F.5.4.2	Leaning or distortion of masonry of bridge sides (wings)
F.5.4.3	Spatial distortion of masonry of abutments or columns
F.5.4.4	Slide out of bridge ledge
F.5.4.5	Separation of frontal wall
F.5.4.6	Separation of surface layers of masonry
F.5.5.1	Cavities – fall out of stones from stone masonry arch or support
F.5.5.2	Cavities – fall out of bricks from brick masonry arch or support

List of typical problems in masonry bridges

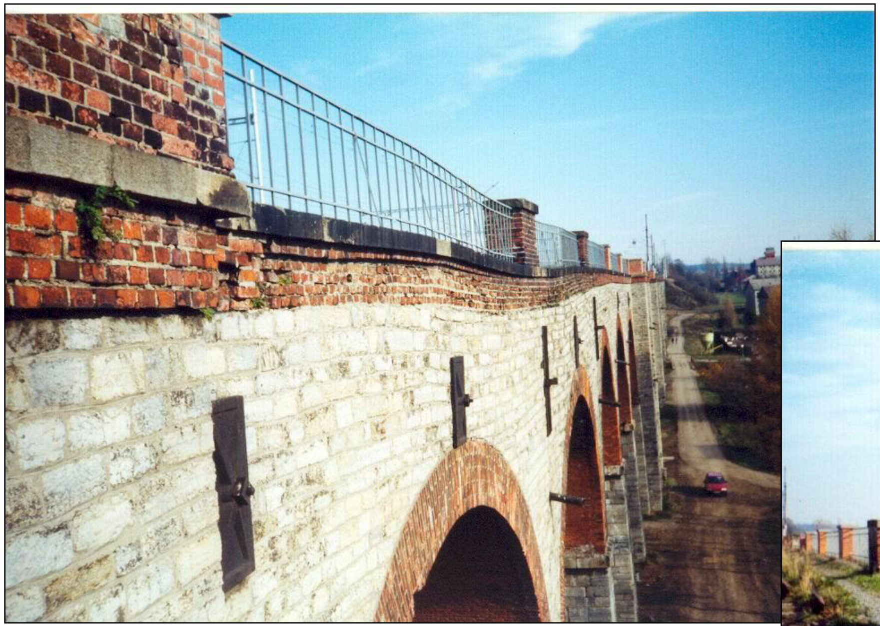
Catalogue list	Problem
F.5.6.1	Degradation of stone
F.5.6.2	Degradation of bricks
F.5.6.3	Degradation of mortar
F.5.6.4	Wear of masonry by traffic

F.5.1.1. – Erosion in foundation members

F.5.1.2. – Erosion under or wash away of protective members of foundations

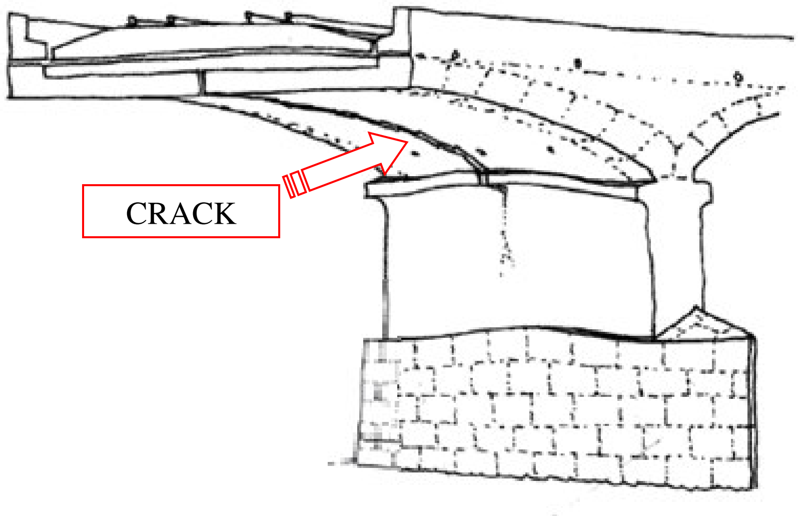


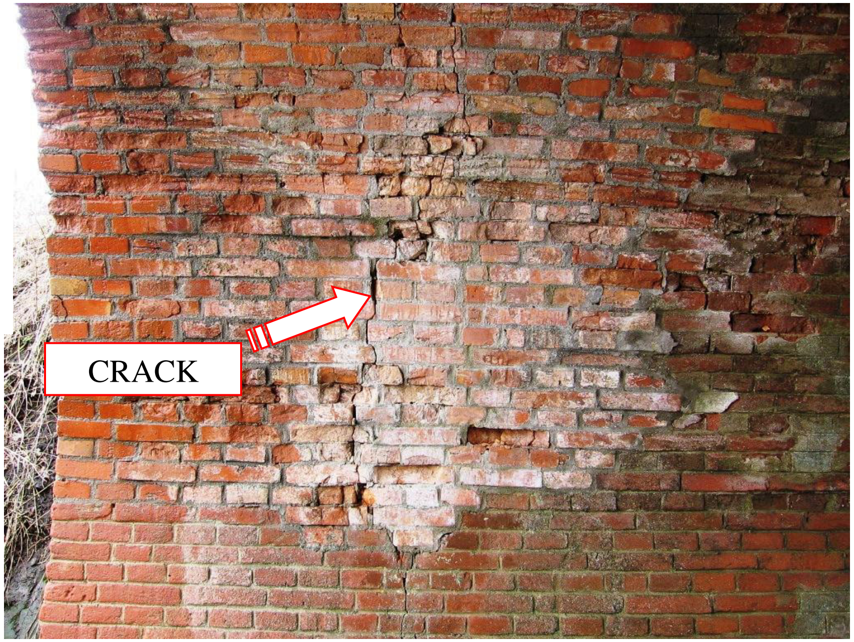
F.5.1.3. – Subsiding of bridge columns and abutments



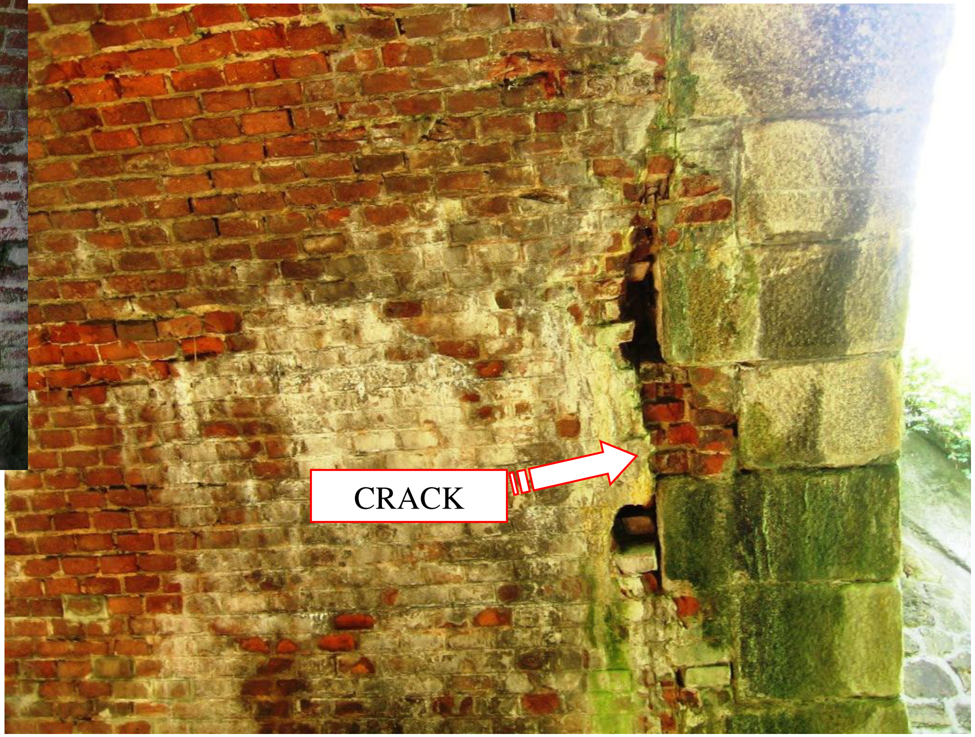
-- Ing. Pavel Dohnálek, Ph.D. Technický ředitel Betosan s.r.o. Nová cesta 291/40 140 00 Praha 4 Czech Republic dohnalek.p@betosan.cz +420 602 149 443

F.5.2.1. – Longitudinal cracks in arches

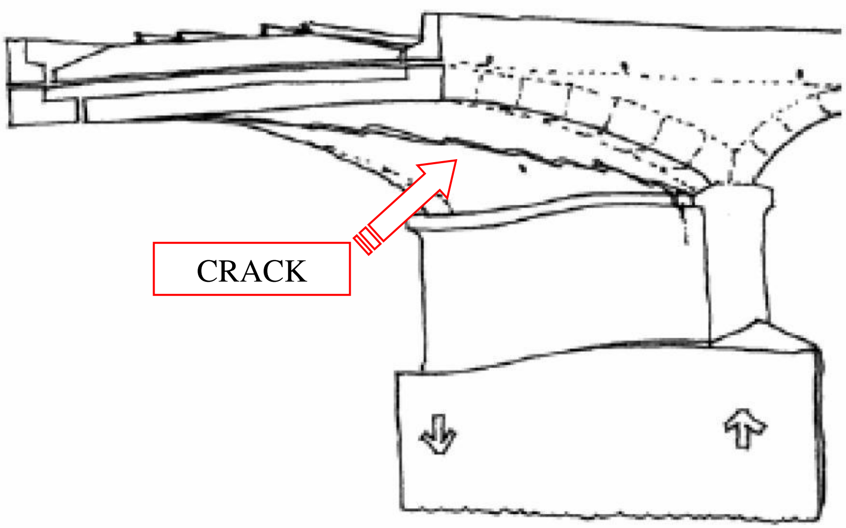


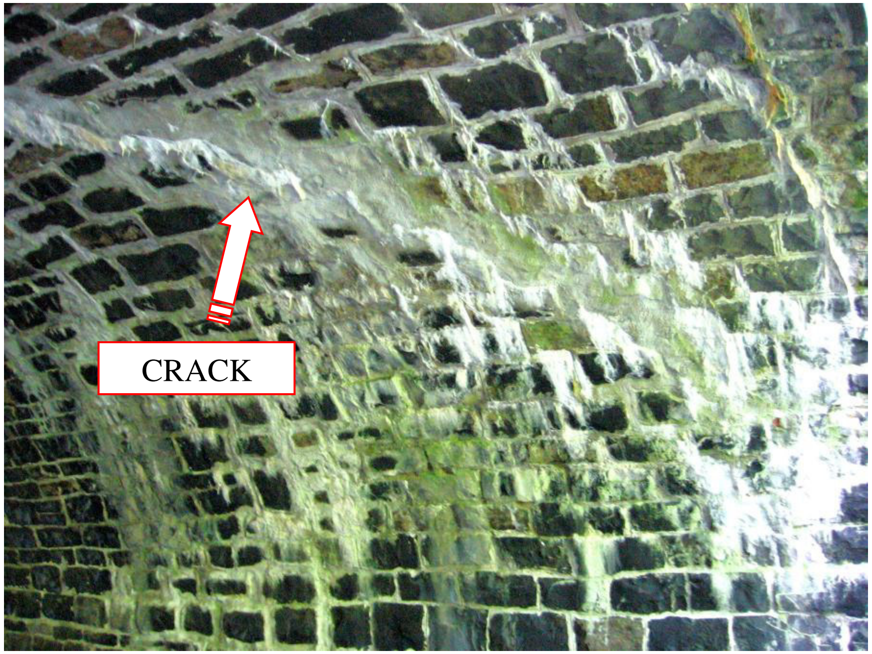


F.5.2.2. – Longitudinal cracks between frontal arch and vault

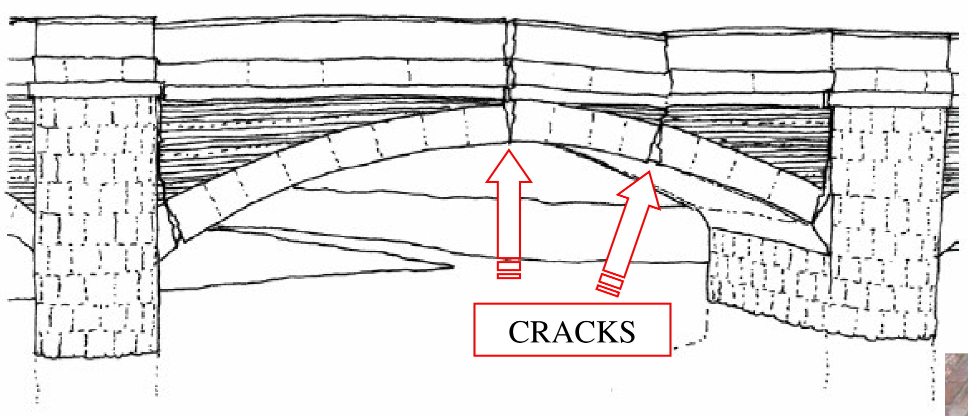


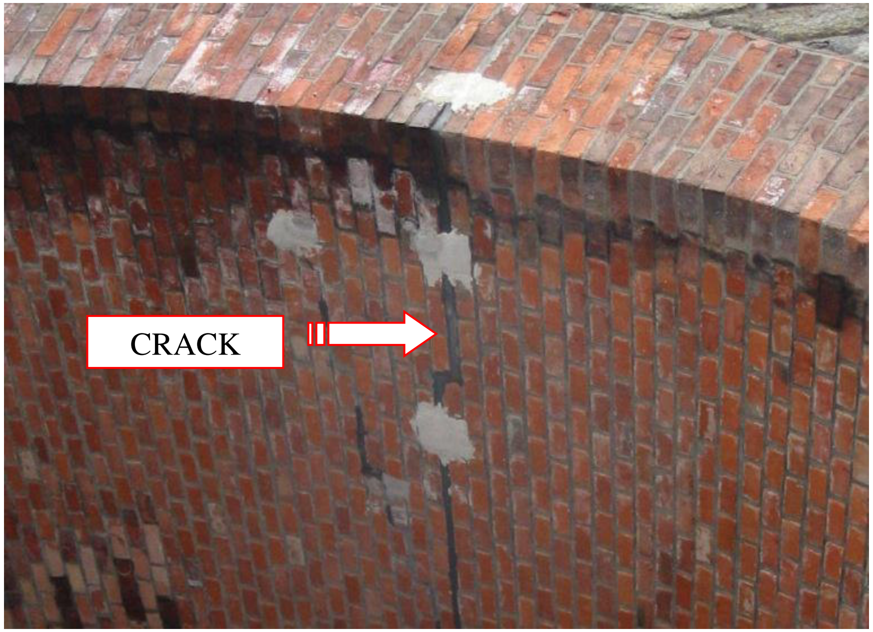
F.5.2.3. – Diagonal cracks in an arch



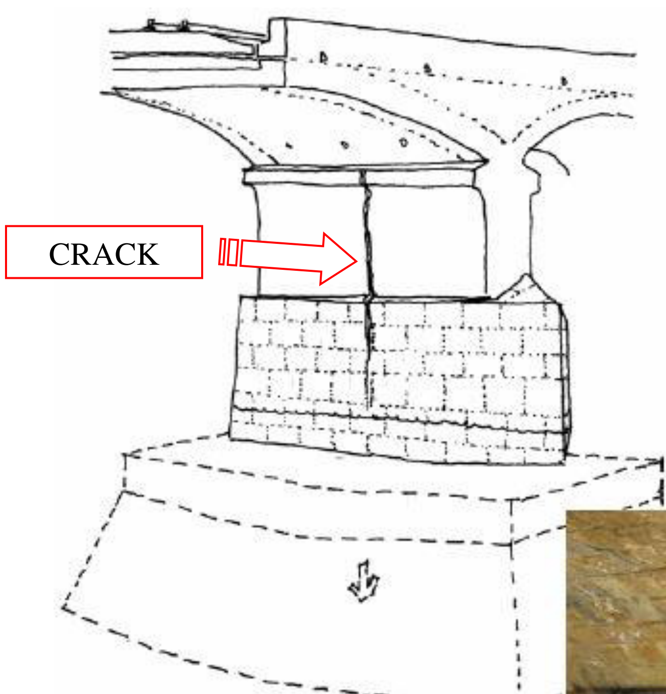


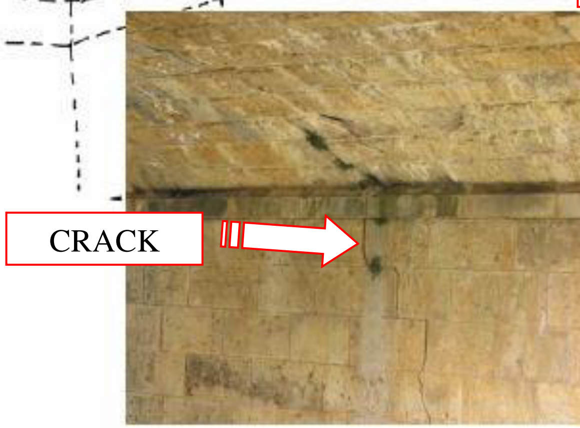
F.5.2.4. – Transverse cracks in an arch



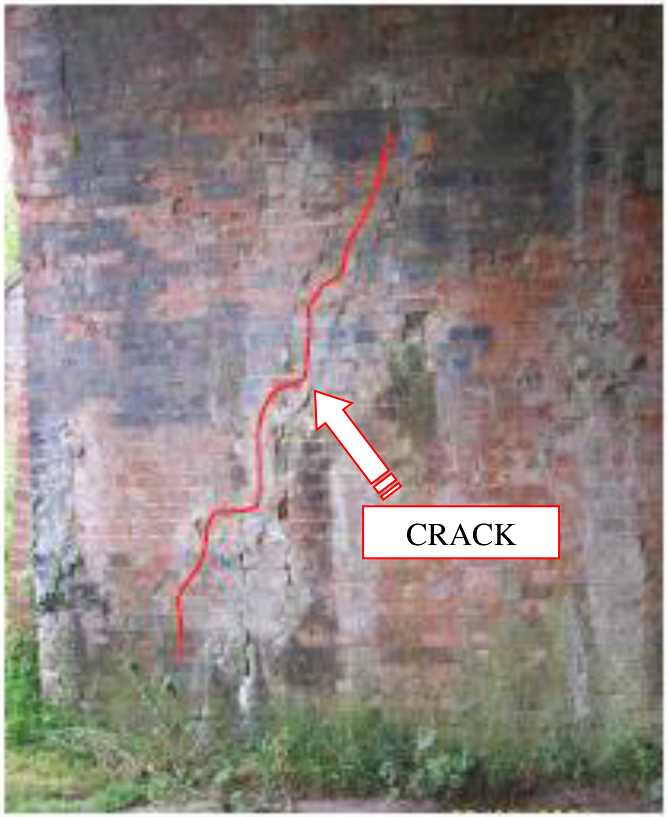


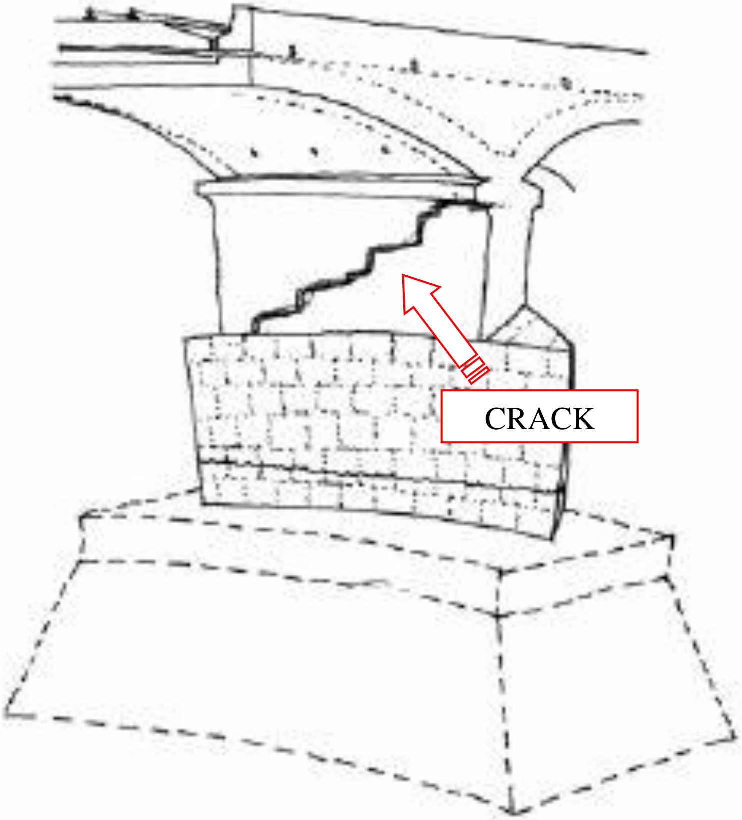
F.5.2.5. – Vertical cracks in columns and abutments



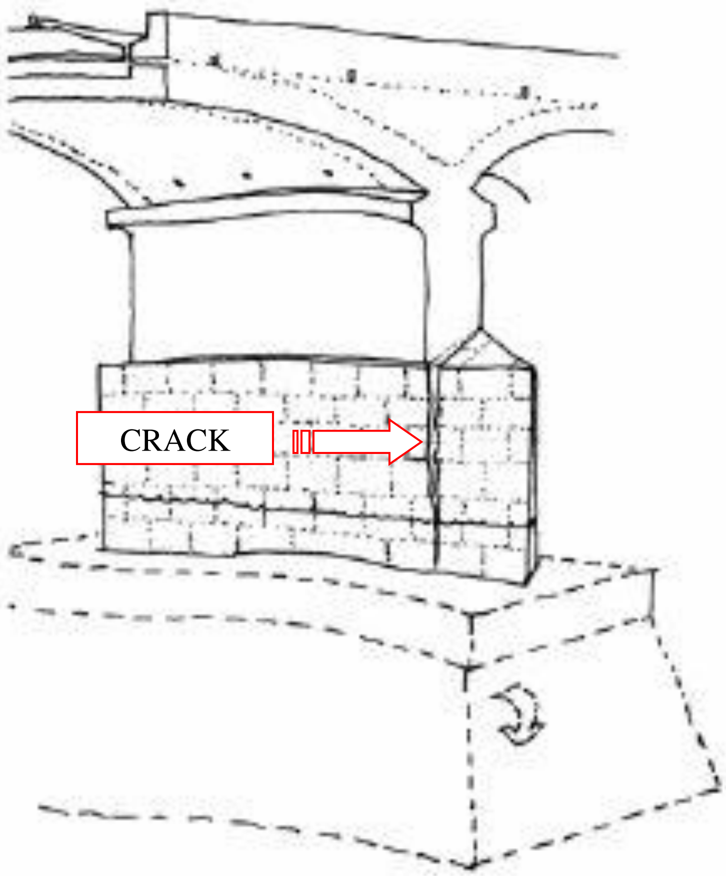


F.5.2.6. – Stepwise cracks in columns, abutments, frontal walls and bridge sides (wings)

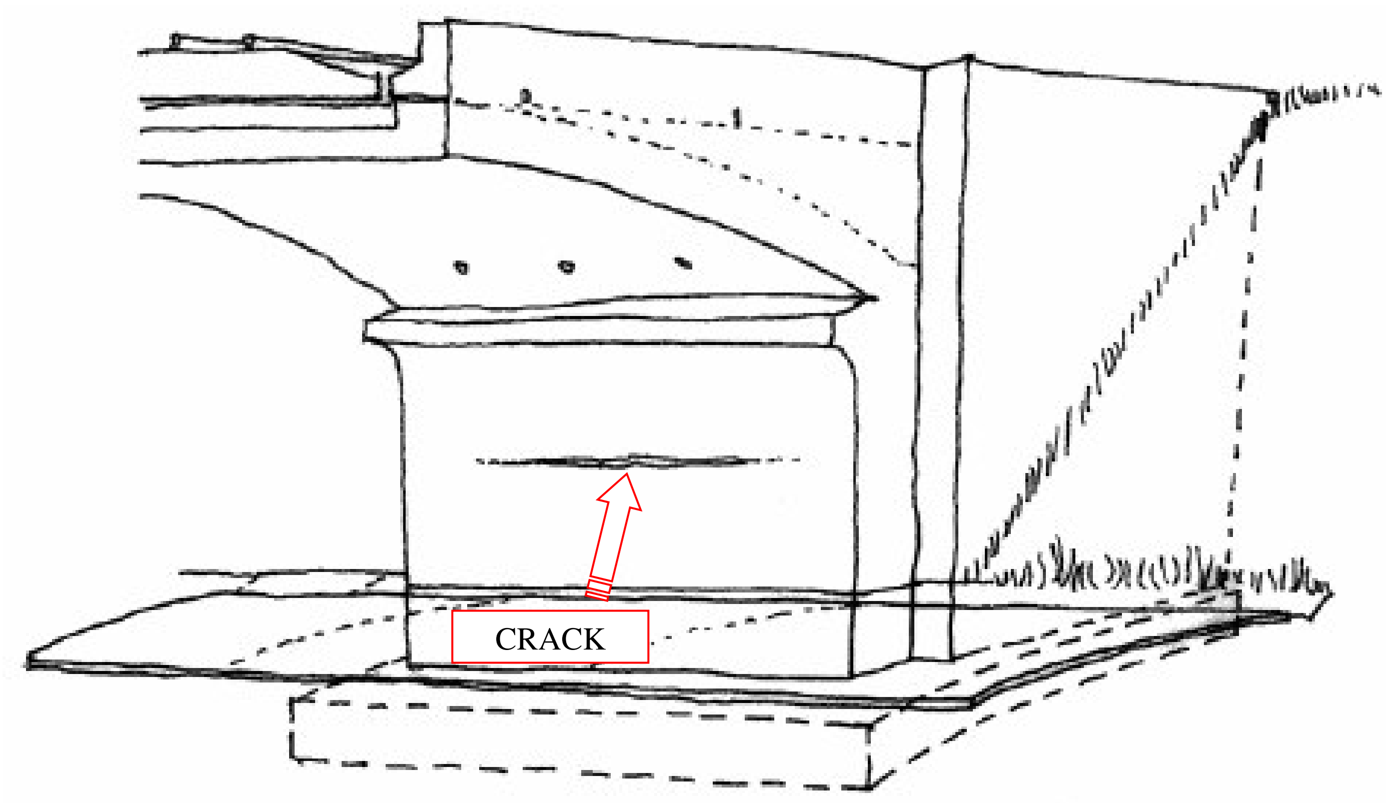




F.5.2.7. – Vertical cracks between breakwater and column



F.5.2.8. – Horizontal cracks in bridge supports



F.5.2.10. – Cracks in stucco

F.5.3. – Water seepage thru masonry arches or lower structure

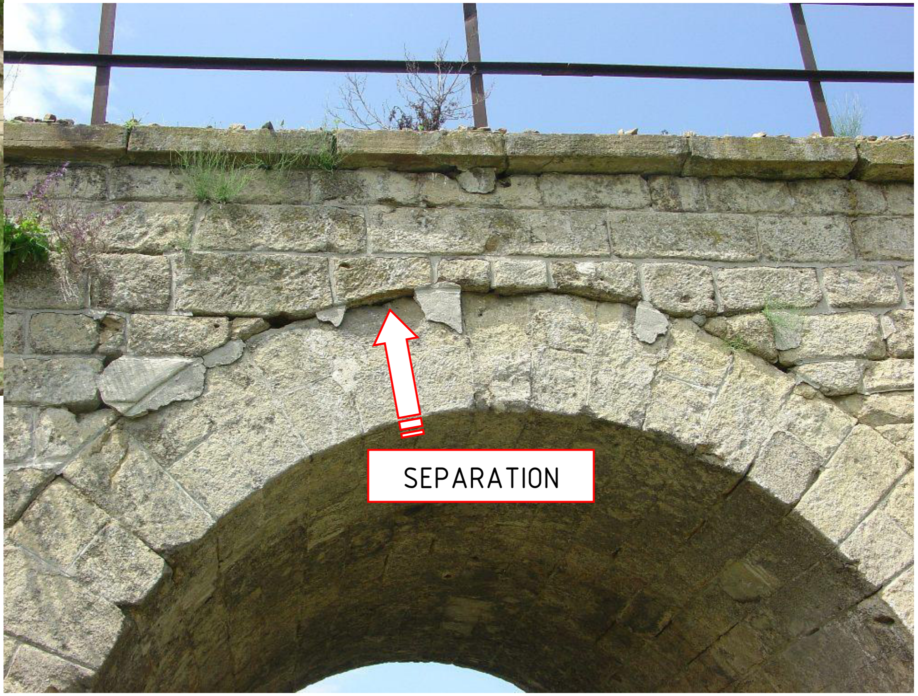
F.5.4.1. – Spatial distortion of frontal wall

F.5.4.2. – Leaning or distortion of masonry of bridge sides (wings)

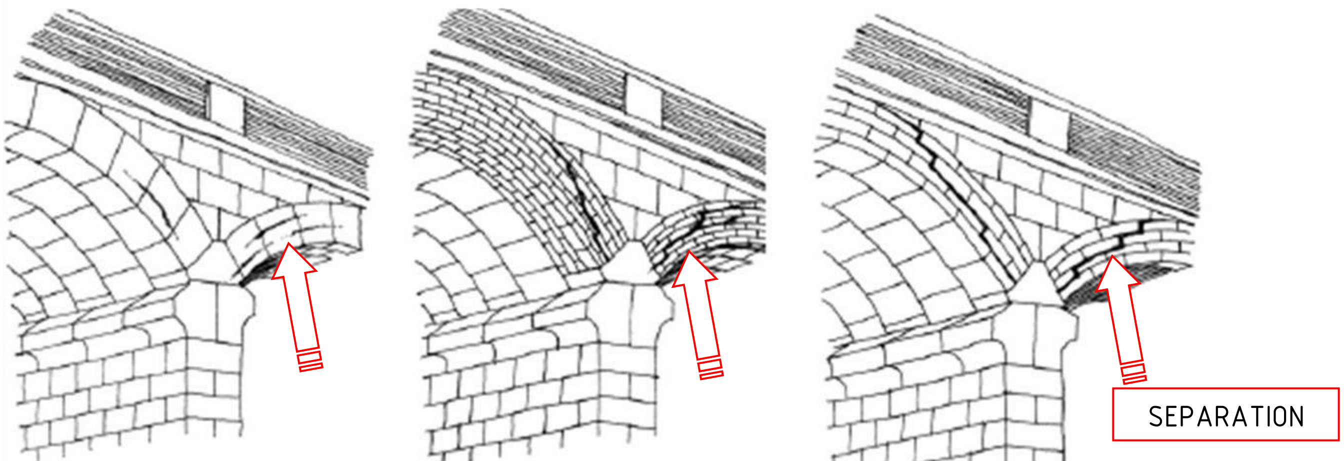
F.5.4.3. – Spatial distortion of masonry abutments or columns

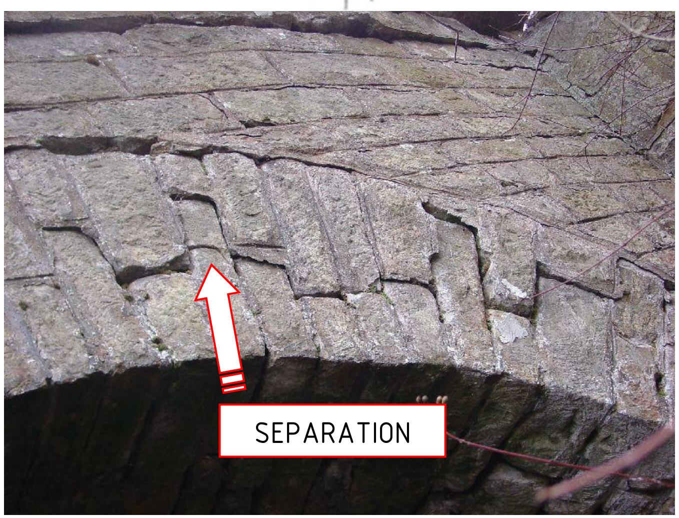
F.5.4.4. – Slide out of bridge ledge

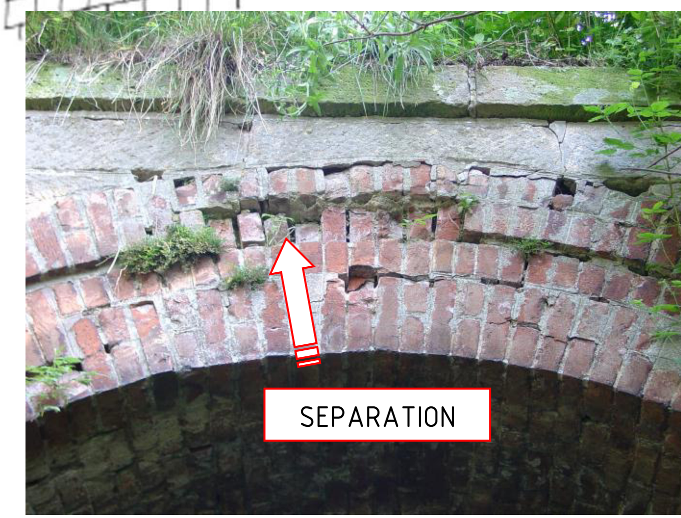
F.5.4.5. – Separation of frontal wall



F.5.4.6. – Separation of surface layers of masonry



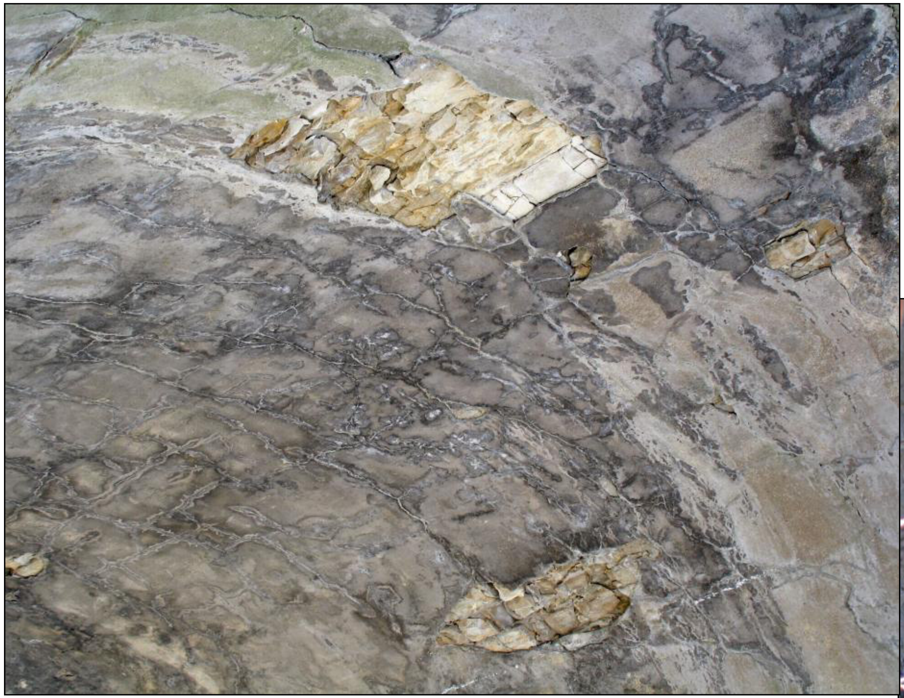




F.5.5.1. – Cavities – fall out of stones from stone masonry arch or support

F.5.5.2. – Cavities – fall out of bricks from brick masonry arch or support

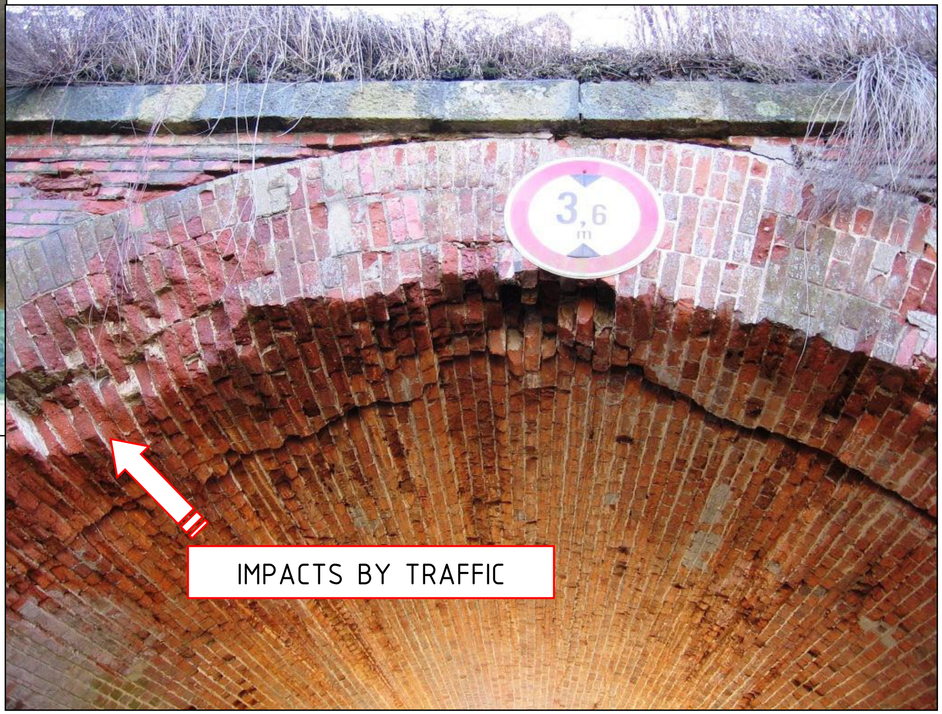
F.5.6.1. – Degradation of stone



F.5.6.2. – Degradation of bricks

F.5.6.3. – Degradation of mortar

F.5.6.4. – Degradation of masonry by traffic



COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control
25th – 29th September, 2017
Faculty of Civil Engineering CTU in Prague
Prague, Czech Republic

Diagnostics and NDT techniques for bridge diagnostics: concrete bridges, reinforcement, prestressing bars

Jan Zatloukal – Czech Technical University in Prague, Czech Republic

ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

COST European Cooperation in Science and Technology

Introduction

- NDT techniques
- Reinforced concrete structures
- Prestressed concrete structures
- Testing of concrete

NDT Techniques

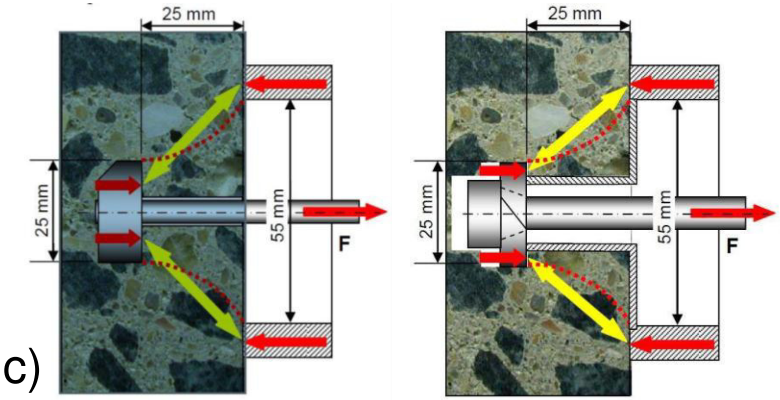
- NDT = Non-Destructive testing
  - „Technical process to quantify characteristic values of material or product according to certain procedure using interaction of energy and material property without affecting serviceability“
  - Example: Concrete test hammer – interaction of energy, material property: Rebound value R → Concrete strength
- Classification according to introduced energy impulse:
  - Mechanical methods (rebound hammer, ultrasound, impact-echo)
  - Electromagnetic methods (radar, thermography, radiography)
  - Magnetic methods (inductive methods, eddy currents, magnetic flux)
  - Electrochemical methods (electrochemical potential mapping)
  - Spectroscopic methods (XRD, XRF, LIBS)

Classical NDT Techniques

- Concrete strength: Rebound Hammer
- Location of reinforcement: Radar and Magnetic detector
- Concrete cover: Magnetic cover meter
- Potential mapping, resistivity measurement
- Semi-destructive techniques:
  - Core taking – concrete strength, carbonation depth, frost resistance, chloride content
  - Powder sample taking – chloride content, XRD (phase analysis), XRF (chemical analysis)
  - Reinforcement probing (diameter, type, strength of reinforcment)

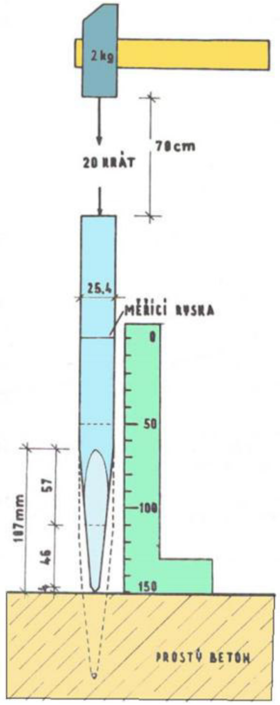
Mechanical methods


a)



c)

a) Rebound hammer
b) Penetration test
c) Local pull-out test
d) Needle indentation
e) Microdrilling



b)


d)


e)

Rebound hammer

- Measurement principle: interaction of mechanical energy and material properties
- Measured value: hammer rebound. Desired value: compressive strength
- Surface hardness = ability to resist penetration (the higher hardness, the less energy is absorbed)
- Compressive strength = comressive stress capacity (ability to resist mechanical loading in compression)

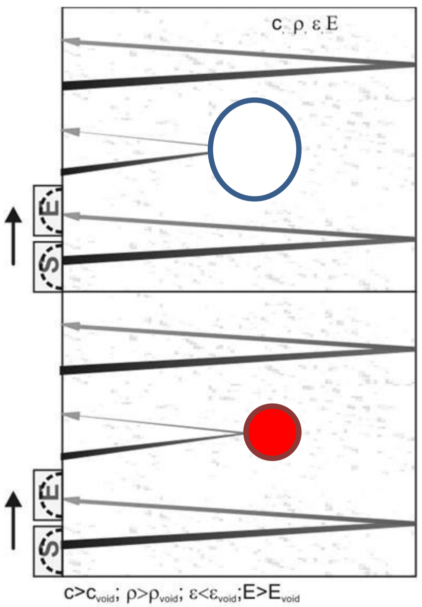
Rebound number **R** = distance of the mass after impact on surface

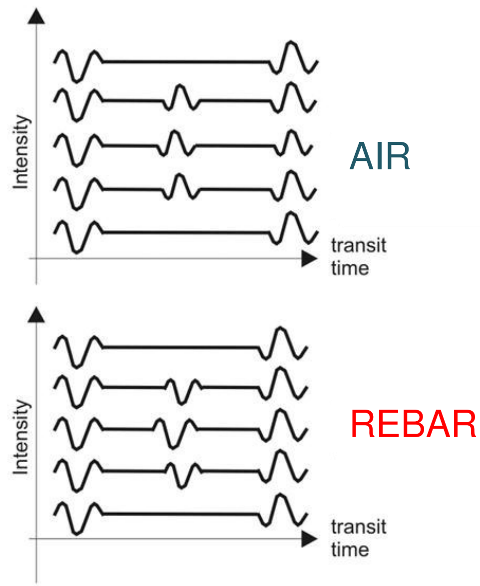
Rebound value **Q** = ratio of velocity v_R and v_0 shortly before and after impact

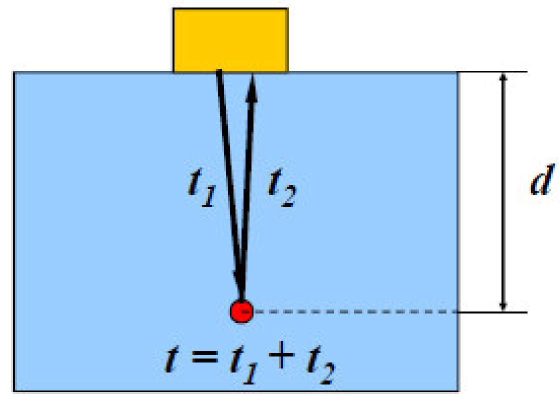
R ≈ 0,75 Q

Radar

- Electromagnetic waves introduced into the material are reflected by interfaces (material/air, material/inclusion)
- Precise reinforcement depth measurement requires knowledge of wave speed



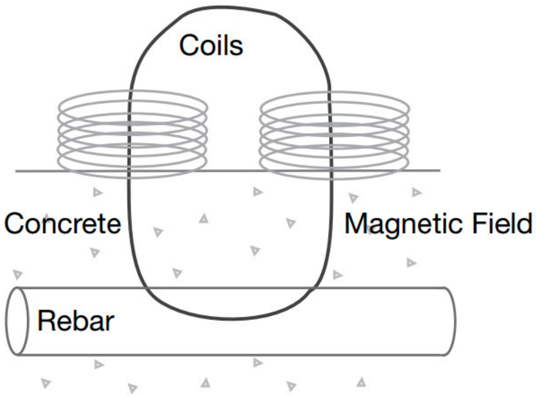




$$d = \frac{v_{material} \cdot t}{2}$$

Inductive magnetic methods

- Introduction of magnetic field into the material
- Rebar location
- Rebar spacing
- Concrete cover
- Rebar diameter
- Rebar orientation



Radar vs. Inductive methods

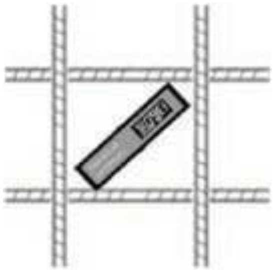
- Effectivity is dependent on the environment and moisture

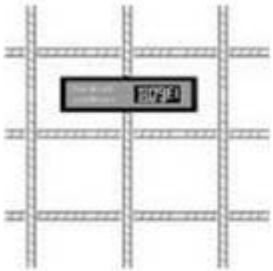
● Steel ○ Metal duct ◌ Drill hole	Air			Concrete			Wet Concrete		
	●	○		●	○	◌	●	○	◌
Radar	+++	+++		++	++	o	o	o	-
Inductive met.	+++	+++		+++	+++	-	+++	+++	-

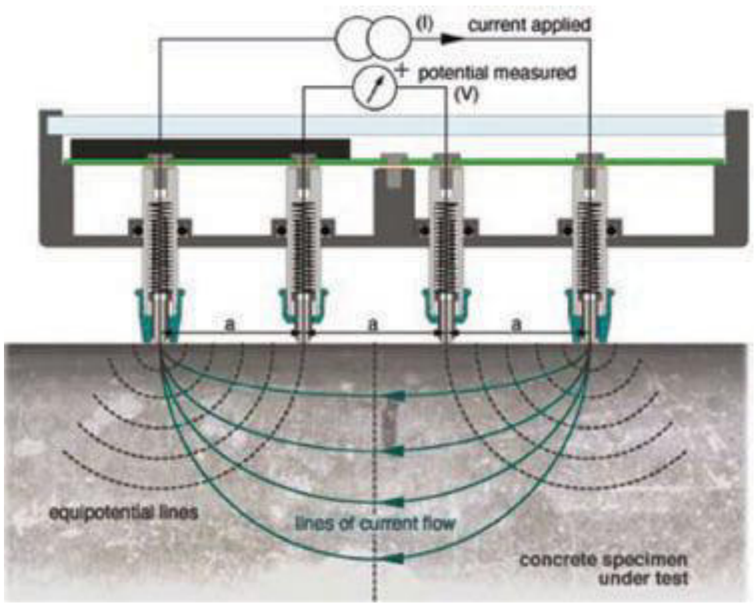
+++ very good ++ good + detectable o weak – no signal

Resistivity measurement

- Electrical resisitivity measurement – dependent on moisture and chemcial content (ions present in material increase conductivity)
- Influnced by rebar orientation

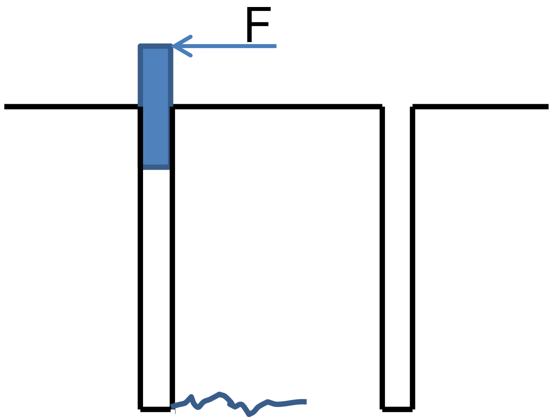






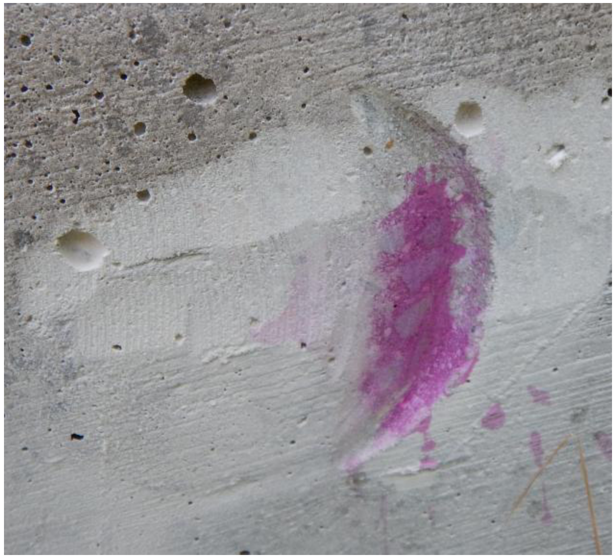
Core taking

- Local damage to structure



Carbonation and Chlorides

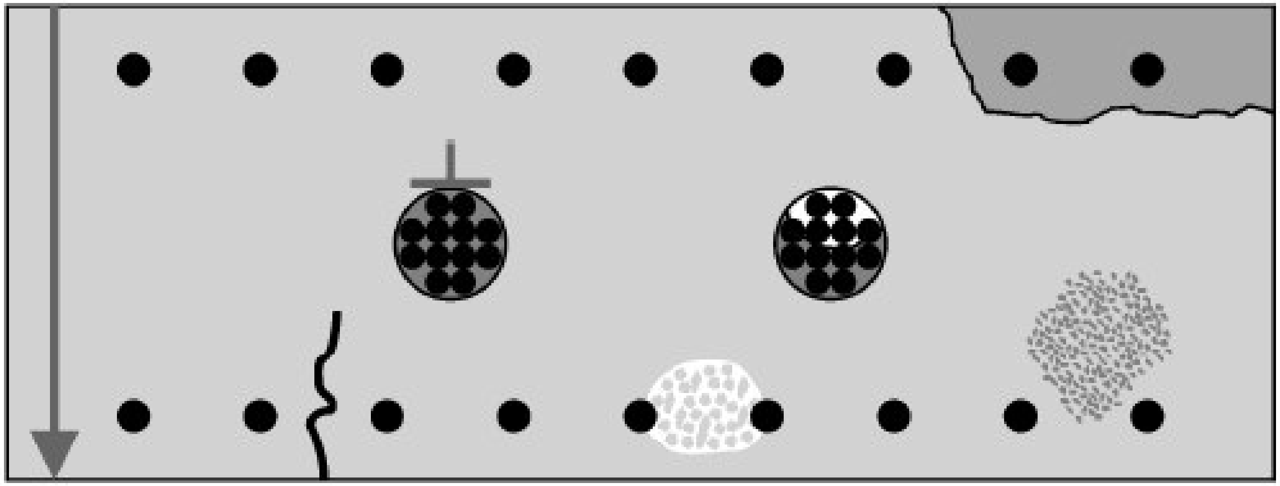
- Steel is protected against corrosion by alkali environment in concrete (pH > 13): Passivation of reinforcement
- *Carbonati*on = reaction of $Ca(OH)_2$ in concrete with aereous CO_2, resulting in $CaCO_3$ (Calcium *Carbonate*) → loss of passivation
- Thickness of carbonated layer determined by indicator (phenolphtalein). Purple = pH > 13.
- Chloride content: loss of passivation even in high alkali environment



Prestressed concrete

- Pre-tensioning
- Post-tensioning – duct grouting

- Single wires, tendons, ducts (plastic or metal)



Reinforcement probing

- Rebars – diameter, type (ribs), steel hardness, corrosion
- Tendons – duct condition, grouting, type of tendon, corrosion

TU1406

COST ACTION

COST ACTION TU1406
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Training School - Prague
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VISUAL INSPECTION AND ASSESSMENT OF CONCRETE PRESTRESSED BRIDGE

A. Anžlin; C. Baera; D. Rumsys; D. Skokandic; I. Tesovic; K. Lellep; N. Pavlinovic; N. Makhoul; T. Asimakopoulos; V. H. Nguyen.

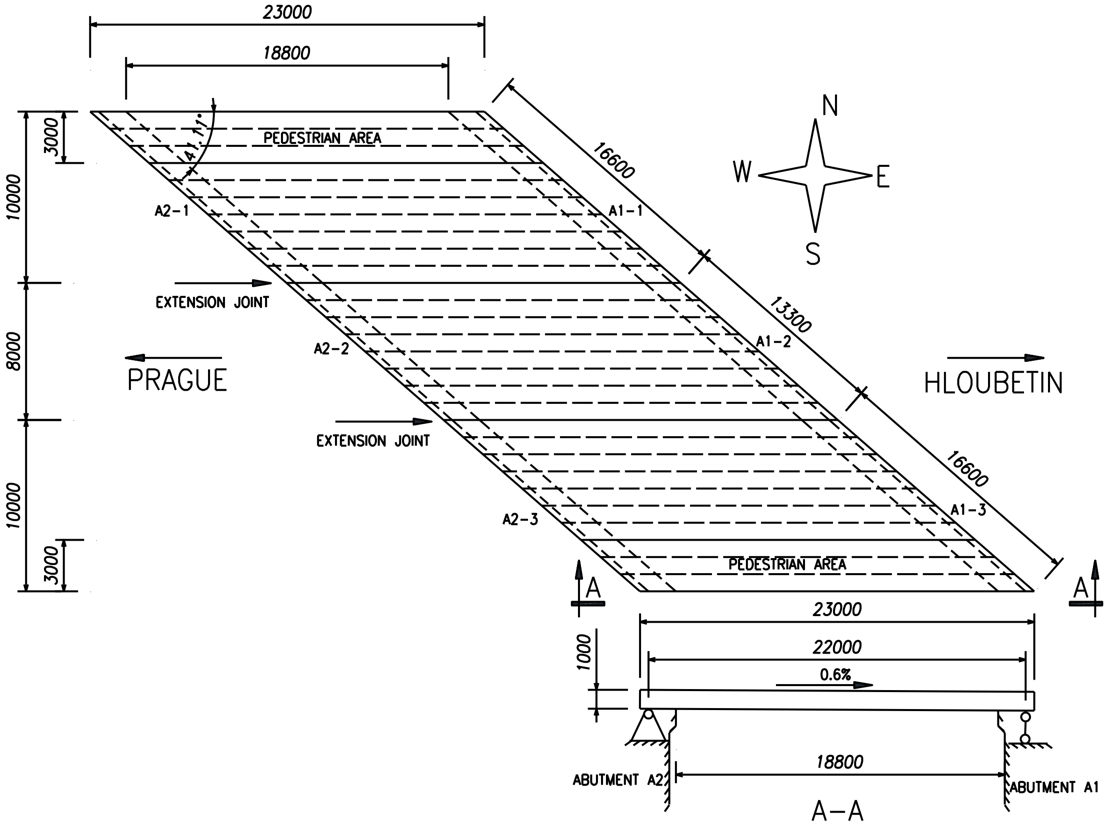
CONTENTS

INTRODUCTION

- **KOLBENOVA BRIDGE**
- Prestressed Concrete girders single span bridge
- Constructed in 1967 – according to the old design codes
- Superstructure is comprised of 28 girders and in situ concrete slab
- Gravity type abutments

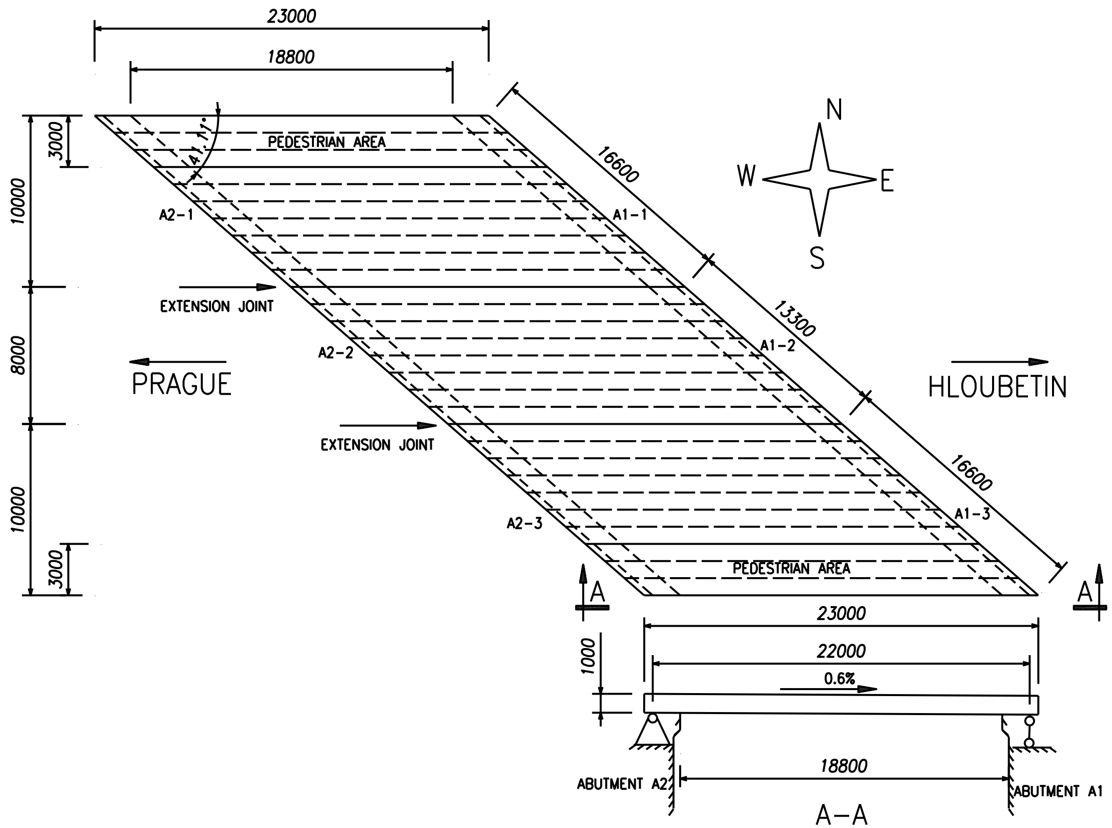
INTRODUCTION

- Bridge span of 22,0 m, with total width of 28(45,5) m
- Skew angle around 41°,



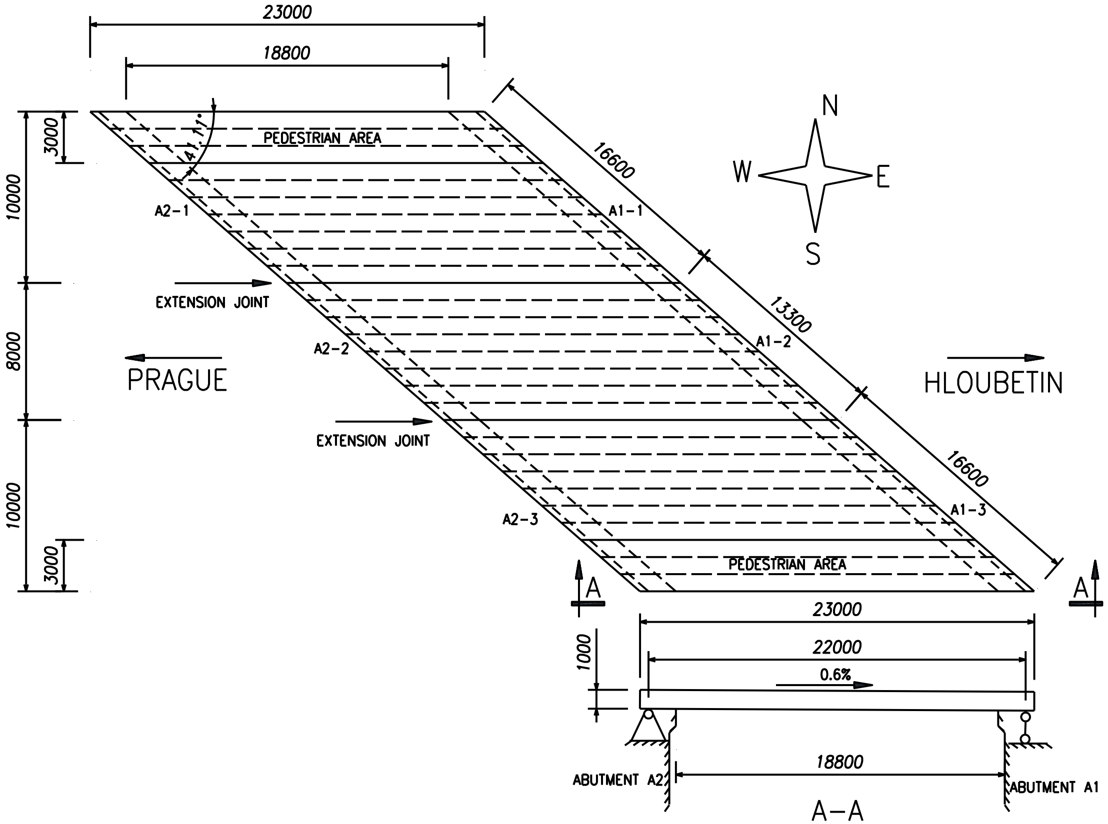
INTRODUCTION

- Two traffic lanes 7,0 m each
- Twin tram tracks in the middle of the bridge, 8,0 m wide



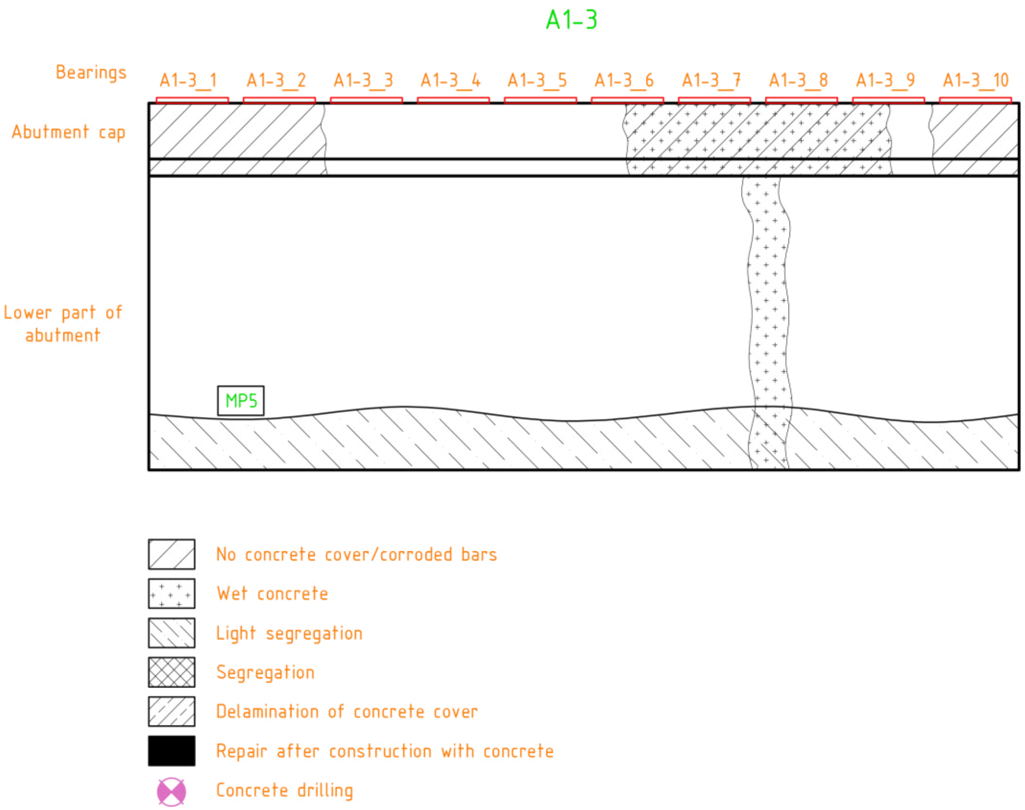
INTRODUCTION

- Bridge is supported on fixed and roller type bearings
- Over 14 000 cars and more than 450 trams per day



VISUAL INSPECTION

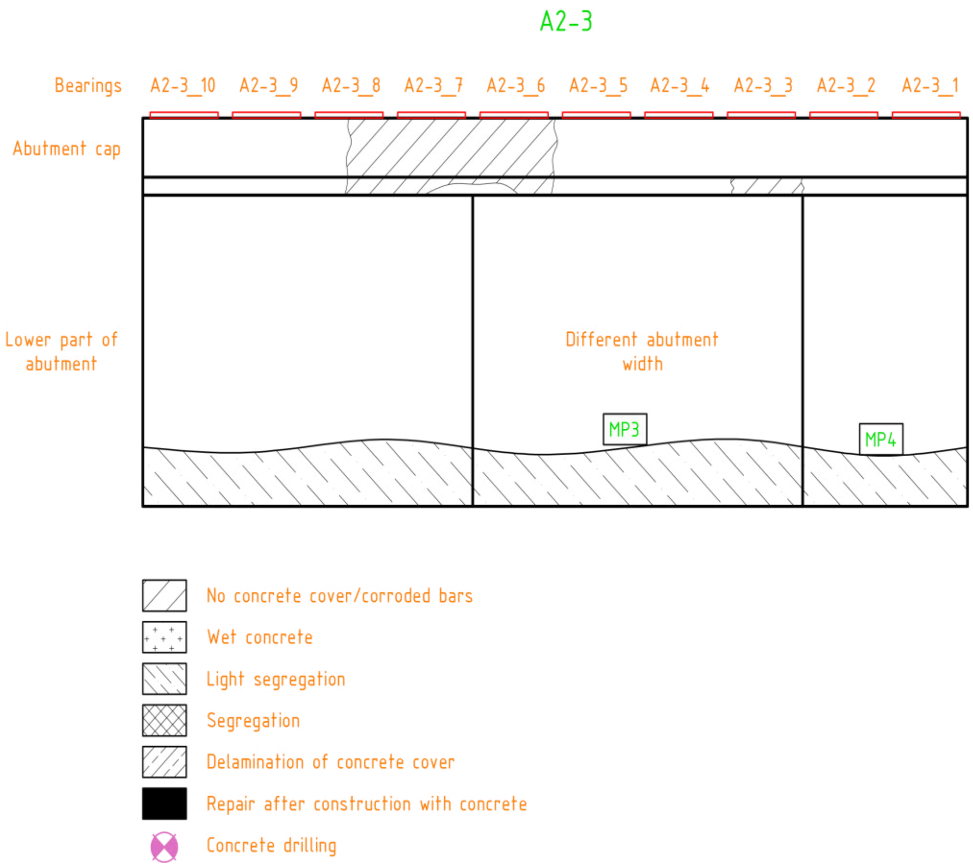
- ## SUBSTRUCTURE – Abutment A1-3



Corrosion of reinforcement on the abutment cap

VISUAL INSPECTION

- **SUBSTRUCTURE – Abutment A2-3**



Corrosion of reinforcement on the abutment cap

VISUAL INSPECTION

- **SUBSTRUCTURE – Bearings**

Bearing for longitudinal movement

Fixed bearing

- **Heavily corroded steel parts due to the water leakage, not servicing their role**

VISUAL INSPECTION

- **SUBSTRUCTURE – Wing walls**
- Generally acceptable situation, loss of cement matrix

VISUAL INSPECTION

- **SUPERSTRUCTURE – Girders**

- Leakage between girders joints

- Initiation of longitudinal reinforcement corrosion

VISUAL INSPECTION

- **SUPERSTRUCTURE – Girders**

- Corrosion of tendons on girder G11 in the middle section

- Corrosion of anchorage plates on edge girder

VISUAL INSPECTION

- **SUPERSTRUCTURE – Pavement and railings**

- Cracks and denivalation of pedestrian walkways

- Bridge railing – changed in 2014

TESTING RESULTS

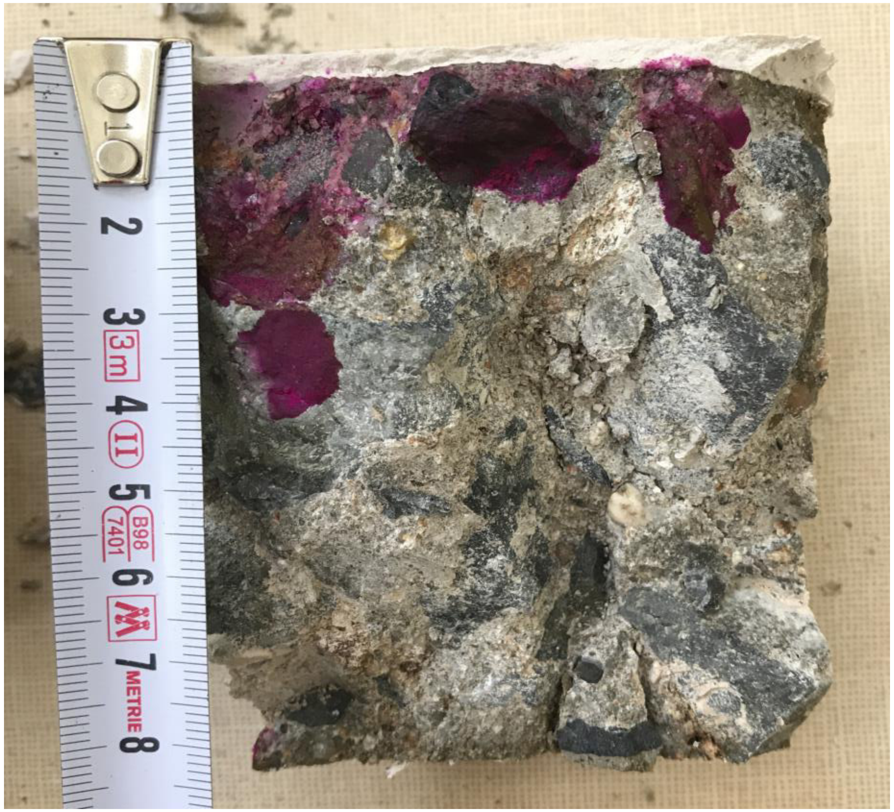
- **COMPRESSION STRENGTH OF CONCRETE**

Element	Measuring point	Results of Schmidt hammer	Result of core samples
Girder	MP-1	93 MPa, 77 MPa, 72 MPa	No core taken
Girder	MP-2	79 MPa, 70 MPa, 71 MPa	28 MPa
Abutment A2-3	MP-3	14 MPa, 17 MPa, 22 MPa	No core taken
Abutment A2-3	MP-4	20 MPa, 22 MPa, 22 MPa	No core taken
Abutment A1-3	MP-5	12 MPa, 13 MPa	No core taken
Abutment A2-1	MP-6	35 MPa	11 MPa
Abutment A1-2	MP-7	-	6 MPa, 9 MPa

TESTING RESULTS

- **CARBONATION**

- Carbonation on the main girder



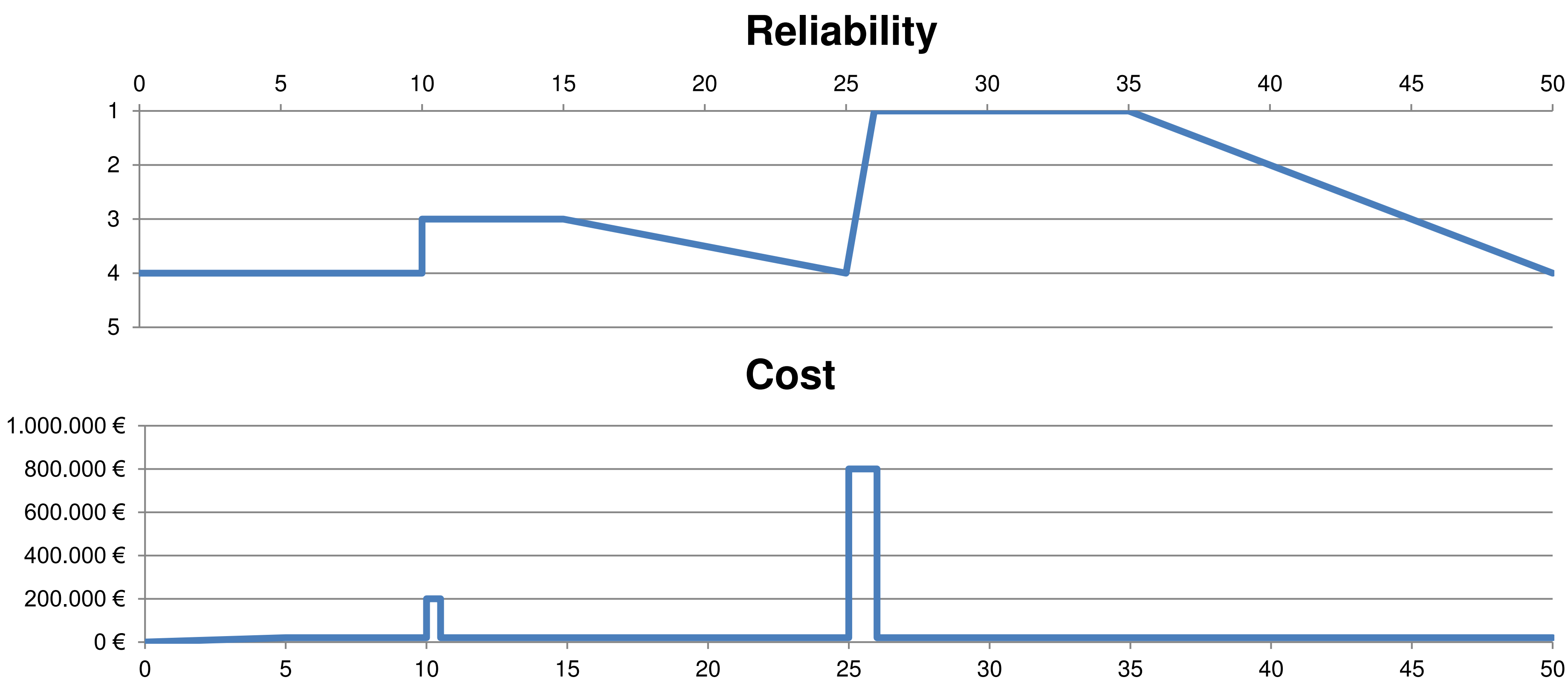
ANALYSIS OF RESULTS

Element	material/ element	failure mode	damages and symptoms	Column1	rating	forecast
Abutment cap	RC concrete	rigid body failure	delamination	realiabilty	4	10
Abutment cap	RC concrete	rigid body failure	corrosion	reliabilty	4	10
Girders	post-tensioned concrete	flexural failure	corrosion	reliabilty	3	25
Girders	post-tensioned concrete	shear failure	corrosion	reliabilty	2	25
Girders	post-tensioned concrete	flexural failure	cracks	reliabilty	2	25
walkway pawement	asfalt	serviceability failure	cracks	reliabilty	3	25
walkway pawement	asfalt	serviceability failure	unevenes	safety	2	25
traffic pavement	asfalt	serviceability failure	cracks	realiabilty	2	25
traffic pavement	asfalt	serviceability failure	unevenes	safety	2	25
new railing	steel	serviceability failure	corrosion initiation, bad fixing	safety	2	25
old railing	steel	serviceability failure	corrosion of the old pedestals	reliabilty	2	25
bearings	roller, fix	serviceability failure	corrosion	realibility	3	25
Girders	anchorage zone	NaN	delamination	reliabilty	2	
Girders	cable anchorage	NaN	corrosion	reliabilty	2	
Abutments	concrete	NaN	loss of cement matrix	realiabilty	2	
Abutments wings	concrete	NaN	loss of cement matrix	realiability	2	
drainage systems		NaN	leackage	realibility	4	
expansion joints	?	NaN	leackage	realibility	2	
Girders	joints	NaN	leackage	reliabilty	3	
waterproofing	HI	NaN	leackage	realibility	4	

scoring table	corrosion
1	no
2	first sigh of deteriorration, with no reduction in the funcitoning of the elements
3	moderate damage, expect some minor influence
4	major, high influence on the functioning of the element
5	no functioning

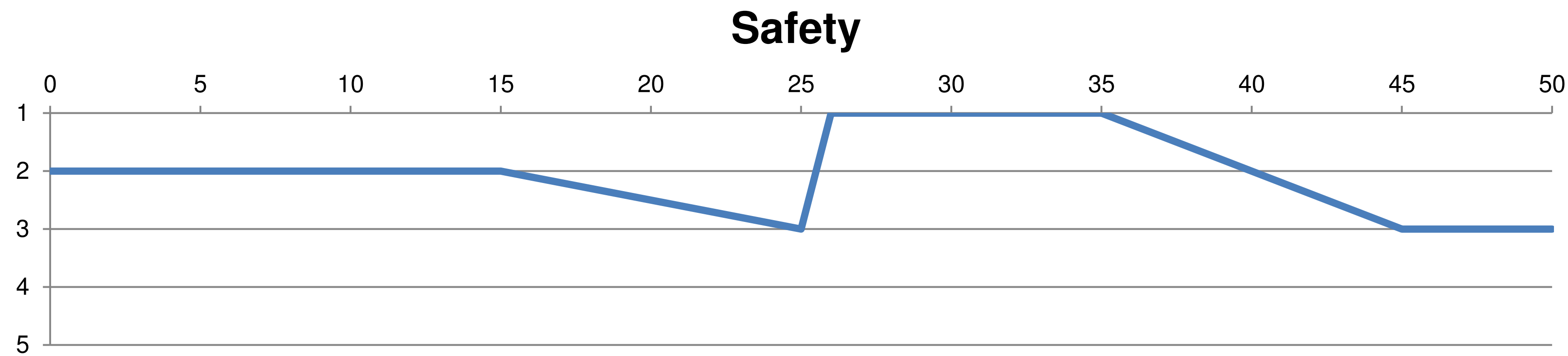
MAINTENANCE SCENARIOS

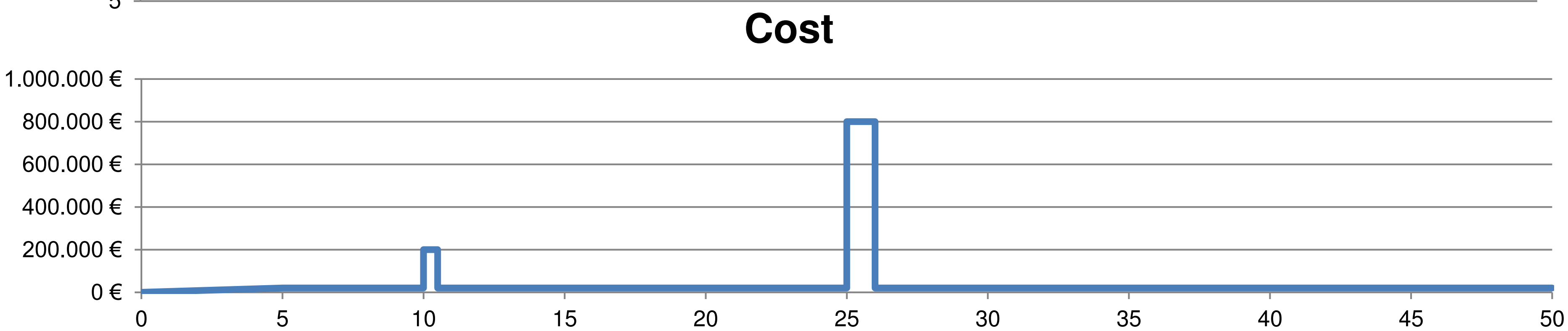
- **REFERENCE SCENARIO**



MAINTENANCE SCENARIOS

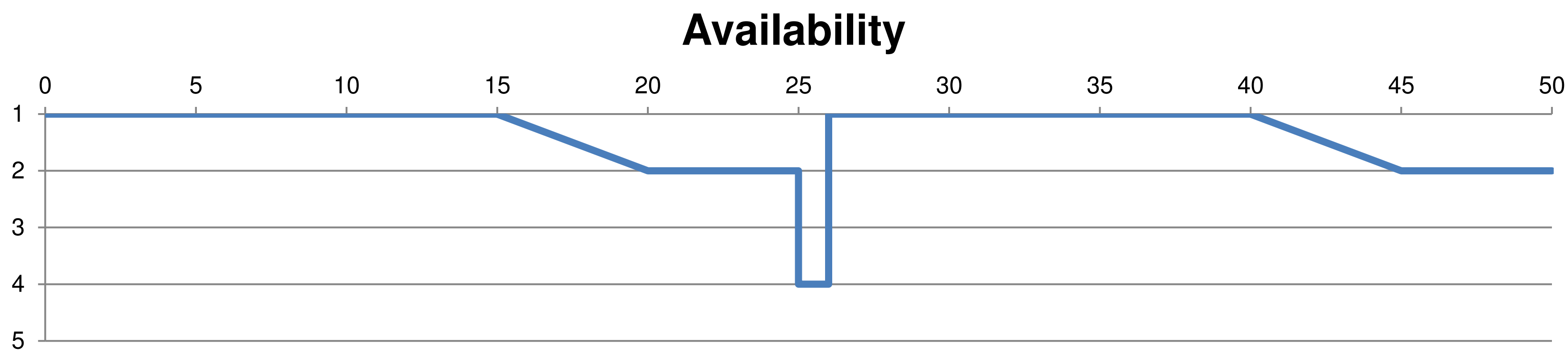
- **REFERENCE SCENARIO**

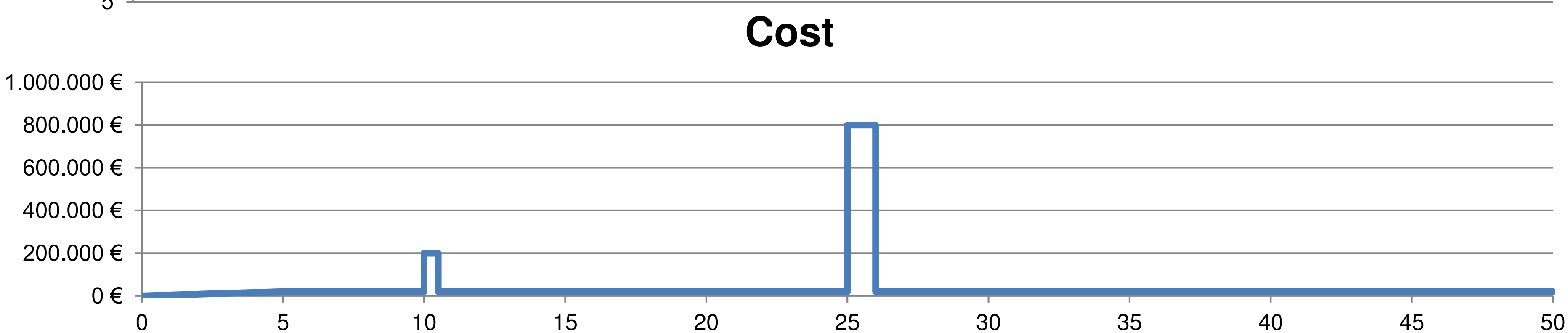




MAINTENANCE SCENARIOS

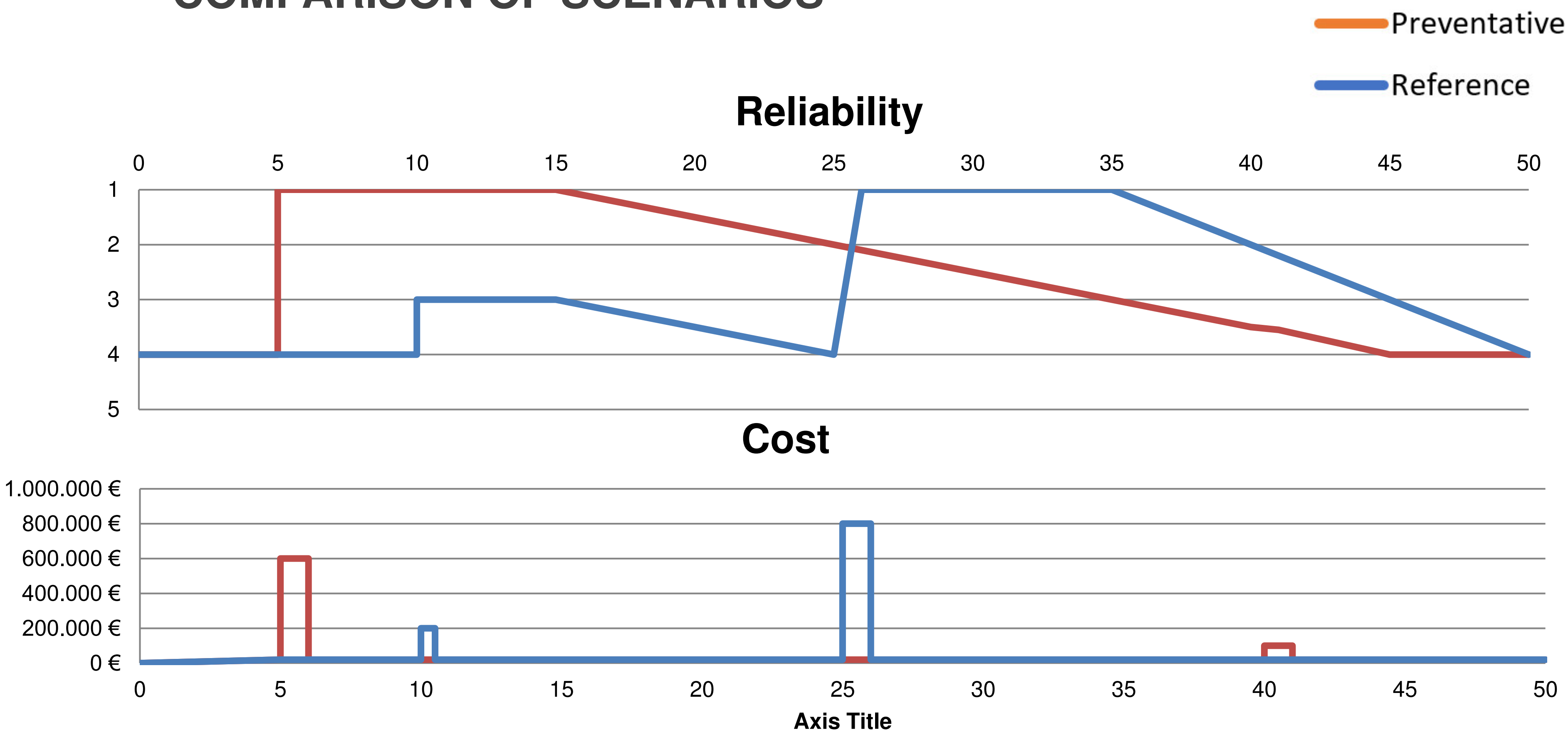
- **REFERENCE SCENARIO**





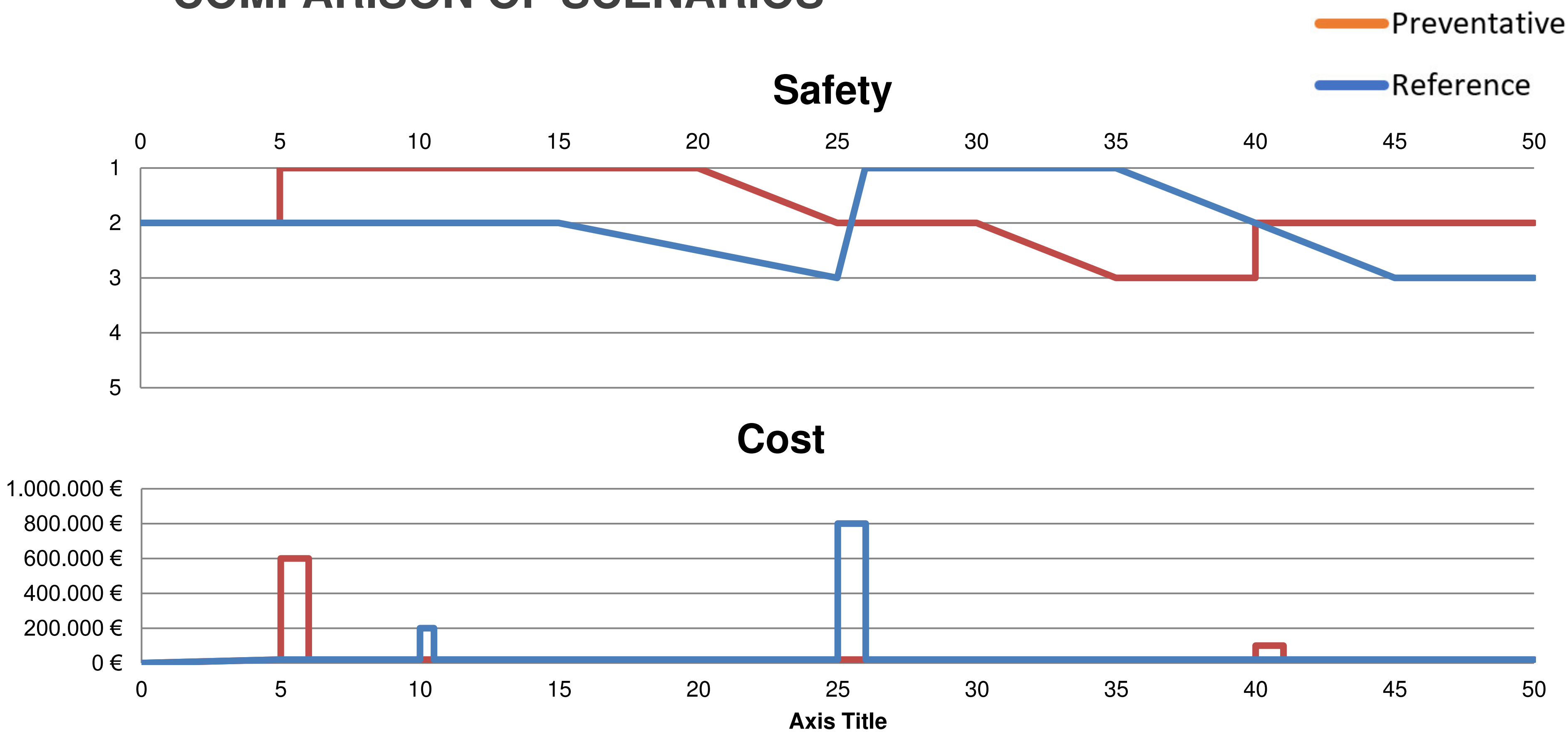
MAINTENANCE SCENARIOS

- COMPARISON OF SCENARIOS



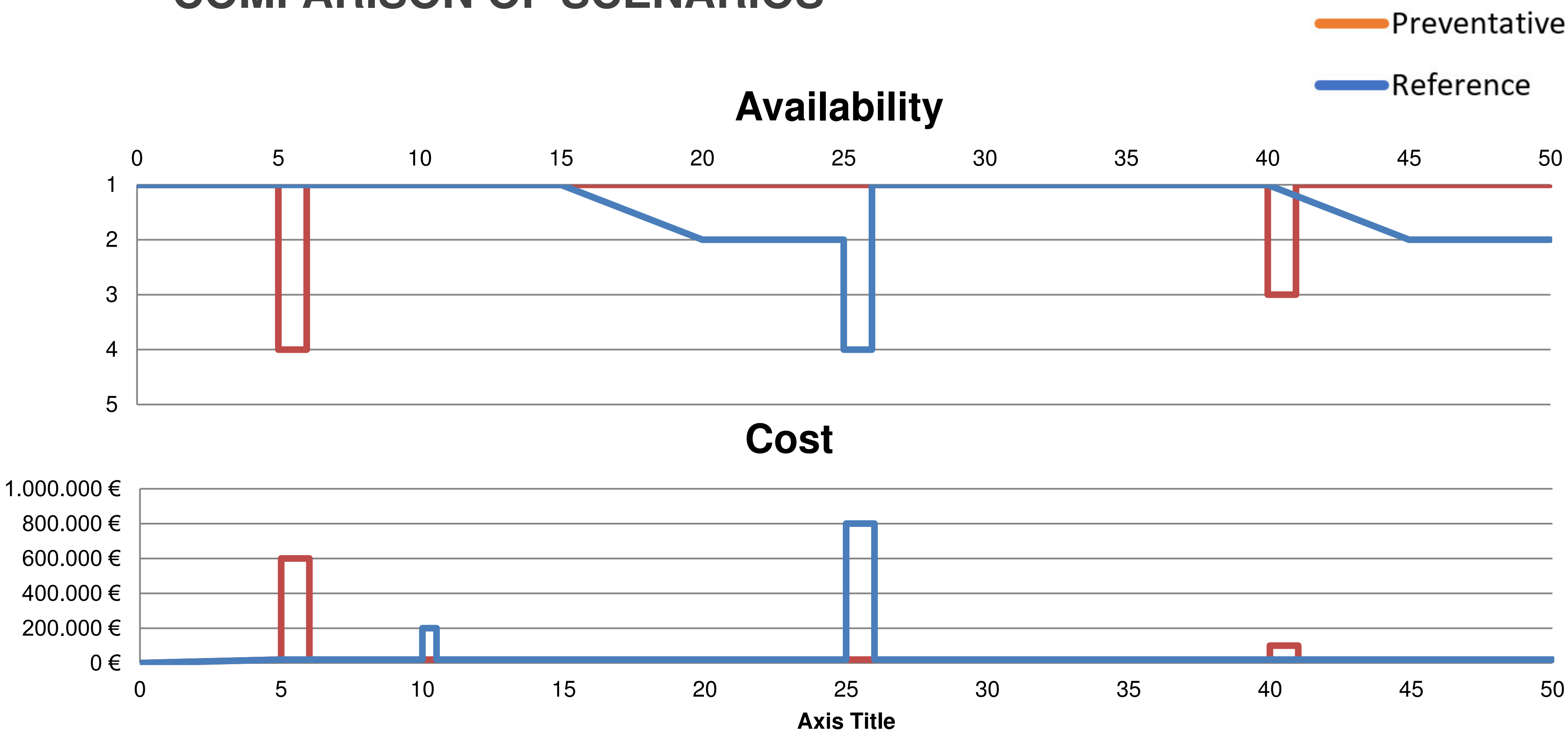
MAINTENANCE SCENARIOS

- COMPARISON OF SCENARIOS



MAINTENANCE SCENARIOS

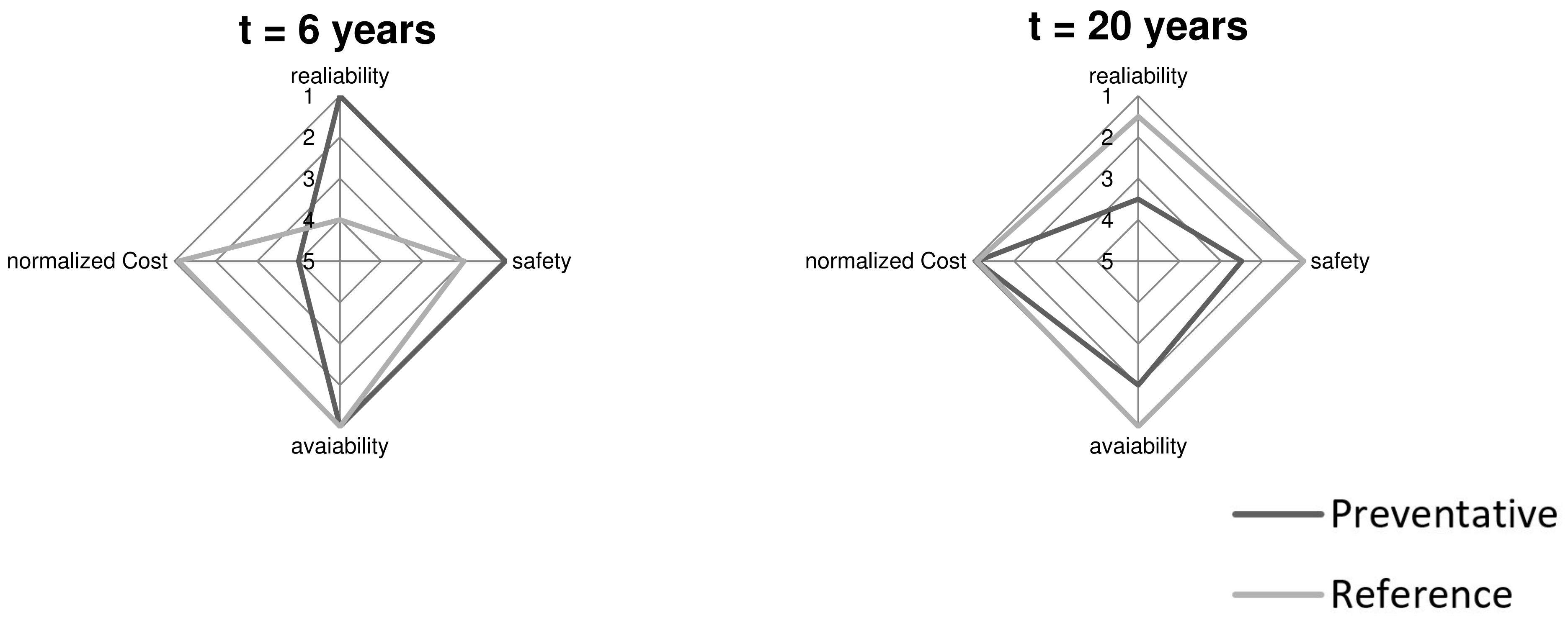
- **COMPARISON OF SCENARIOS**



MAINTENANCE SCENARIOS

SPIDER DIAGRAMS

- Normalizing the KPI's



CONCLUSIONS

Visual inspection:

- *Abutment cap (delamination, corrosion)*
- *Girder (visible tendon duct)*
- *Leakages*

Snapshot quality control:

- *Reliability 4*
- *Safety 2*

Dynamic quality control:

- *Reference scenario (10 y → AC, 25 y → big investment)*
- *Preventative scenario (5 y → big investment, 40 y → for safety)*

Assumption vs. quality control

- *Big influence, various scenarious, experiences*

COST ACTION TU1406
QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES,
STANDARDIZATION AT A EUROPEAN LEVEL

TRAINING SCHOOL
PRAGUE

Quality Specifications for Roadway Bridges, Standardization at European Level

September 25-28, 2017

Faculty of Civil engineering CTU, Prague, Czech Republic

[REPORT FOR THE PRE-STRESSED CONCRETE BRIDGE]

STUDENT INFORMATION

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Date	September 28, 2017

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

CONTENTS

1. INTRODUCTION

This training school is a part of COST TU1406 and the purpose was to validate the proposed framework with a set of inspectors with experience from bridge assessment in practice, to test the proposed framework with three different bridge typologies and to develop some exchange of knowledge between participants.

The task of this part of the working group was to assess the condition of the Kolbenova concrete bridge near Prague. The scope of the training school included:

1. preparatory work before going on site;
2. inspection on site;
3. laboratory testing;
4. assessment of reliability and safety;
5. assessment of remaining service life;
6. creating two maintenance scenarios.

The authors of this report are (in alphabetical order):

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9. Theodoros Asimakopoulos;
10. Viet Ha Nguyen.

1.1. GENERAL DESCRIPTION OF THE BRIDGE

The structure that is the object of evaluation of the present Technical Report is a Prestressed Concrete Bridge, namely **KOLBENOVA BRIDGE**, situated in the outskirts of the city of Prague (**Error! Reference source not found.** and Figure 1.1-2). The general description of the structure is given in Table 1.

Figure 1.1-1 - General overview of the Kolbenova bridge superstructure

Figure 1.1-2 - General overview of the Kolbenova bridge substructure

Table 1 – General description of the structure

GENERAL IDENTIFICATION DATA	
Road Name	Magistrat hlavniho mesta Prahy, TSK PRAHA, Praha 9
Traffic	Trucks : 1000 cars / 24h Personal cars: 13600 cars / 24h Tram: 450 cars/24h Total: 14350 cars / 24h
Bridge Name	MP-2 KOLBENOVA (obj.c. 610 – 004)
Identification Code	Y – 500..3
Construction Year	1967
Length	27,97m
Obstacle	train railway currently disaffected
Skew	41 degrees
Number of span	1
Bright with	18.99m (direct distance 11.43m)
Bright high	6.56m
Loads	acc. to V-CZEN

GEOMETRY	
Footpath	3.0 m x 2 (Steel handrail (railings) at both sides)
Carriageway	7.0 m x 2 (Two lanes in each directions)
Tram profiles	8.0 m
Width	28.0m
Total Width	28.40 m
Surface	671.40m2

SUBSTRUCTURE	
ABUTMENTS:	
Material	Reinforced Concrete, Class B 250 and B 135

Type	Classical form, direct foundations
Description	Abutments consist of three parts, containing successively (16.0m, 13.3m, 16.0m). The thickness of the abutments is 2.7m, the length is 46.86m and the high 8.05m.
Wingwall	Parallel frestending

SUPERSTRUCTURE

DECK	
Static system	Simply supported beam
Span 1	
Length	23,64m
Static length	22,0m
Material	Prestressed and reinforced concrete, Class C 35/40
Type	Simple beam
Description	The span construction is panel-shaped and consists in a number of 28 prefabricated mounting beams (factory mark KA 61-21z), cross-section (l x h) 1.0 x 1.0 m. Mounting elements consists of three parts.
BEARINGS	
Material	Steel
Type	Sliding - connected to the Abutment 1 (opposite to the Prague side of the bridge
	Fixed - connected to the Abutment 2 (Prague side of the bridge)
EXPANSION JOINTS	
Material	Copper
Position	Abutment 2
Description	Existence of pipe drainage at expansion joints in a mounting beam.
WATERPROOFING	There is
DRAINAGE	Transverse and longitudinal slopes (draining grid is not on the bridge)
UTILITIES	Water pipe; Gas pipe; Electrical installation

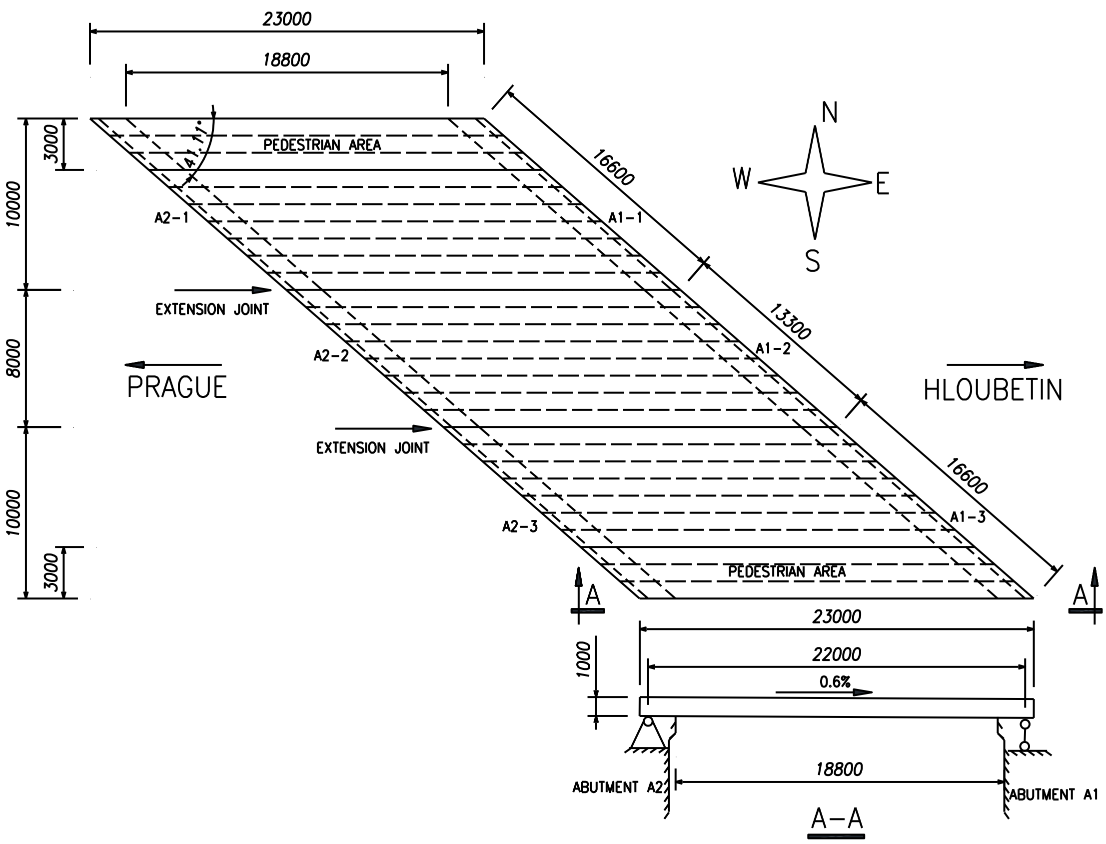

Figure 1.1-3 – Plan view of Kolbenova bridge

2. VISUAL INSPECTION

2.1. SUBSTRUCTURE

2.1.1. ABUTMENTS

The abutments are numbered based on:

- the end of the bridge:
    - A1 – the abutment on the east side of the bridge;
    - A2 – the abutment on the west side of the bridge.
- sections based on the perpendicular division:
    - section 1 is under the lanes, that head towards Prague;
    - section 2 is the middle section that is under the tram lines;
    - section 3 is under the lanes, that head out of Prague.

The abutments consist of two parts – the gravity part, that has no reinforcement and the upper part, that is reinforced. The numbering and damages of abutments can be seen in the following Figures (**Error! Reference source not found.**…Figure 2.1-9).

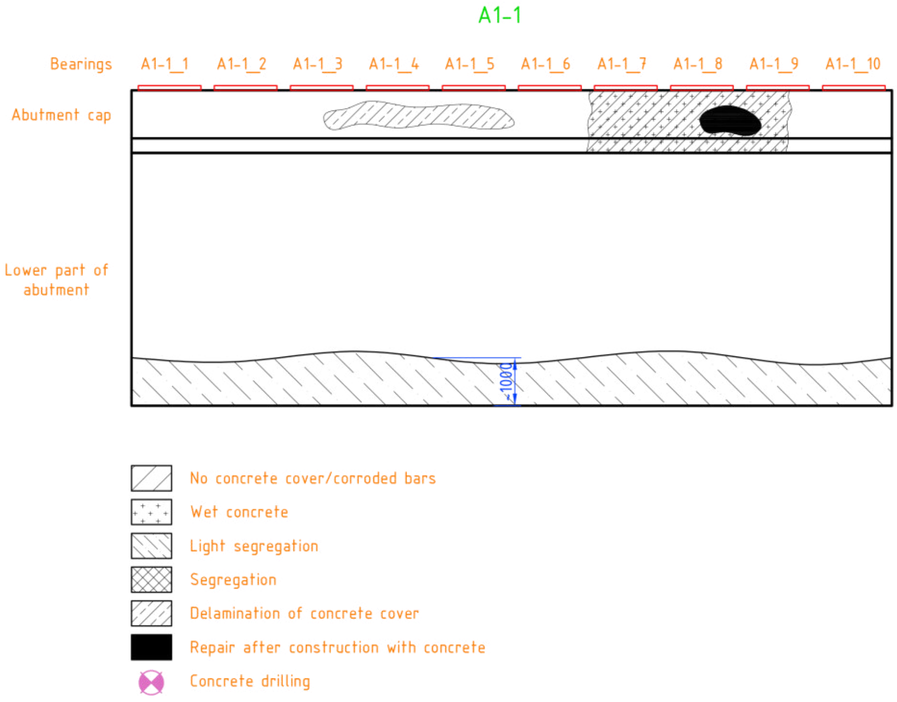

Figure 2.1-1 - A1-1 numbering and damages

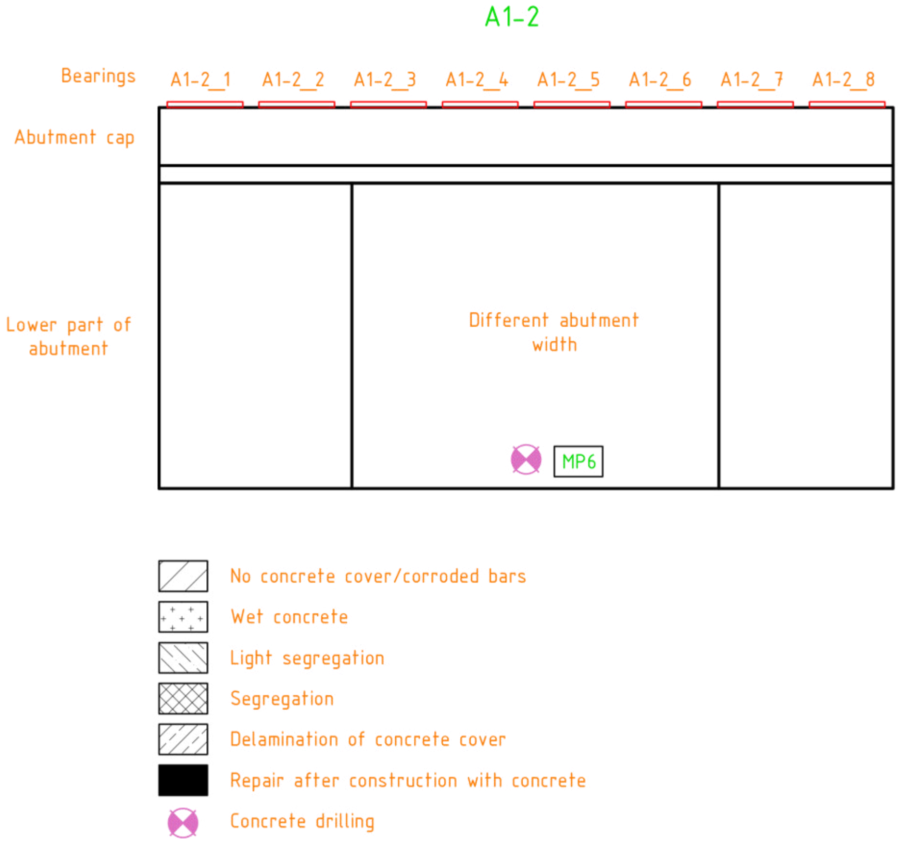

Figure 2.1-2 - A1-2 numbering and damages

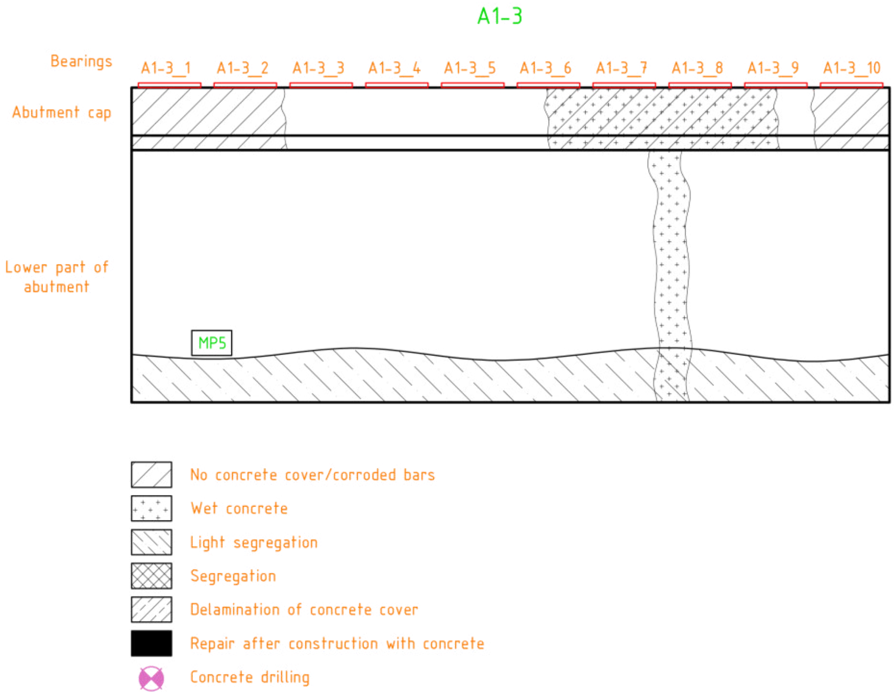

Figure 2.1-3 - A1-3 numbering and damages

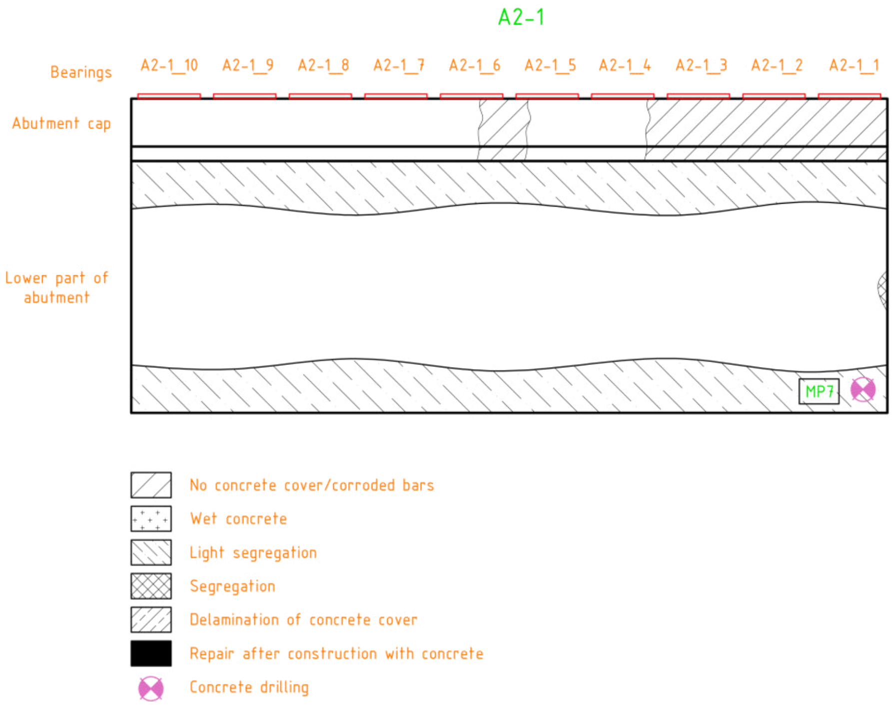

Figure 2.1-4 - A2-1 numbering and damages

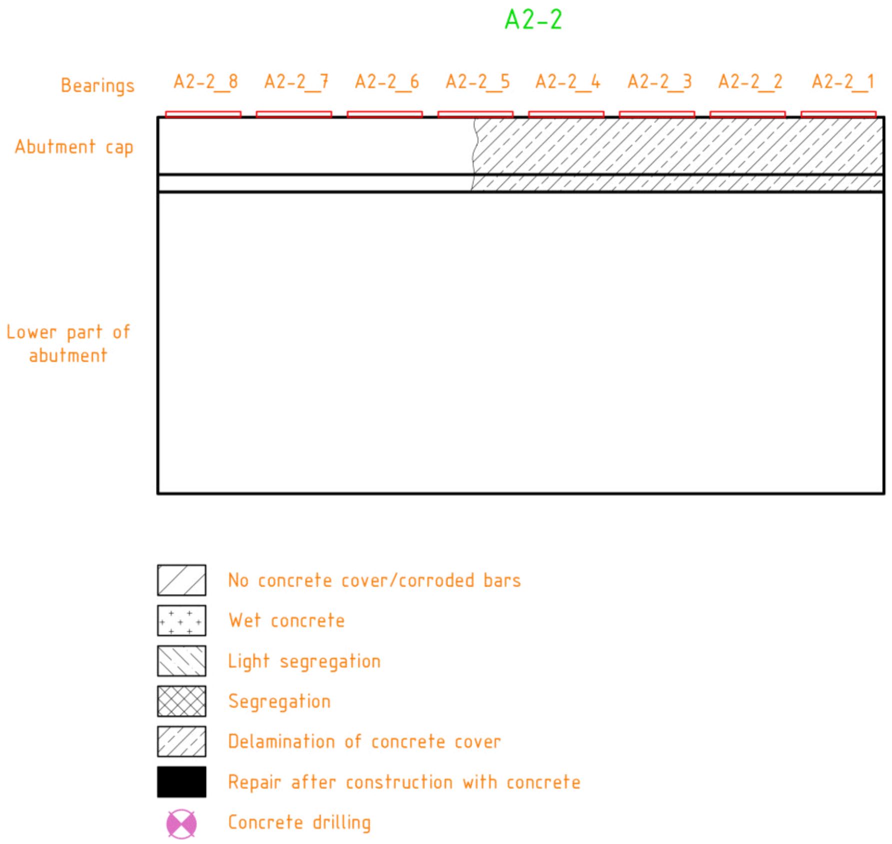

Figure 2.1-5 - A2-2 numbering and damages

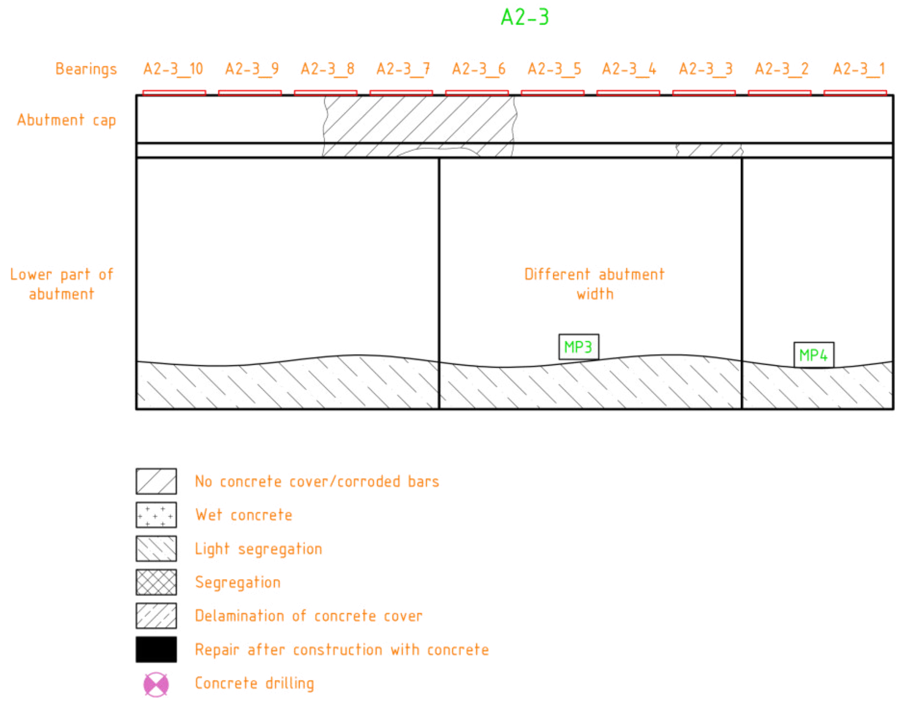

Figure 2.1-6 - A2-3 numbering and damages

Figure 2.1-7 – A1-3 damages of concrete cover and corroded bars

Figure 2.1-8 - A2-1 damages of concrete cover and corroded bars

Figure 2.1-9 – Water leakage at A1-3

2.1.2. BEARINGS

The bearings are numbered by the abutments and sections (abutments A1 and A2 and sections 1…3). Each abutment has its own number according to the girder it is supporting and is illustrated in **Error! Reference source not found.**...Figure 2.1-6. The girders are simply supported with roller bearings at abutment A1 and fixed bearings at abutment A2. Pictures of the state of the bearings are in Figure 2.1-10…Figure 2.1-15.


Figure 2.1-10 - Bearing A1-3_10


Figure 2.1-11 - Bearing A1-3_9

Figure 2.1-12 - Bearing A1-3_8

Figure 2.1-13 - Bearing A1-3_7

Figure 2.1-14 - Bearing A1-3_6

Figure 2.1-15 - Bearing A2-3_10

2.1.3. WING WALLS

Wing walls have minor damages (e.g. loss of cement matrix in Figure 2.1-16) and there are no exposed reinforcing bars.

Figure 2.1-16 – Loss of cement matrix at wingwall

2.2. SUPERSTRUCTURE

2.2.1. GIRDERS

Bridge is comprised of totally 28 prestressed prefabricated concrete box girders, 10 in north and south sections and 8 in the middle section. Girders are longitudinally comprised of 4 sections which are mutually connected with longitudinally prestressed tendons. Girders are labelled according to Figure 2.2-1.

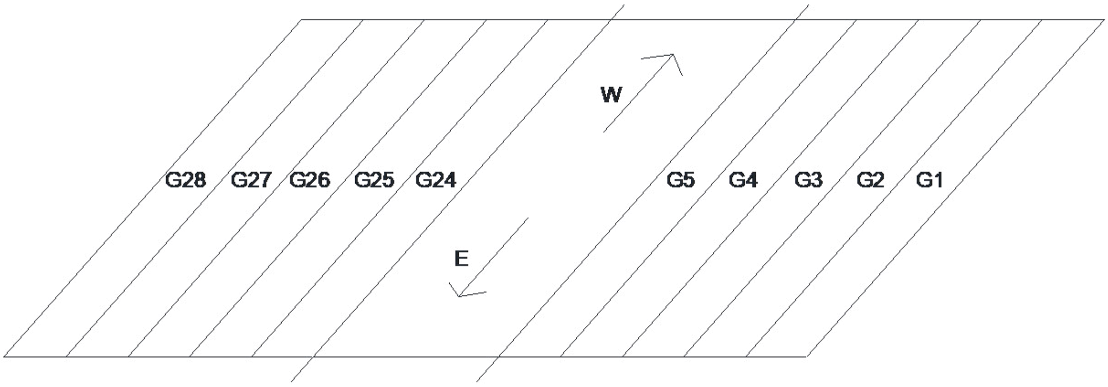

Figure 2.2-1 - Labels and orientation of the girders

Visual inspections of girders reveal that the bridge has serious drainage issues, as majority of longitudinal joints between girders are seriously affected by water. Probable cause is bad drainage system that causes water from the pavement entering the bridge structure, causing corrosion of longitudinal and shear reinforcement and delamination of concrete cover accordingly.

Figure 2.2-2 - Leakage between girders joints

Figure 2.2-3 - Leakage between girder joints

Amount of corrosion varies from girder to girder, according to amount of water leakage between them. Most seriously affected girder is number G11, where the corroded tendon is visible:

Figure 2.2-4 - Girder G11 with visible tendons

Figure 2.2-5 - Girder G11

Initiation of longitudinal reinforcement corrosion is also visible on other girders, mainly on edge part of the bridge, where leakage is most severe. In general, these girders are not endangered at present time, but corrosion progression should be monitored in the future.

Figure 2.2-6 - Initiation of longitudinal reinforcement corrosion on girders G1-G5

Figure 2.2-7 - Initiation of longitudinal reinforcement corrosion o girders G1-G7

Water leakage also caused corrosion of shear reinforcement (stirrups) on some of the girders, mainly on edge girders and close to bearings. Corrosion is only in initiation phase and it doesn't affect the bridge shear capacity at present.

Figure 2.2-8 - Initiation of stirrups corrosion on bearings G1-G6

Delamination of concrete cover on girders affected with corrosion is causing chunks of concrete falling under the bridge, as shown on the figure below. As the space under the bridge is hardly accessible and is in no use, this delamination of concrete cover does not represent immediate danger.

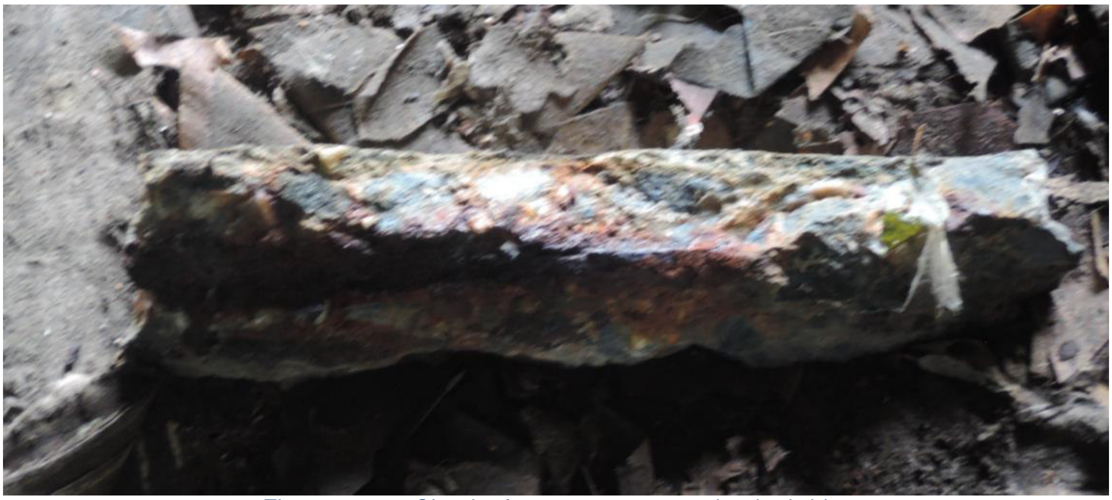
Figure 2.2-9 - Chunk of concrete cover under the bridge

Although some of the girders are seriously affected by corrosion, no signs of flexural and shear cracks were noted during the visual inspection of the bridge.

During the inspection of the bearings on edge girders, it was revealed that anchorage plates on the end of girders are corroded and surrounding concrete has fell away, exposing the plate to environmental impact.


Figure 2.2-10 - Corrosion of anchorage plate and spalling of surrounding concrete

Impact of anchorage plate corrosion on prestressed tendons cannot be established without experimental testing, but there are no signs of tendon failure on the girder (if tendons are properly grouted, corrosion progression will not affect them).

2.2.1.PAVEMENT

Asphalt in the traffic lanes has been recently repaired and is in relatively good condition, no major cracks or denivelation areas were noted during the visual inspection. Pedestrian walkaways are also repaired number of times, but with serious flaws, with bad inclination and denivelations, causing the water to remain on the walkaways.

Figure 2.2-11 - Denivelation of the pedestrian walkaway

On the middle strip (rails) of the pavement amount of cracks is noted, along with vegetation growing out beneath the blocks. These defects don't affect bridge load capacity, but they are affecting serviceability for the users, and also allowing water to penetrate in the bridge structure.

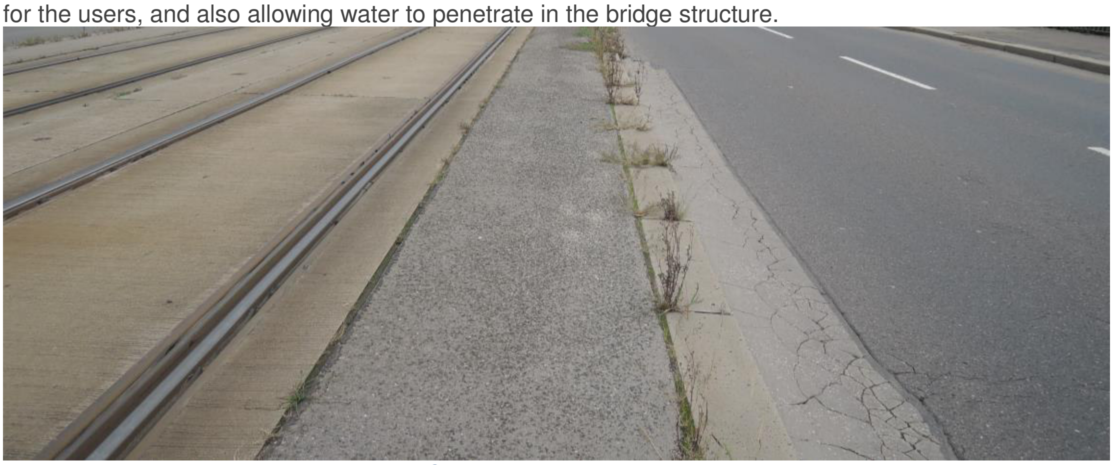

Figure 2.2-12 - Cracks and vegetation in the middle strip

Pavement drainage system is comprised of drains on each side of the bridge, placed before and after of bridge expansion joints (covered in asphalt). Drains are not in very good condition, although they are relatively clean, but theirs damage is allowing the water to penetrate in the bridge structure. Also, water is not draining from walkaways, causing the edge girders to deteriorate.

Figure 2.2-13 - Pavement drain - damage on the left is causing the water penetration in the structure

Overall, bridge pavement is in relatively good condition, there are no major damages that would impact the serviceability of the bridge. Most important issue for the bridge reliability is drainage system that would need major reconstruction.

2.2.2.RAILINGS

New bridge railings have been constructed in 2014, and is in overall good condition, beside the occasional spots of corrosion initiation. It should be noted that old railing has not been properly removed, and old anchorage spots have remained on bridge end beam.

Figure 2.2-14 - Anchorage of removed railing

Figure 2.2-15 – New bridge railing

2.2.3.EDGE BEAM OF BRIDGE SUPERSTRUCTURE

Bridge edge beam is monolithic, connected to the bridge deck, and gas pipe is attached with steel anchorages to it. There are no visible damages to edge beam, beside the delamination of concrete cover, which occurs occasionally along the beam.

3. RESULTS OF TESTING

3.1. STRENGTH OF CONCRETE

The strength of concrete was tested in two ways – using an NDT method (rebound hammer) and taking cores. Cores were taken from three places of the structure – two from the abutments (MP-6 and MP-7) and one from the girder (MP-2).

The results of the concrete strength estimation using the Schmidt Hammer regard the following:

- each location has 1…3 sets of impacts and each set has 11…15 impacts;
- the results are given as a mean value of all impacts;
- the conversion curve from the Q-value to the concrete strength used is “Curve EU”;
- the strength evaluation is given as a 150 mm cubic value.

The results of the strength testing is given in Table 2.The result of the core testing for MP-2 (girder) is not reliable because the ends of the cylinder were uneven. Pictures of the cores after the compression test are in Figure 3.1-1 and Figure 3.1-2.

Table 2 - Concrete strength testing results

Element	Measuring point	Results of Schmidt hammer	Result of core samples
Girder	MP-1	93 MPa, 77 MPa, 72 MPa	No core taken
Girder	MP-2	79 MPa, 70 MPa, 71 MPa	28 MPa
Abutment A2-3	MP-3	14 MPa, 17 MPa, 22 MPa	No core taken
Abutment A2-3	MP-4	20 MPa, 22 MPa, 22 MPa	No core taken
Abutment A1-3	MP-5	12 MPa, 13 MPa	No core taken
Abutment A2-1	MP-6	35 MPa	11 MPa
Abutment A1-2	MP-7	-	6 MPa, 9 MPa

Figure 3.1-1 - Concrete core from girder (MP-2) after compression test

Figure 3.1-2 - Concrete core from abutment (MP-6) after compression test

3.2. CARBONATION

Carbonation depth was assessed using a phenolphthalein solution. It is important for the concrete of the girder, where it was only a few millimeters (**Error! Reference source not found.**). For the abutment walls it is not important, because there is no reinforcement.

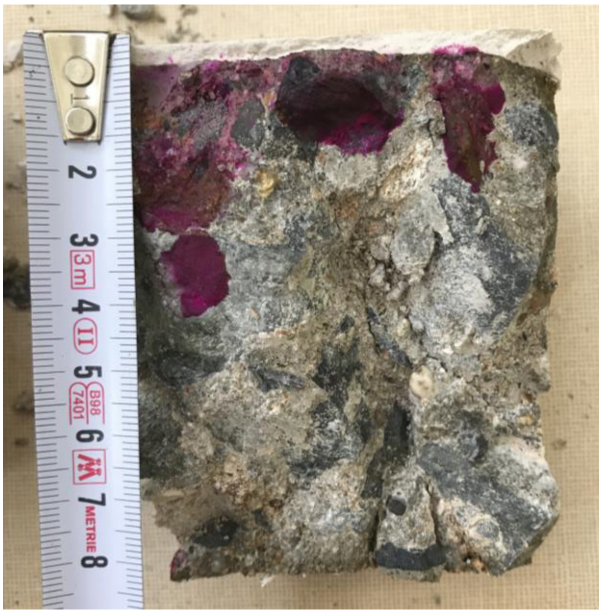

Figure 3.2-1 - Carbonation of the main girder core

4. ANALYSIS

4.1. THE SNAPSHOT ASSESSMENT OF RELIABILITY AND SAFETY

After the visual inspection the possible failure modes of the bridge elements were identified, which were:

- flexural failure;
- shear failure;
- rigid body failure;
- serviceability failure.

The more detailed descriptions of the bridge elements and failure modes related to the reliability and safety of the bridge are shown in **Error! Reference source not found.**. Before the assessment of the elements the scoring table was established with a scale from 1…5, where 1 means no reduction in the functioning of the elements or no signs of deterioration and 5 meaning no functioning or complete failure of the element. The highest value of rating of reliability related to the visual inspection is 4, which was tribute for the cap of the abutment, where the delamination and corrosion can cause rigid body failure of the deck. The assessment of safety (life and limb) was worst for railing and traffic pavement (score of 2).

Table 3 - Assessment of the reliability and safety of the bridge elements

Element	Material/ element	Year of construction/ reconstruction	Failure mode	Damages and symptoms	Reliabilit/ safety	Rating
Abutment cap	Reinforced concrete	1967	rigid body failure	delamination	realiabilty	4
Traffic pavement	Asfalt	?	serviceability failure	cracks	realiabilty	2
Bearings	Roller, fixed	1967	serviceability failure	corrosion	realibility	3
Abutment cap	Reinforced concrete	1967	rigid body failure	corrosion	reliabilty	4
Girders	Post-tensioned concrete	1967	flexural failure	corrosion	reliabilty	3
Girders	Post-tensioned concrete	1967	shear failure	corrosion	reliabilty	2
Girders	Post-tensioned concrete	1967	flexural failure	cracks	reliabilty	2
Walkway pawement	Asfalt	?	serviceability failure	cracks	reliabilty	3
Old railing	Steel	1967 (speculation)	serviceability failure	corrosion of the old pedestals	reliabilty	2
Walkway pawement	Asfalt	?	serviceability failure	unevenes	safety	2
Traffic pavement	Asfalt	?	serviceability failure	unevenes	safety	2
New railing	Steel	2014	serviceability failure	initiation of corrosion of the elements, bad fixing	safety	2

4.2. MAINTENANCE SCENARIOS

4.2.1. REFERENCE SCENARIO

The reference scenario represents the most common approach for the maintenance of the structure where action is taken only at threshold values of KPI. Two rehabilitation measures were considered in this scenario:

- the rehabilitation of the heavily corroding abutment cap with an approximate cost of 200 000 € in 10 years;
- the remediation of the pavement, waterproofing, railing, drainage system and bearings with an approximate cost of 600 000 € in 25 years.

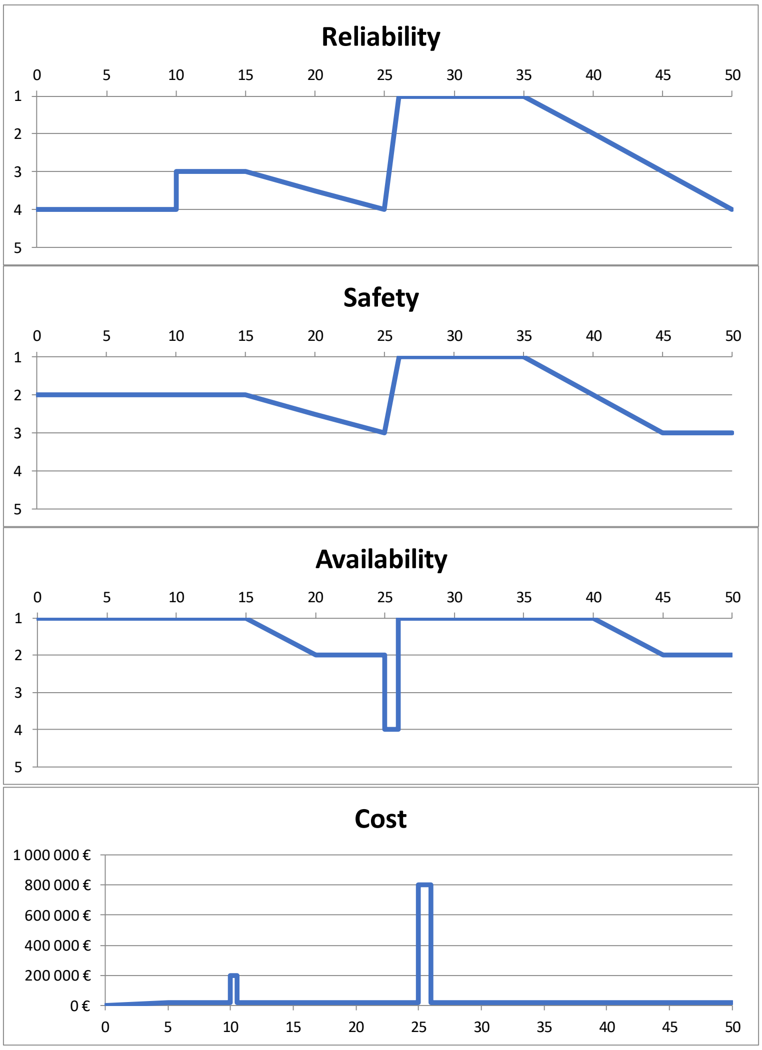

Figure 4.2-1 - Reference scenario reliability, safety, availability and costs

4.2.2.PREVENTATIVE SCENARIO

The preventative scenario includes a complete remediation measure in 5 years, where the abutments, girders, pavements, drainage system, waterproofing and bridge bearings are rehabilitated.

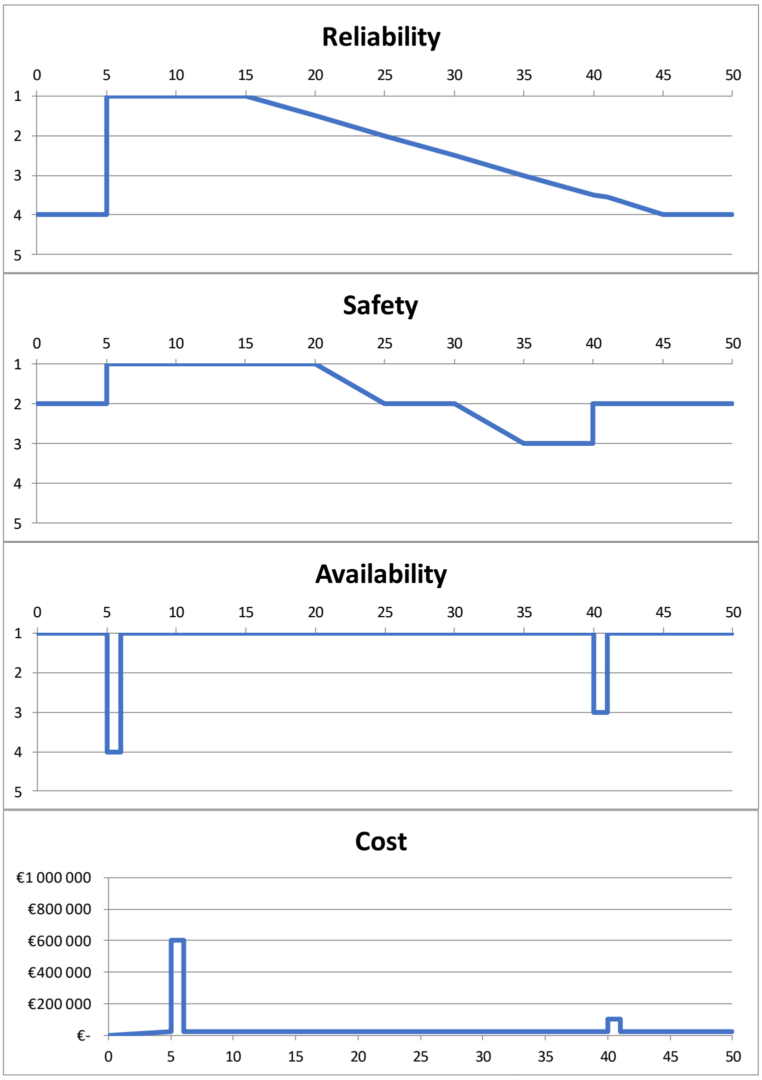

Figure 4.2-2 – Preventative scenario reliability, safety, availability and costs

4.3. SPIDER-DIAGRAM

In order to draw the spider-diagram we normalized the costs of the remediation measures to the maximum assumed value of the two scenarios. The spider diagrams were chosen to be done for the 6th and 20th year and are illustrated in Figure 4.3-1 and Figure 4.3-2.

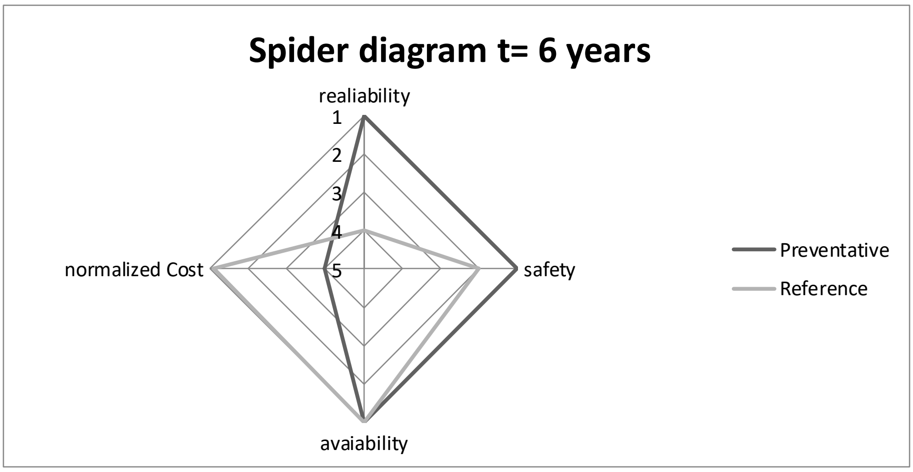

Figure 4.3-1 - Spider diagram for the 6th year

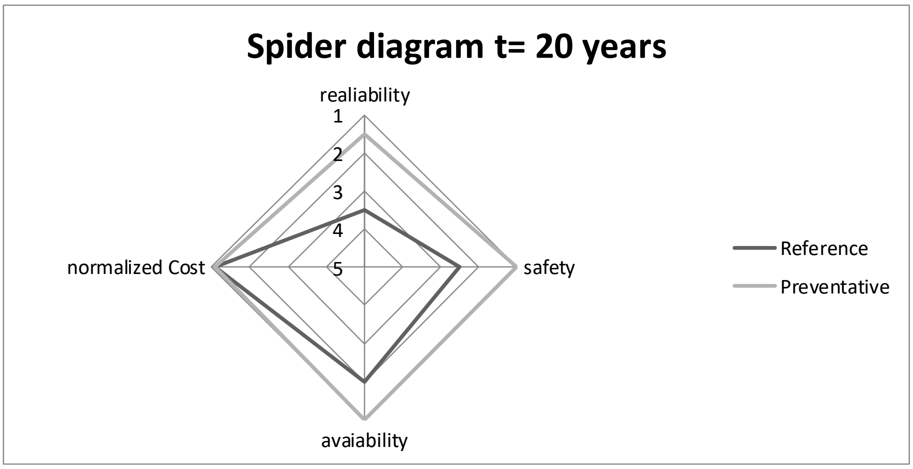

Figure 4.3-2 - Spider diagram for the 20th year

5. CONCLUSIONS

Visual inspection:

- Abutment cap (delamination, corrosion)
- Girder (visible tendon duct)
- Leakages

Snapshot quality control:

- Reliability 4
- Safety 2

Dynamic quality control:

- *Reference scenario (10 y → AC, 25 y → big investment)*
- *Preventative scenario (5 y → big investment, 40 y → for safety)*
- *Normalization to the respect of the replacement of the whole structure (new bridge) should be taken into account in future studies.*

Assumption vs. quality control

- Big influence, various scenarios, experiences

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QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School on Bridge Quality Control
25th – 29th September, 2017
Faculty of Civil Engineering CTU in Prague
Prague, Czech Republic

MASONRY ARCH BRIDGE

Milan Petřík – Mott MacDonald CZ, Czech Republic
Dmitry Stuchevsky – Kedmor Engineers, Israel
Milan Bosnjakovic – Public Investment Management Office, Government of Serbia
Tomasz Kaminski - Wroclaw University of Science and Technology, Poland

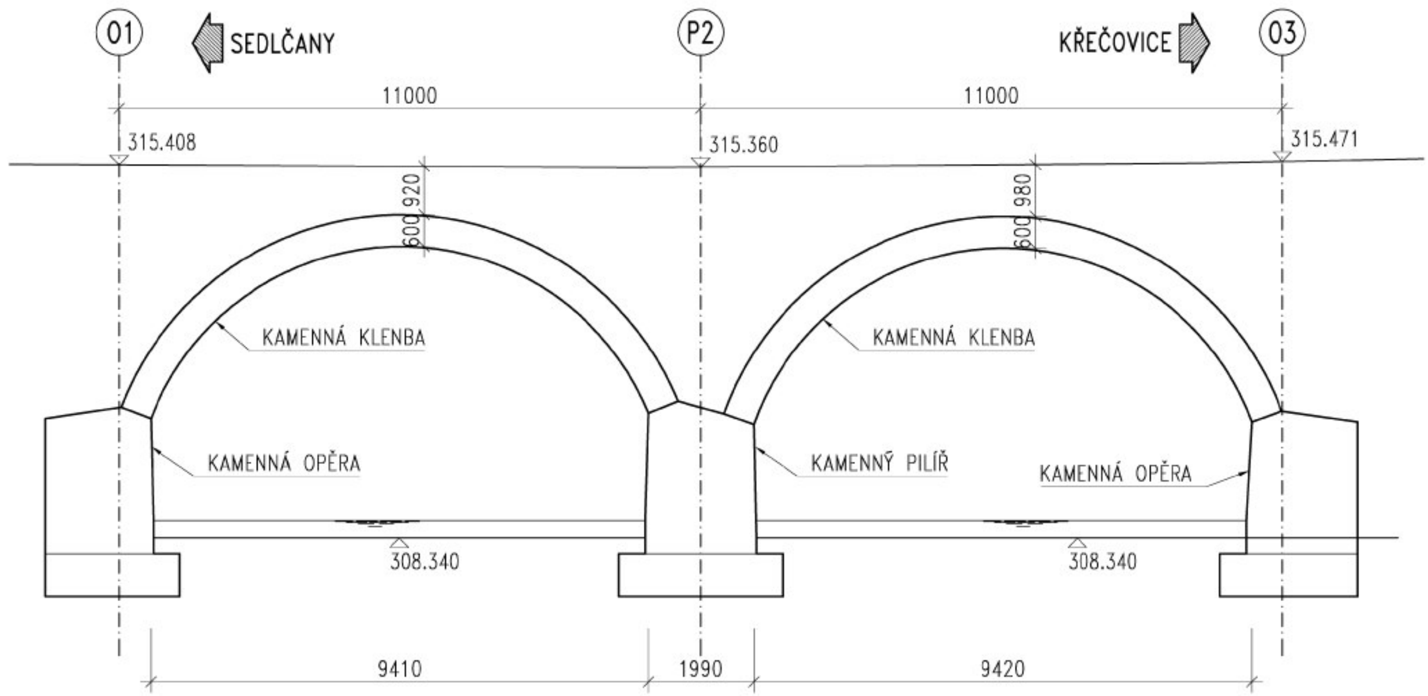
ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

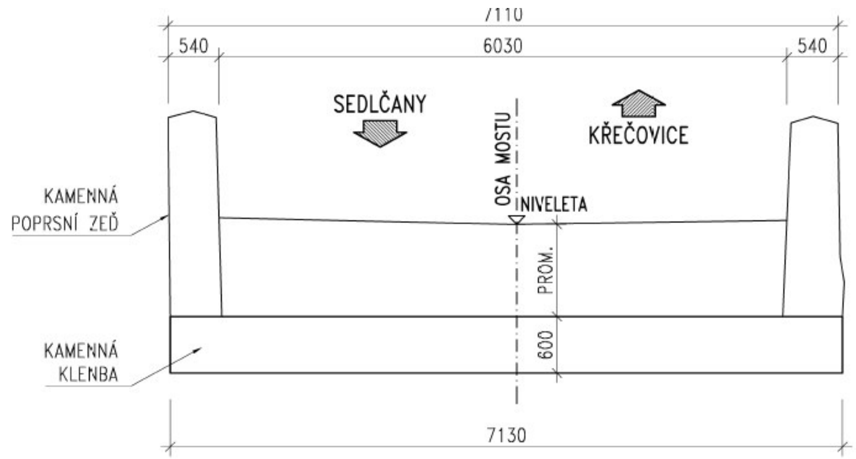
GENERAL DATA

- The inspected bridge is a two-span stone arch structure built in 1873. The bridge carries road across the stream Mastík in Osečany town.



GENERAL DATA

- FOUNDATION
- SUBSTRUCTURE
- SUPERSTRUCTURE
- ACCESSORIES

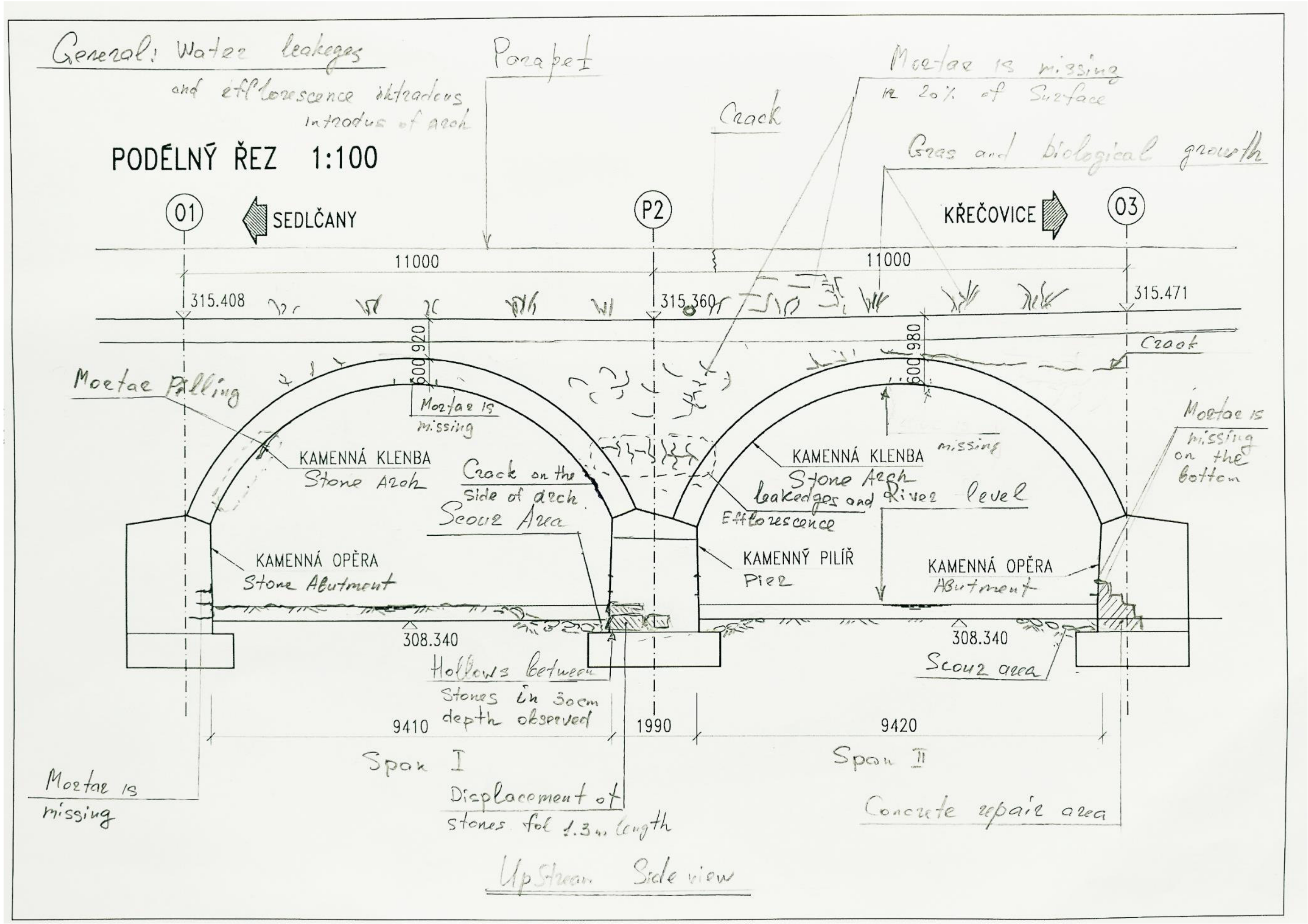


ADDITIONAL FINDINGS

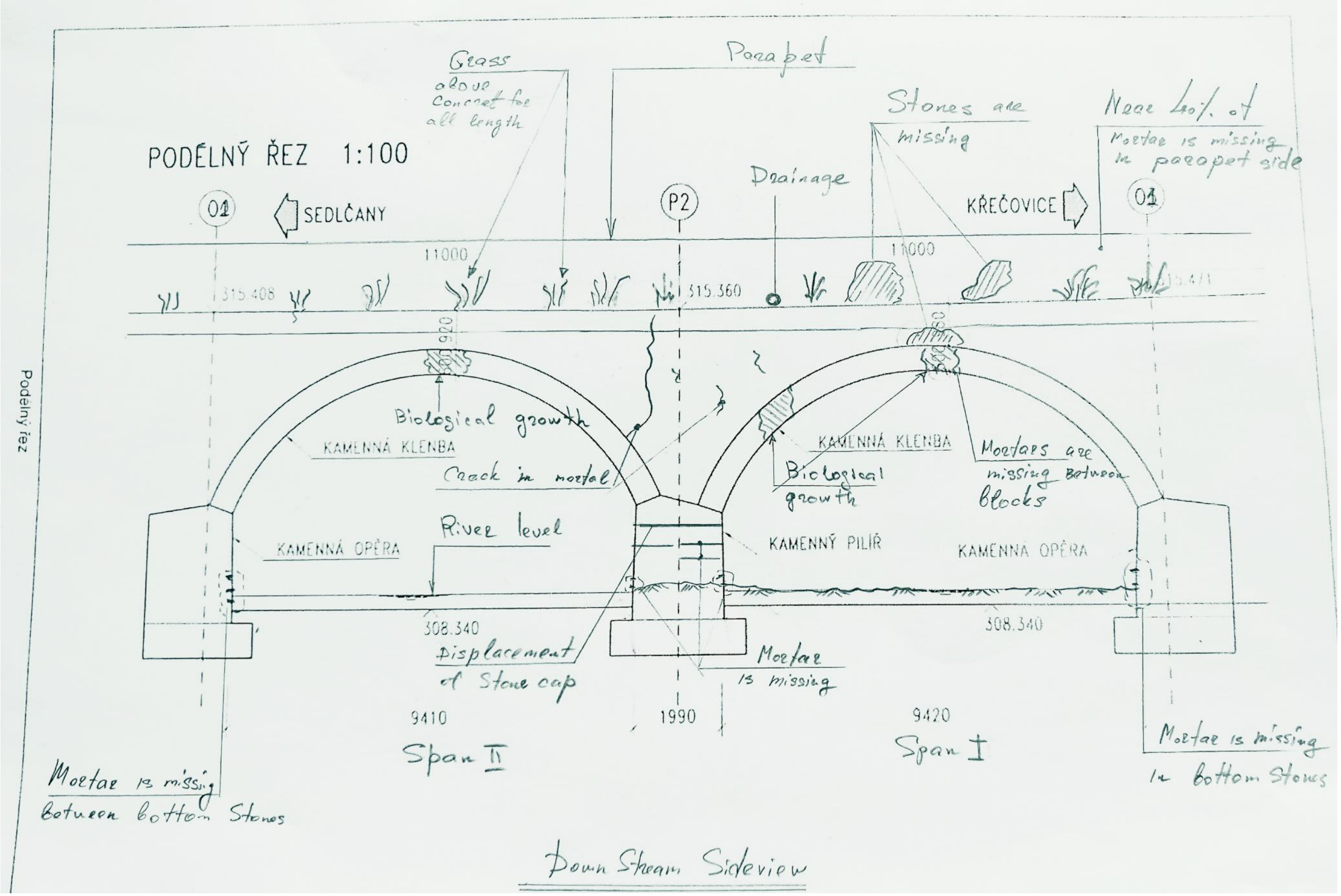
DEFECTS

- Scour of supports
- Fractures of spandrel walls
- Damage waterproofing of the arch and spandrel walls
- Loss of mortar
- Loss of stones
- Degradation and cracking of parapets
- Plant vegetation (biological growth)
- Defects of pavement
- Erosion of embankment
- Inefficiency of drainage

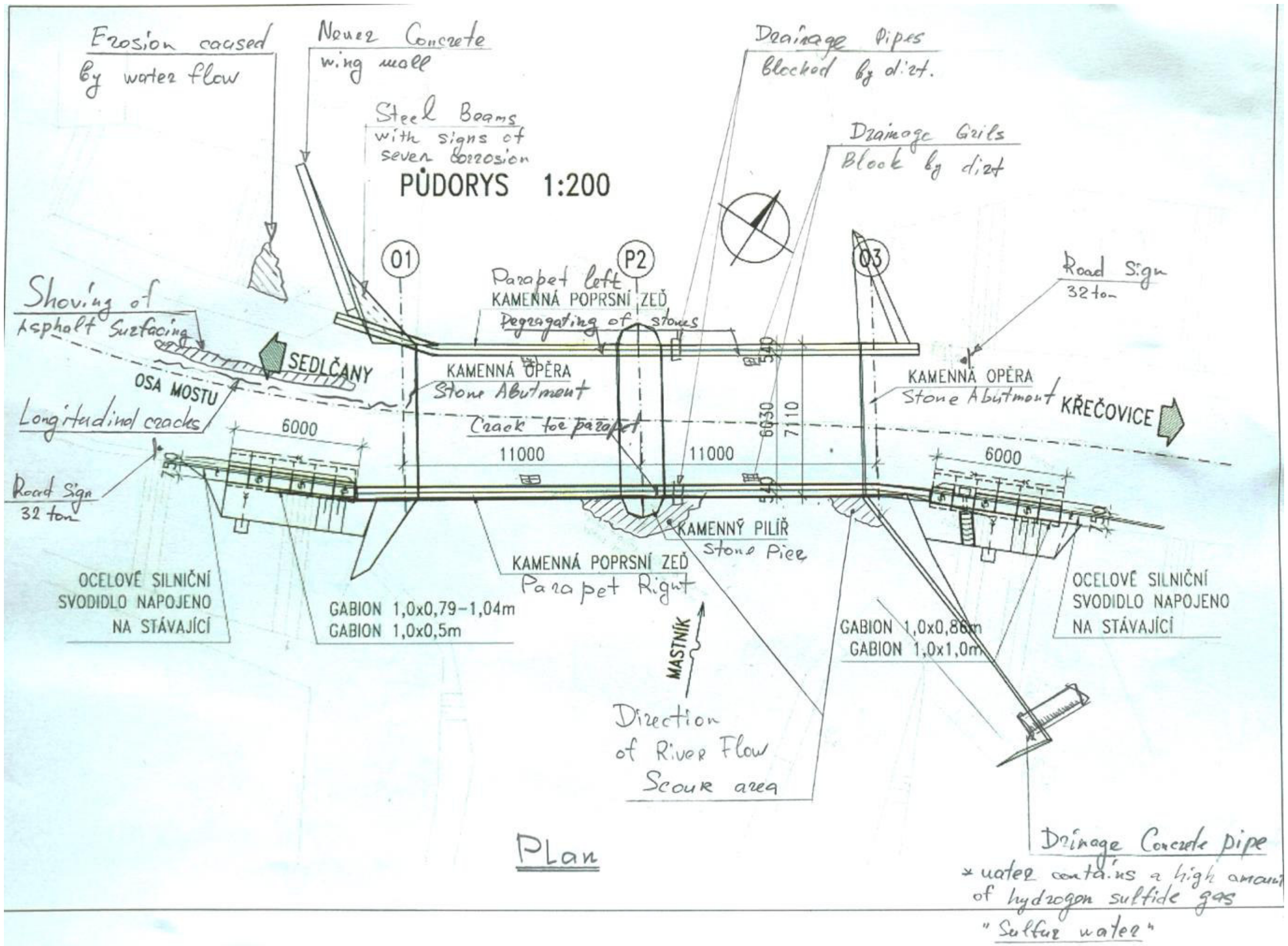
DEFECTS


General: Water leakages and efflorescence intrados introdus of arch
Parapet
Mortar is missing in 20% of surface
Crack
Gras and biological growth
PODÉLNÝ ŘEZ 1:100
01
SEDLČANY
P2
KŘEČOVICE
03
11000
11000
315.408
315.360
315.471
Crack
920
600
980
600
Mortar falling
Mortar is missing
KAMENNÁ KLENBA
Stone Arch
Crack on the side of arch
Scour Area
missing
KAMENNÁ KLENBA
Stone Arch
Leakages and efflorescence
River level
Mortar is missing on the bottom
KAMENNÁ OPĚRA
Stone Abutment
KAMENNÝ PILÍŘ
Pier
KAMENNÁ OPĚRA
Abutment
308.340
308.340
Scour area
Hollows between stones in 30cm depth observed
9410
1990
9420
Span I
Span II
Mortar is missing
Displacement of stones for 1.3m length
Concrete repair area
UpStream Side view

DEFECTS


Grass above Concrete for all length
Parapet
Stones are missing
Near 40% of Mortar is missing in parapet side
PODÉLNÝ ŘEZ 1:100
Drainage
01
SEDLČANY
P2
KŘEČOVICE
01
11000
315.408
315.360
11000
Podélný řez
Biological growth
KAMENNÁ KLENBA
Crack in mortal
KAMENNÁ KLENBA
Biological growth
Mortars are missing Between Blocks
River level
KAMENNÁ OPĚRA
KAMENNÝ PILÍŘ
KAMENNÁ OPĚRA
308.340
308.340
Displacement of Stone cap
Mortar is missing
9410
1990
9420
Span II
Span I
Mortar is missing between bottom Stones
Mortar is missing in bottom Stones
Down Stream Sideview

DEFECTS

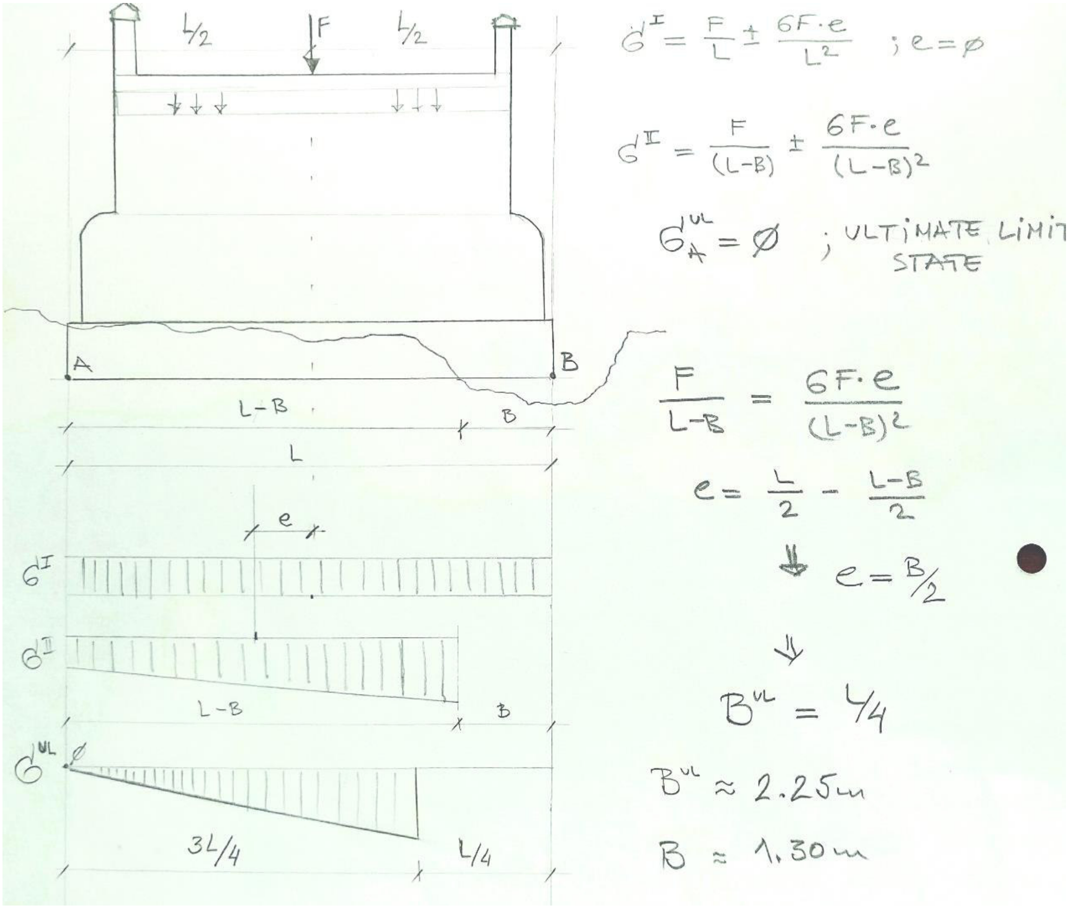

Erosion caused by water flow
Never Concrete wing wall
Steel Beams with signs of seven corrosion
PŮDORYS 1:200
Drainage Pipes blocked by dirt.
Drainage Grils Block by dirt
01
P2
03
Showing of Asphalt Surfacing
Parapet left
KAMENNÁ POPRSNÍ ZEĎ
Degragating of stones
Road Sign 32 ton
SEDLČANY
OSA MOSTU
KAMENNÁ OPĚRA
Stone Abutment
KAMENNÁ OPĚRA
Stone Abutment
KŘEČOVICE
Longitudinal cracks
Crack for parapet
6000
11000
11000
6030
7110
6000
Road Sign 32 ton
KAMENNÝ PILÍŘ
Stone Pier
OCELOVÉ SILNIČNÍ SVODIDLO NAPOJENO NA STÁVAJÍCÍ
GABION 1,0x0,79-1,04m
GABION 1,0x0,5m
KAMENNÁ POPRSNÍ ZEĎ
Parapet Right
MASTNÍK
GABION 1,0x0,86m
GABION 1,0x1,0m
OCELOVÉ SILNIČNÍ SVODIDLO NAPOJENO NA STÁVAJÍCÍ
Direction of River Flow
Scour area
Plan
Drinage Concrete pipe
* water contains a high amount of hydrogen sulfide gas
"Sulfur water"

DEFECTS

DEFECTS




POTENTIAL FAILURE MODE OF THE BRIDGE



- Assumed ULS of the foundation at settlement is related to occurrence of lifting of one of the edges of the it. It may occur when the width B of the scour is reaching ¼ of the length of the foundation according to the scheme.

MATERIAL TESTING



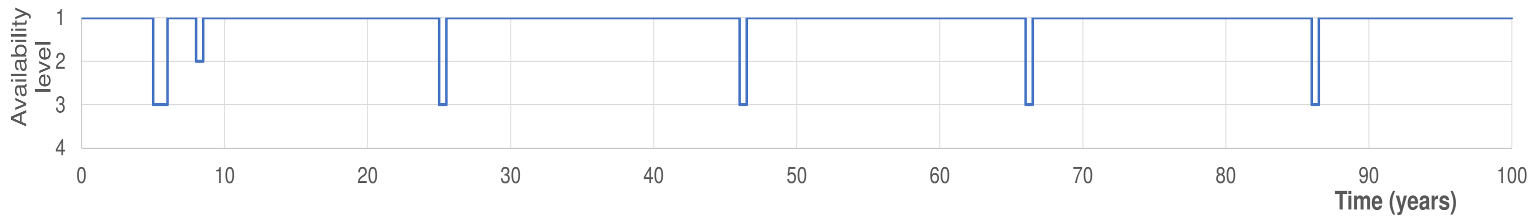

MATERIAL TESTING

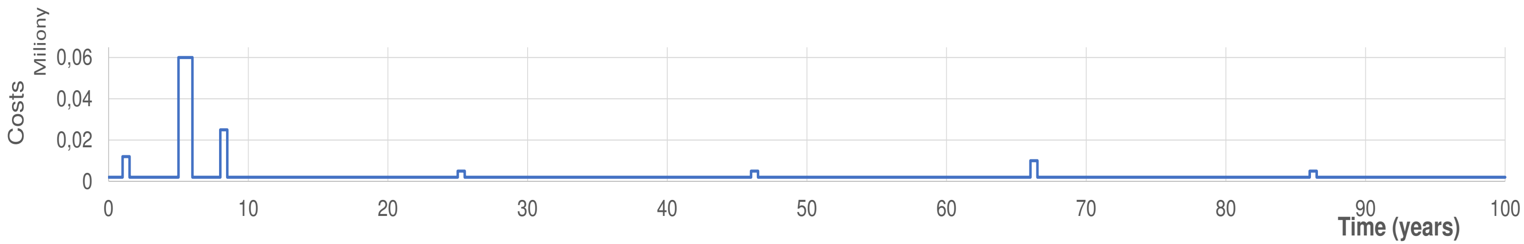
Specimen	Diameter [mm]	Area [cm^2]	Maximum Force [kN]	Maximum Stress [MPa]
No. 1	73,85	35,80*	10,1	28,2
No. 2	73,60	42,52	16,4	38,6

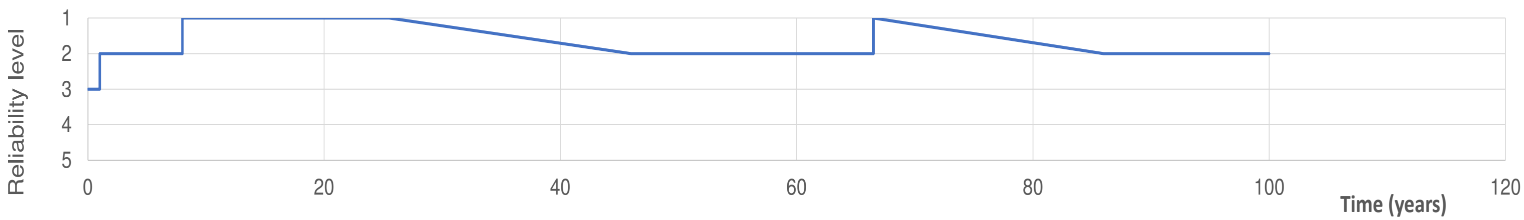
KEY PERFORMANCE INDICATORS

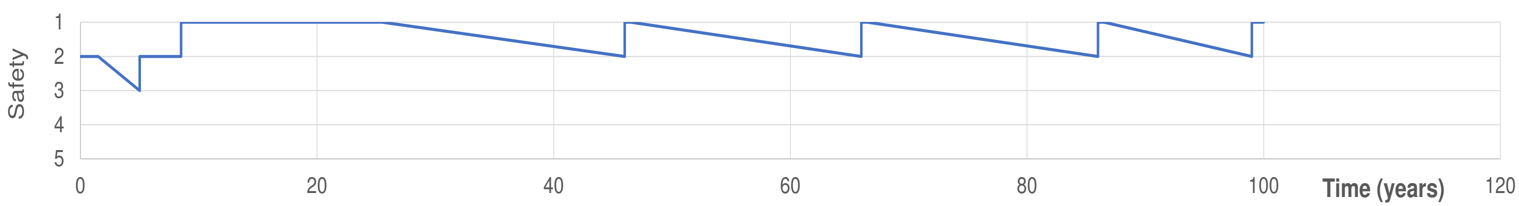
Structure	Component	Material	Design and construction	Failure mode	Vurnerable zone	Symptoms	KPI	Performance indicator		Estimated failure time
Two span arch bridge	Pier	Stone	1871	Global failure	Foundations	Stone displacement	Reliability (Structure safety)	3	3	**25 years**
	Abutment	Stone	1871		Foundations	Stone displacement		2		**25 years**
	Spandrel walls	Stone	1871	Wall collapse	Bottom section of spandrel wall	Stone displacement		2		**15 years**
	Parapets	Stone	2015	Parapet collapse	Bottom section of parapet	Stone displacement	Safety	2	2	**15 years**
	Pavement	Asphalt concrete	2015	Skid resistance	Top surface	Crack & sweating		2		**5 years**

PREVENTATIVE APPROACH

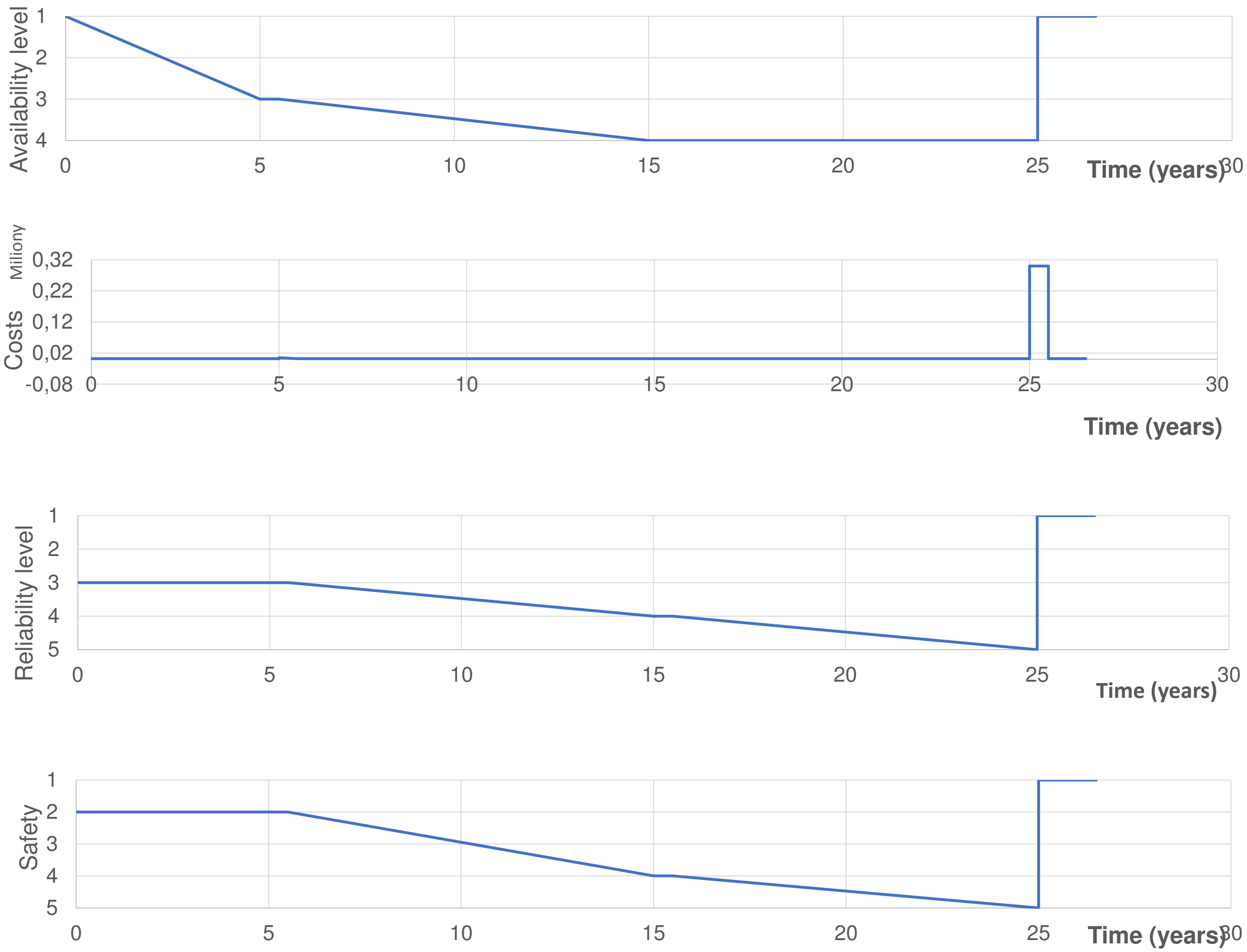




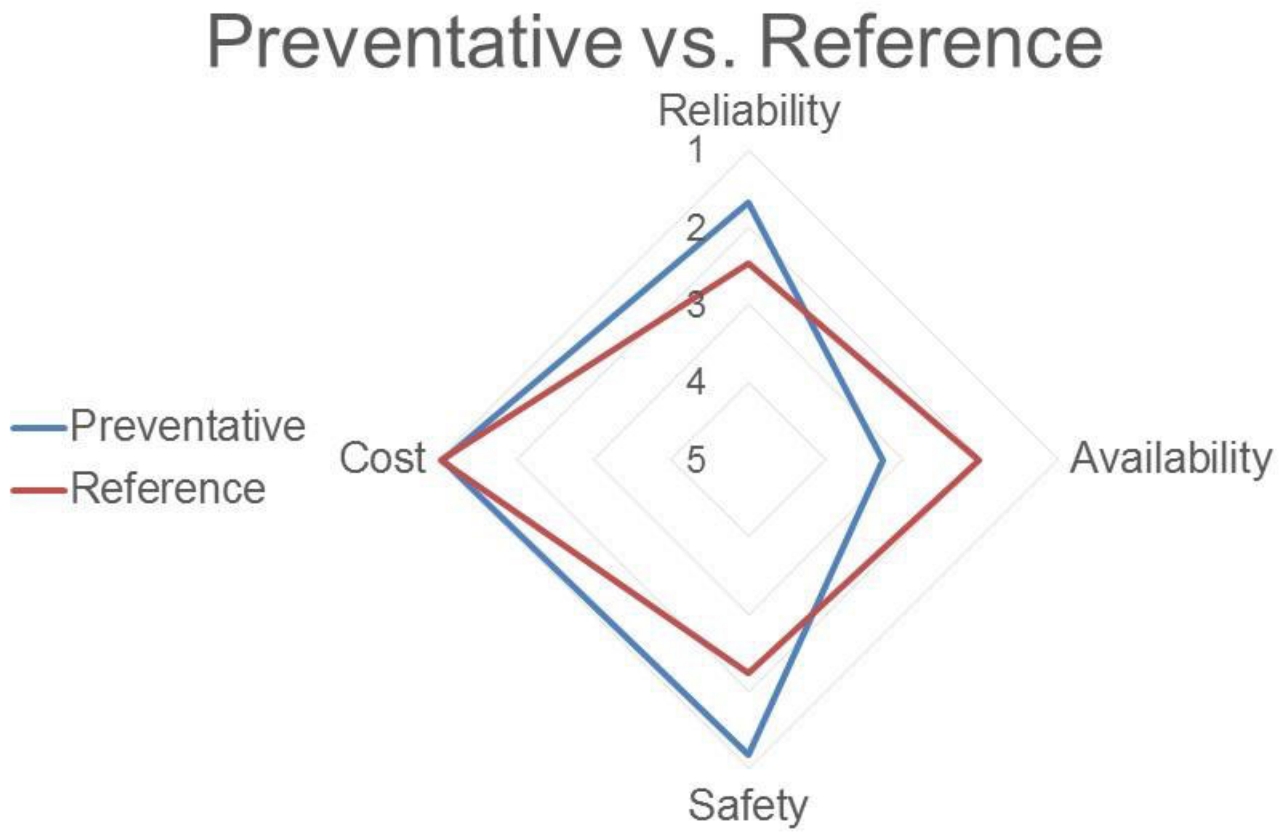




REFERENCE APPROACH



CONCLUSIONS



COST ACTION TU1406

QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

TRAINING SCHOOL

PRAGUE

Training School on Bridge Quality Control

25th – 28th September, 2017

Faculty of Civil Engineering CTU in Prague

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Date	September 27, 2017	

ESF provides the COST Office through a European Commission contract

COST is supported by the EU Framework Programme

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

CONTENTS

1. GENERAL DATA ON THE BRIDGE

The inspected bridge is a two-span stone arch structure built in 1873. The bridge carries road across the stream Mastík in Osečany town. General views of the bridge are presented below.

Fig. 1 Side view of the bridge (downstream side)

Fig. 2 Side view of the bridge (upstream side)

Fig. 3 A view along the road from the left side of the bridge

Fig. 4 A view along the road from the right side of the bridge

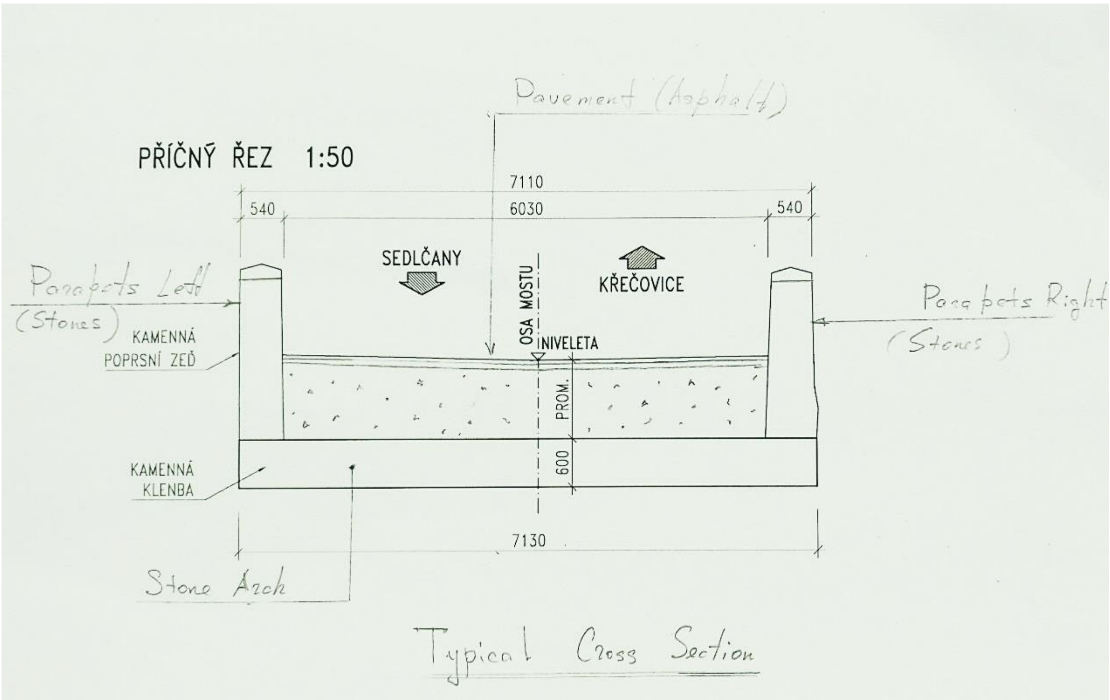


Fig. 5 General cross section of the bridge

1.1. FOUNDATION

Foundations are inaccessible according to type of structure and according to sketches from BMS we expect they are pad foundations.

1.2. SUBSTRUCTURE

Abutments and middle pier are made of carved stone.
The wing walls are skewed and made of stone with shotcrete cover. Left wing wall of abutment 1 has been extended by concrete massive wing wall during widening the bridge.
On the right side of the bridge there are adjacent gabion walls before and after the bridge.

1.3. SUPERSTRUCTURE

Superstructure is two span stone arches. The external edges of arches and spandrel walls are made of carved stone, middle parts are made of uncarved stone material of different lesser quality. There is a stone cornice on top of spandrel. Internal part of superstructure and some local parts of spandrel wall are covered by shotcrete.
The structure was in the past widened on left side above abutment with two steel beams with reinforced concrete slab.

1.4. ACCESSORIES

There is asphalt pavement on the bridge. There are stone parapets with capstones along the road followed up by steel barriers outside of bridge.
Each side of bridge is equipped with two drainage grills and one concrete pipe to lead a surface water out of the pavement surface.
On left side of the bridge there is a steel pipe utility above the cornice.
In front of the bridge there are vertical traffic signs with bearing capacity limitation.

1.5. ADDITIONAL FINDINGS

1. In the period between current and last inspections road pavement was reconstructed probably for increase of reliability and safety of users:
    - Two gabion walls performed near the right parapet from both sides of it including asphalts patch near the parapets.
    - Asphalt replaced in few places and performed in head of gabions from the right side of road.
2. The shotcrete was performed on arch's intrados surface, spandrels and wing walls to prevent stones falling.
3. Concrete drainage pipe installed in south-east wing wall.
4. Abutment #03 repaired by concrete patch on the upper stream side of the element. The defect is probably caused by floating water from concrete pipe with concentration of high amount of hydrogen sulfides.
5. Upstream side of pier probably was repaired. Hollows were found between repaired stones.
6. Concrete retaining wall was constructed by North West wing wall (with Steel Beams bearing on heads of the them and concrete casting over) for widening of the road at the area.

Fig. 6 Widening of the bridge

Fig. 7 Repaired part of abutment 3

Fig. 8 Gabions on the embankment of the bridge

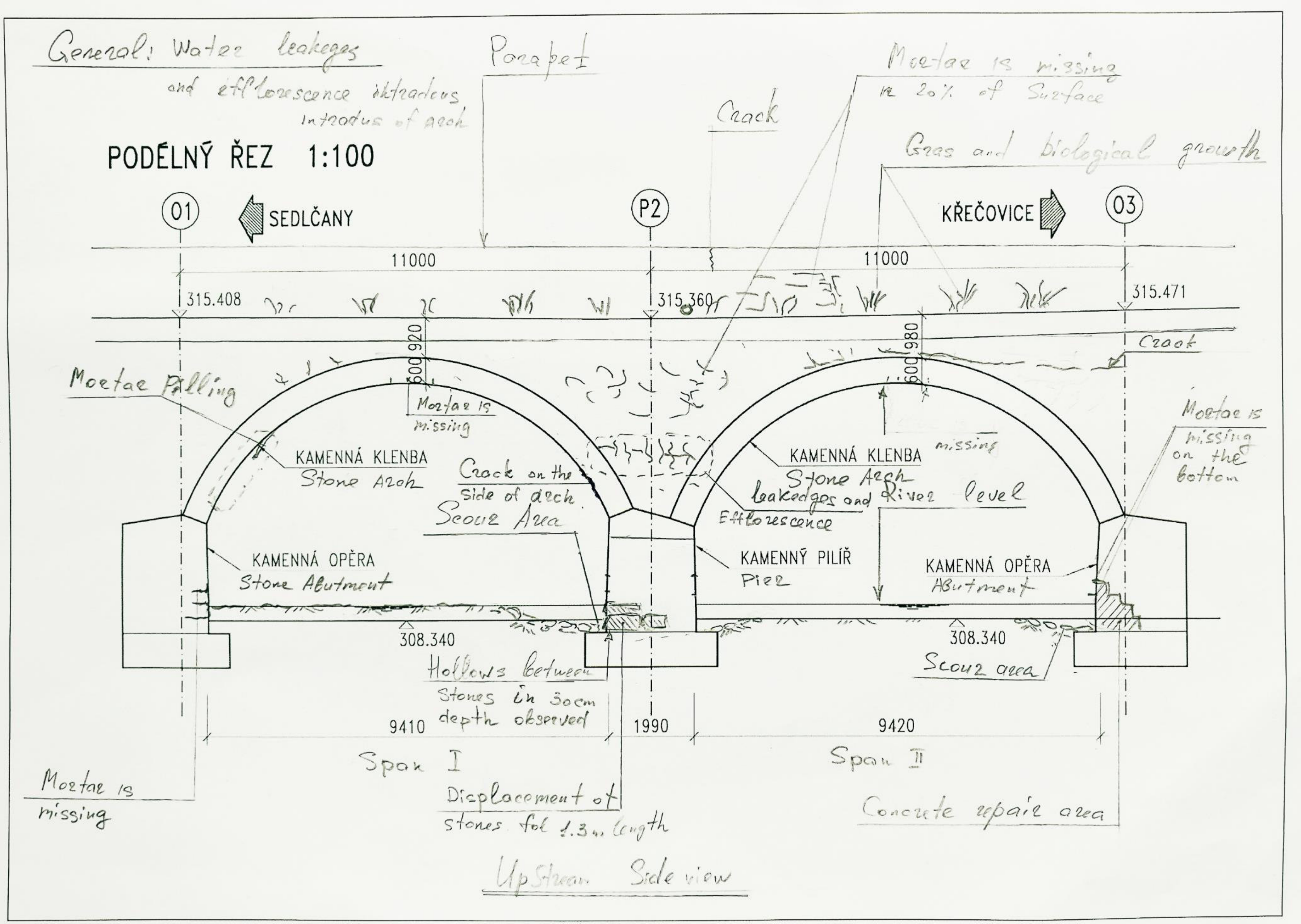
2. TECHNICAL CONDITION

2.1. COLLECTION OF DEFECTS

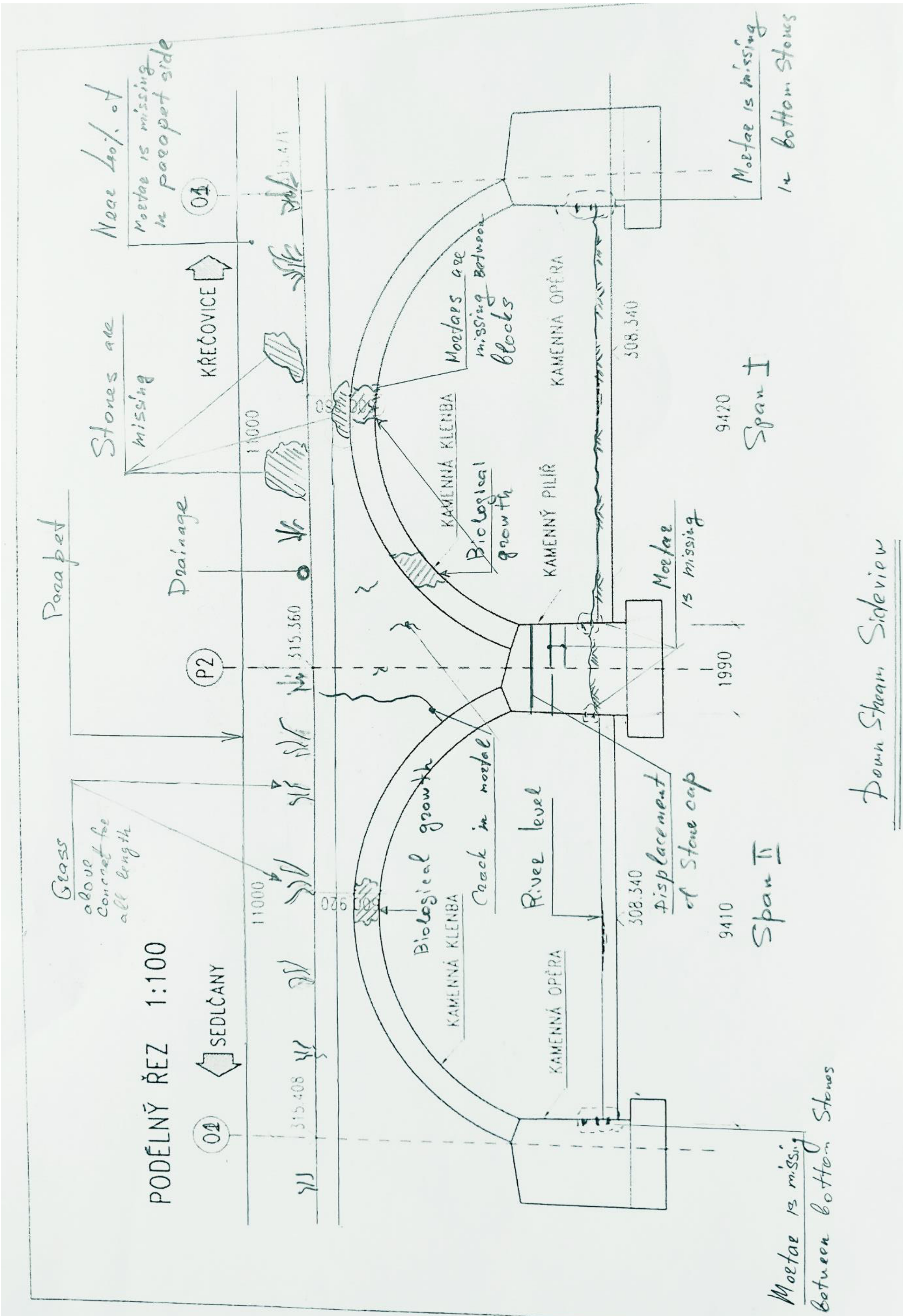
The types of defects discovered on the analyzed bridge are:

1. Scour of supports
2. Fractures of spandrel walls
3. Damage waterproofing of the arch and spandrel walls
4. Loss of mortar
5. Loss of stones
6. Degradation and cracking of parapets
7. Plant vegetation (biological growth)
8. Defects of pavement
9. Erosion of embankment
10. Inefficiency of drainage

All the defects are presented on the sketches below.

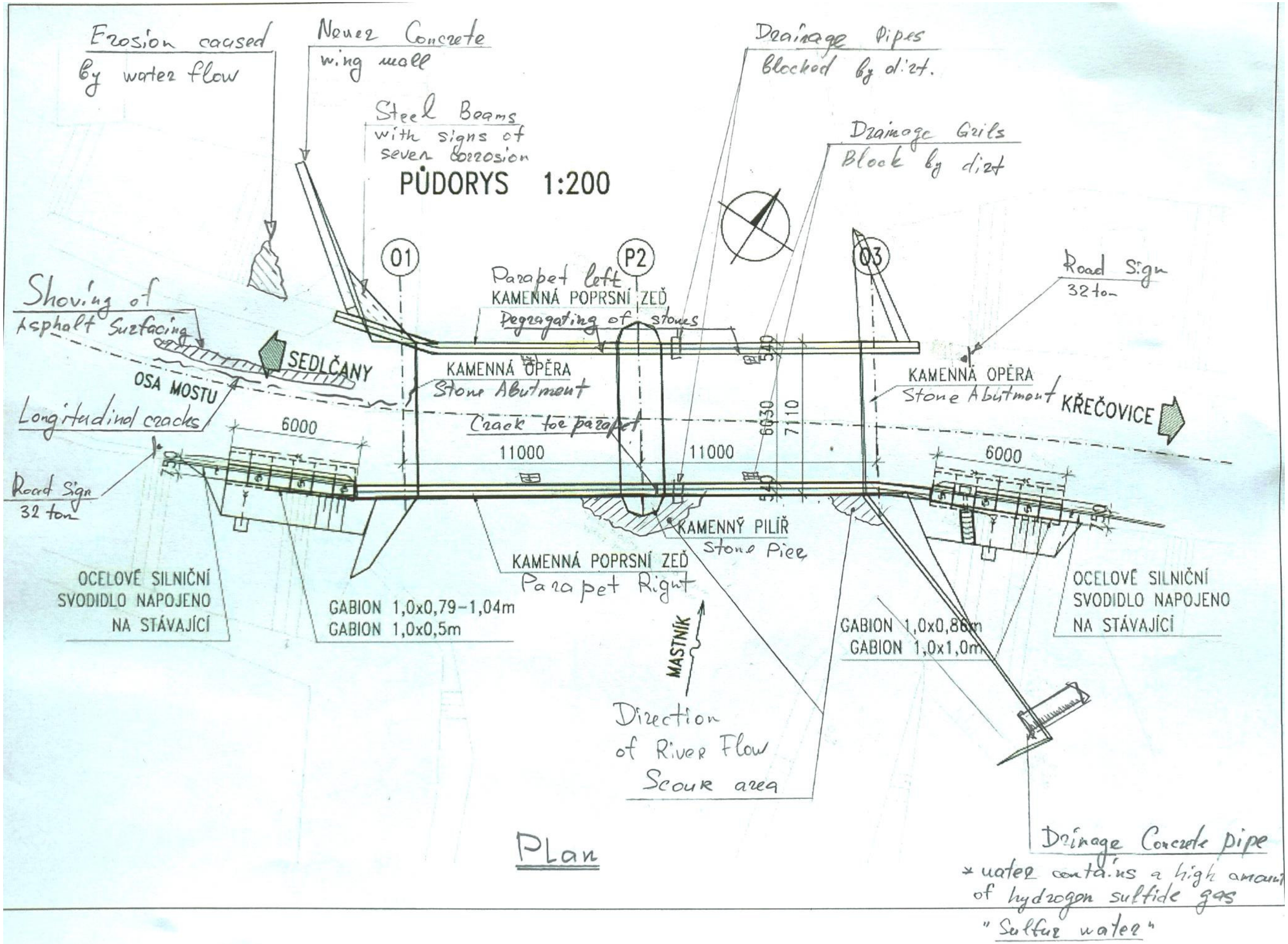


General: Water leakeges
and efflorescence intradous introdus of arch
PODÉLNÝ ŘEZ 1:100
01
SEDLČANY
P2
KŘEČOVICE
03
Parapet
Crack
Mortar is missing in 20% of Surface
Gras and biological growth
11000
11000
315.408
315.360
315.471
920
600
980
600
Crack
Mortar Falling
Mortar is missing
missing
KAMENNÁ KLENBA
Stone Arch
Crack on the side of arch
Scour Area
KAMENNÁ KLENBA
Stone Arch
leakedges and Efflorescence
River level
Mortar is missing on the bottom
KAMENNÁ OPĚRA
Stone Abutment
KAMENNÝ PILÍŘ
Pier
KAMENNÁ OPĚRA
Abutment
308.340
308.340
Hollows between Stones in 30cm depth observed
Scour area
9410
1990
9420
Span I
Span II
Mortar is missing
Displacement of stones for 1.3m length
Concrete repair area
UpStream Side view



PODÉLNÝ ŘEZ 1:100
SEDLČANY
KŘEČOVICE
01
P2
01
315.408
315.360
11000
11000
308.340
308.340
9410
9420
1990
KAMENNÁ KLENBA
KAMENNÁ OPĚRA
KAMENNÝ PILÍŘ
KAMENNÁ KLENBA
KAMENNÁ OPĚRA
Parapet
Drainage
Stones are missing
Near 40% of Mortar is missing in parapet side
Grass above Concret for all length
Biological growth
Crack in mortal
River level
Displacement of Stone cap
Biological growth
Mortar is missing
Mortars are missing Between blocks
Span I
Span II
Down Stream Sideview
Mortar is missing Between bottom Stones
Mortar is missing in bottom Stones

Podélný řez


Erosion caused by water flow
Newer Concrete wing wall
Steel Beams with signs of seven corrosion
PŮDORYS 1:200
Drainage Pipes Blocked by dirt.
Drainage Grils Block by dirt
Road Sign 32 ton
01
P2
03
Parapet left
KAMENNÁ POPRSNÍ ZEĎ
Degragating of stones
Shoving of Asphalt Surfacing
SEDLČANY
OSA MOSTU
Longitudinal cracks
KAMENNÁ OPĚRA
Stone Abutment
Crack toe parapet
KŘEČOVICE
6000
11000
11000
540
6030
7110
540
6000
Road Sign 32 ton
KAMENNÝ PILÍŘ
Stone Piee
KAMENNÁ POPRSNÍ ZEĎ
Parapet Right
OCELOVÉ SILNIČNÍ SVODIDLO NAPOJENO NA STÁVAJÍCÍ
GABION 1,0x0,79–1,04m
GABION 1,0x0,5m
MASTNÍK
GABION 1,0x0,86m
GABION 1,0x1,0m
OCELOVÉ SILNIČNÍ SVODIDLO NAPOJENO NA STÁVAJÍCÍ
Direction of River Flow
Scour area
Plan
Drinage Concrete pipe
* water contains a high amount of hydrogon sulfide gas
"Sulfur water"

2.2. DEFECTS OF THE MAIN STRUCTURAL ELEMENTS

2.2.1. SCOUR OF SUPPORTS

Fig. 9 Scour of the pier (upstream side)

Fig. 10 Scour of the abutment 3 (upstream side)

2.2.2. FRACTURES OF SPANDREL WALL

Fig. 11 Horizontal fracture of the spandrel wall over span 2 (upstream side)

Fig. 12 Vertical fracture of the spandrel wall over pier (downstream side)

Fig. 13 Horizontal fracture between spandrel wall and the arch over span 1 (downstream side)

Fig. 14 Horizontal fracture of the spandrel wall over the pier (upstream side)

2.2.3. DAMAGE WATERPROOFING OF THE ARCH AND SPANDREL WALLS

Fig. 15 Leaching in the arch in span 1

Fig. 16 Leaching in the spandrel wall and parapets in span 1 (downstream side)

Fig. 17 Leaching in the spandrel wall and parapets in span 2 (downstream side)

Fig. 18 Leaching in the arch in span 1

2.2.4. LOSS OF MORTAR

Fig. 19 Loss of mortar in spandrel wall (upstream side)

Fig. 20 Loss of mortar in wing wall (downstream side)

Fig. 21 Loss of mortar in the pier (downstream side)

Fig. 22 Loss of mortar in the abutment 1 (upstream side)

2.2.5. LOSS OF STONES

Fig. 23 Loss of blocks in parapet (downstream side)

2.2.6. DEGRADATION AND CRACKING OF PARAPET

Fig. 24 Degradation of stones in parapet (downstream side)

Fig. 25 Degradation of stones in parapet (upstream side)

Fig. 26 Transverse cracking of parapet (upstream side)

2.2.7. PLANT VEGETATION ON PARAPETS

Fig. 27 Plant vegetation on the parapet (downstream side)

2.2.8. DEFECTS OF PAVEMENT

Fig. 28 Cracks and shoving of the pavement

2.2.9. EROSION OF EMBANKMENT

Fig. 29 Erosion of the embankment over abutment 1 (downstream side)

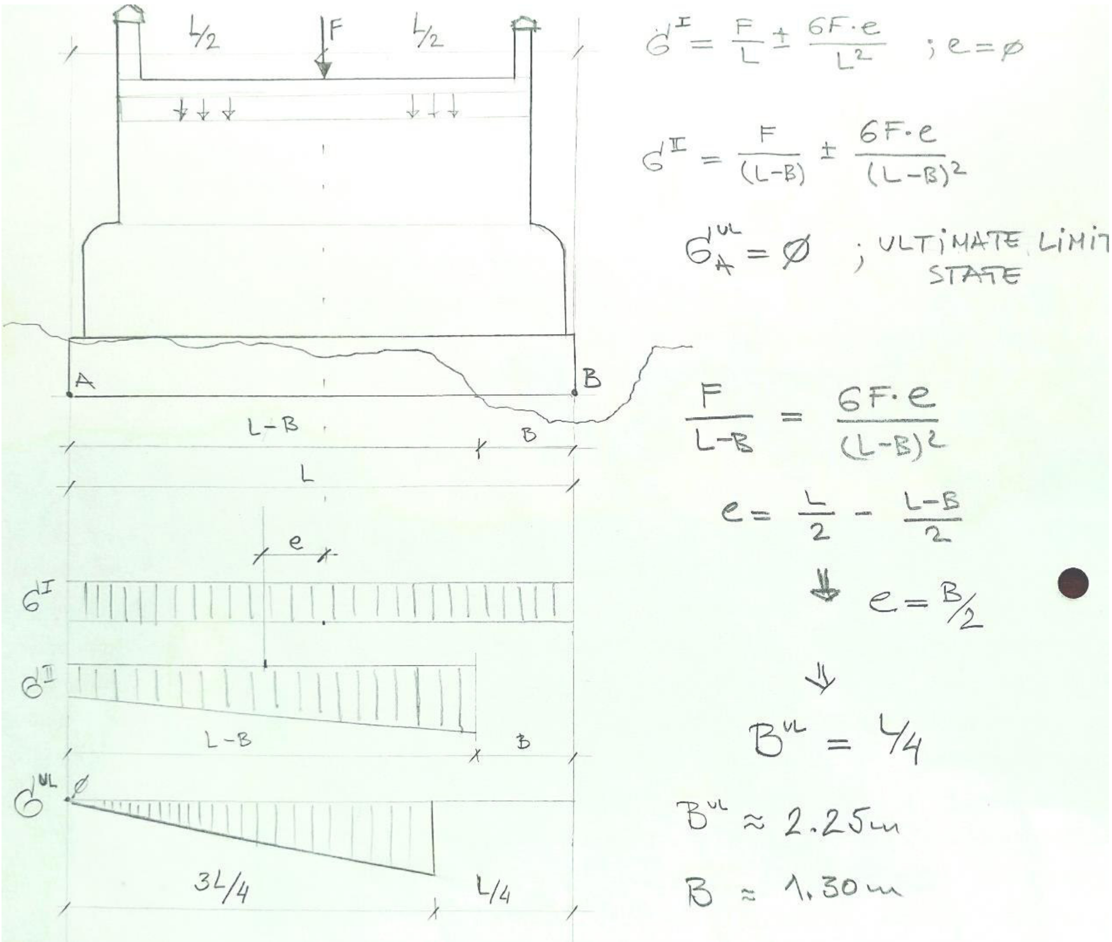
2.2.10. INEFFICIENCY OF DRAINAGE

Fig. 30 Block drainage (upstream side)

Fig. 31 Improperly shaped drainage pipes (downstream side)

3. POTENTIAL FAILURE MODE OF THE BRIDGE

Considered as the most probable failure mode is settlement of the pier foundation due to scour. Assumed ULS of the foundation at settlement is related to occurrence of lifting of one of the edges of the it. It may occur when the width B of the scour is reaching ¼ of the length of the foundation according to the scheme below.



Estimated critical B value of the scour is equal to 2,25 m. The current measured value of the scour is 1.30 m. Thus, the adopted value of the reliability for the considered failure mode is 3.

4. MATERIAL TESTING

4.1. SPECIMEN DRILLING

Two drills of the material were taken from the structure: from the arch springing at the abutment 1 and from the abutment 3.

Fig. 32 Taking of specimens from the arch springing at the abutment 1

Fig. 33 Taking of specimens from the abutment 3

Two full size specimen were cut out from the drills: no 1 and 2.

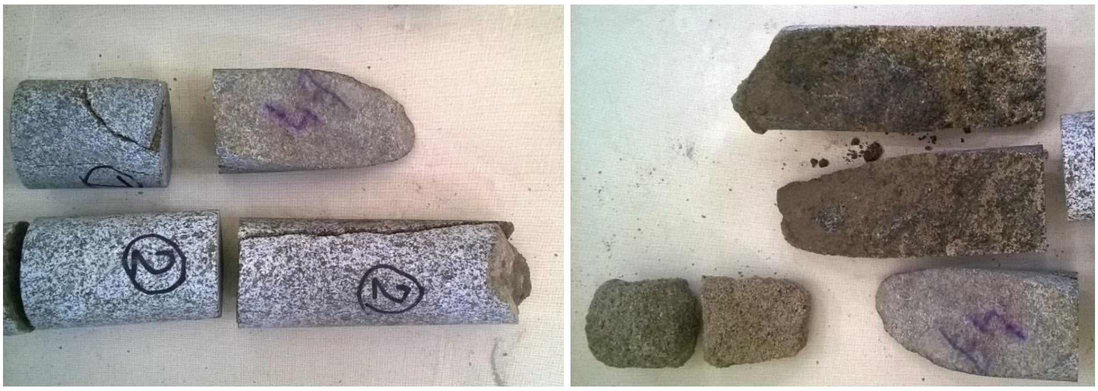


Fig. 34 Specimens prepared for testing

4.1. LABORATORY TESTING

Process of the specimen testing is presented in photos below.

Fig. 35 Specimen no. 1 during loading test

Fig. 36 Specimen no. 2 during loading test

4.2. TEST RESULTS

The received results of the tests are given below.

Specimen	Diameter [mm]	Area [cm^2]	Maximum Force [kN]	Maximum Stress [MPa]
No. 1	73,85	35,80*	10,1	28,2
No. 2	73,60	42,52	16,4	38,6

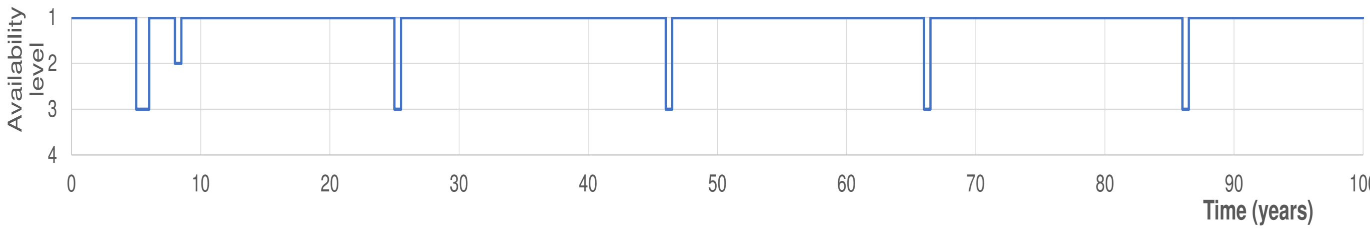
Fig. 37 Condition of specimens after loading test

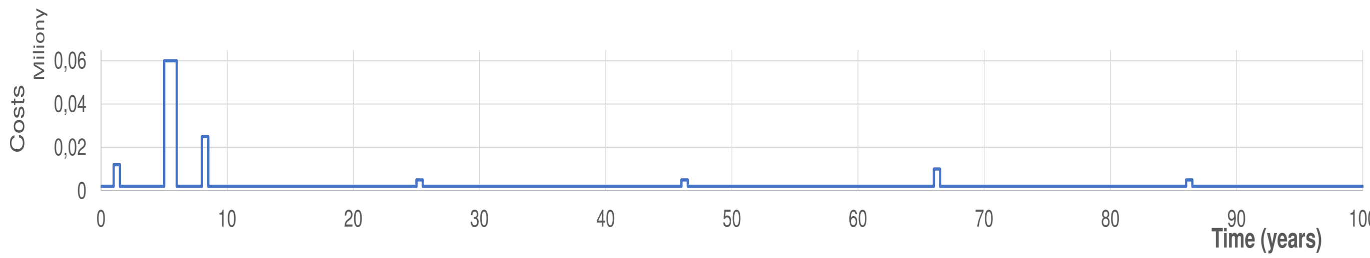
5. KEY PERFORMANCE INDICATORS

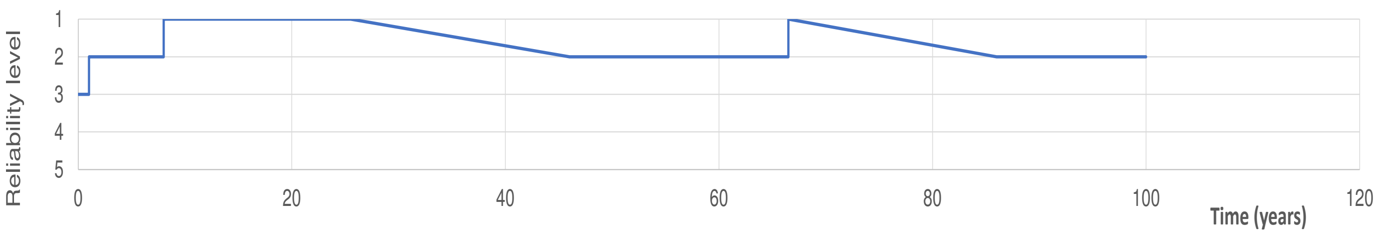
5.1. CURRENT STATE EVALUATION

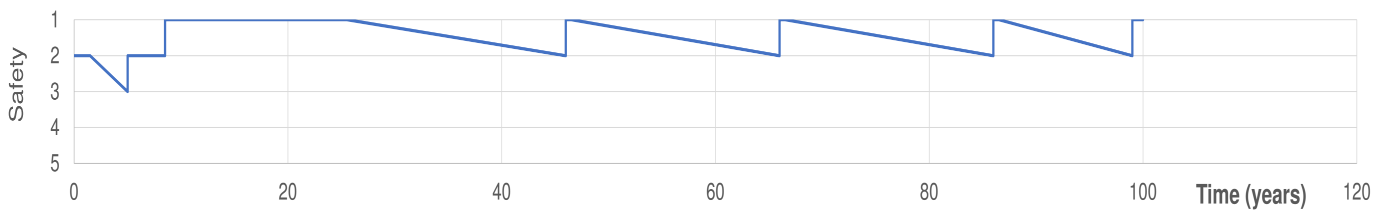
Structure	Component	Material	Design and construction	Failure mode	Vurnerable zone	Symptoms	KPI	Performance indicator		Estimated failure time
Two span arch bridge	Pier	Stone	1871	Global failure	Foundations	Stone displacement	Reliability (Structure safety)	3	**3**	**25 years**
	Abutment	Stone	1871		Foundations	Stone displacement		2		**25 years**
	Spandrel walls	Stone	1871	Wall collapse	Bottom section of spandrel wall	Stone displacement		2		**15 years**
	Parapets	Stone	2015	Parapet collapse	Bottom section of parapet	Stone displacement	Safety	2	**2**	**15 years**
	Pavement	Asphalt concrete	2015	Skid resistance	Top surface	Crack & sweating		2		**5 years**

5.2. PREVENTATIVE APPROACH

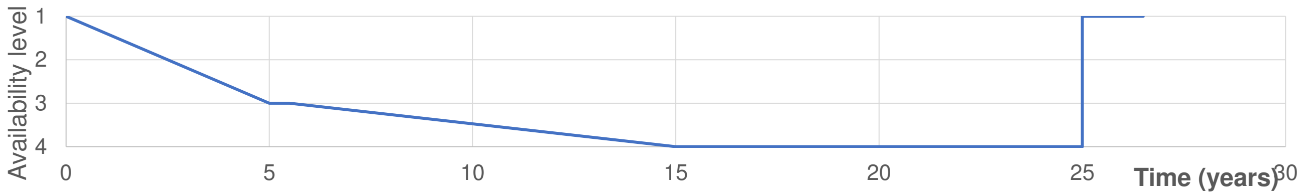


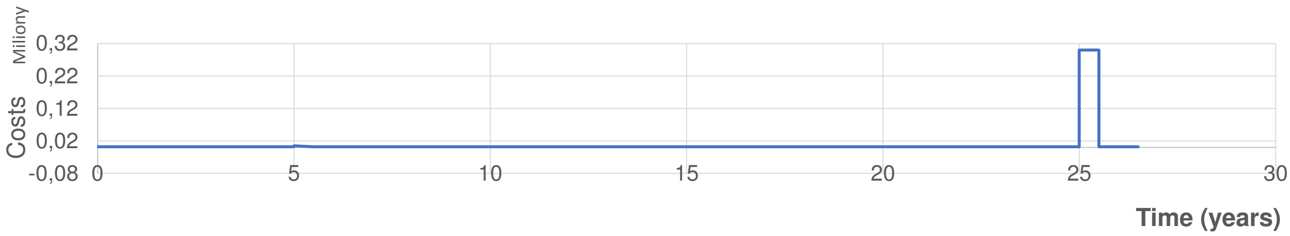


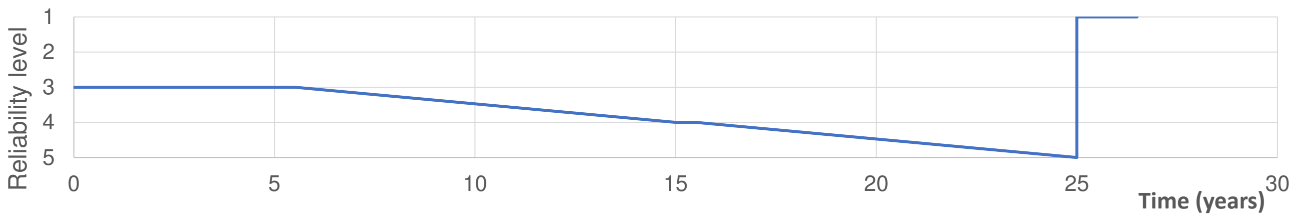


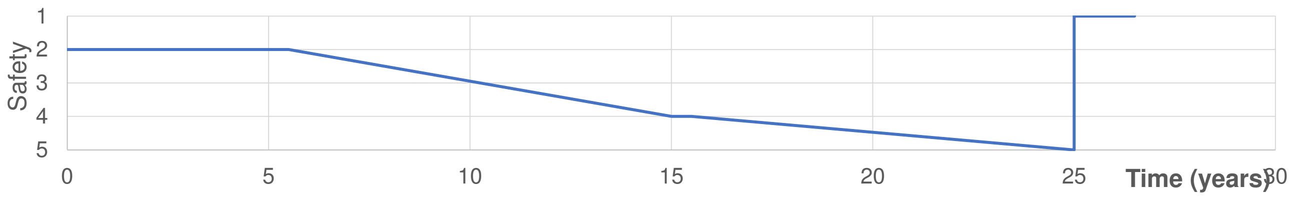


5.1. REFERENCE APPROACH (BRIDGE REPLACEMENT)

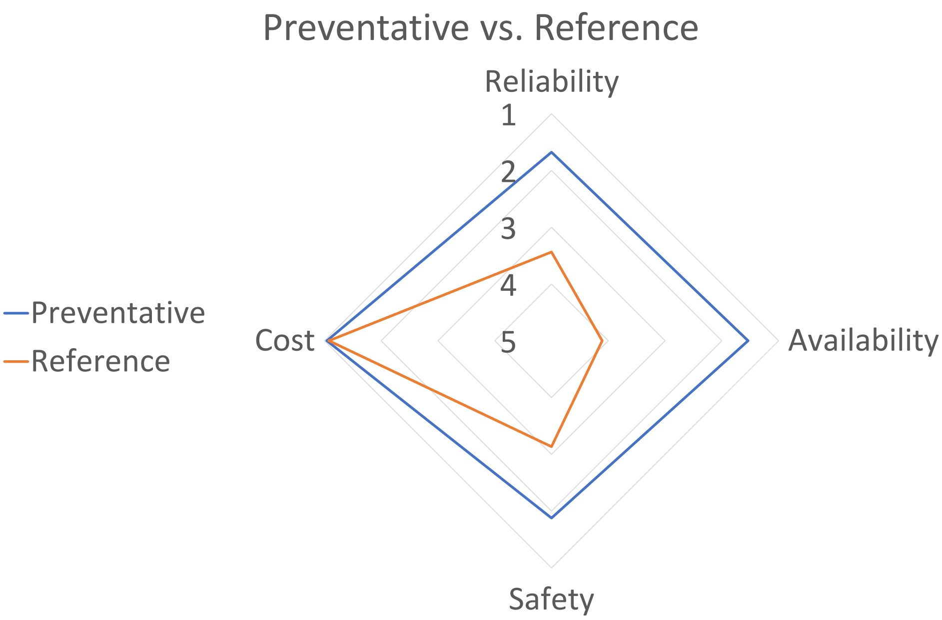








5.2. COMPARISON OF THE APPROACHES



According to the carried out analysis the preventative

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QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Training School - Prague
Bridge Quality Control
25th – 28th September, 2017
Faculty of Civil Engineering CTU in Prague
Prague, Czech Republic

Assessment of Čechův Bridge

Alexander Jiponov, Kerstin Lang, Aron Bjarnason, Mariano Angelo Zanini,

Patryk Mazur, Paul Cahill, Sérgio Pereira

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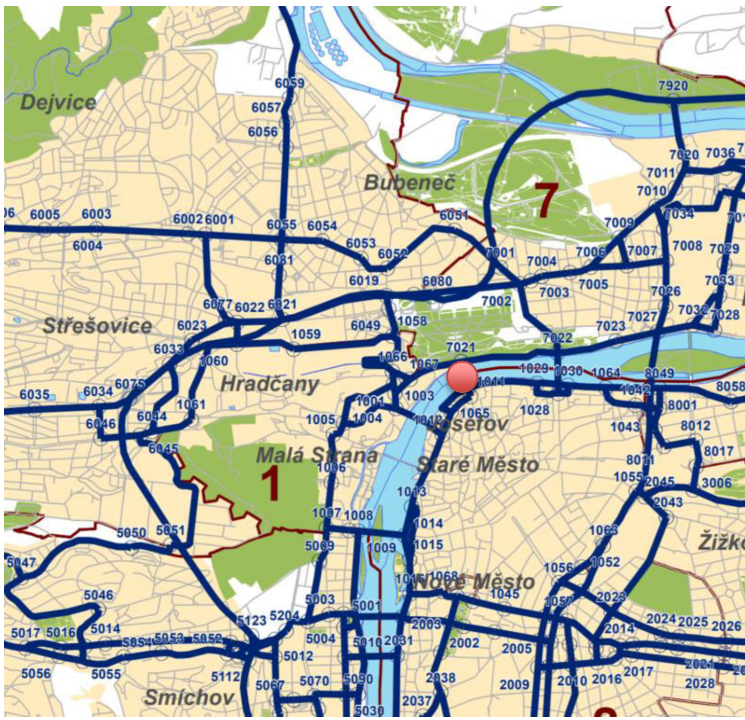
SECTION TITLE

1. Overview of bridge
2. Condition inspection of bridge
3. Material testing of bridge
4. Assessment table
5. Maintenance
6. Conclusions

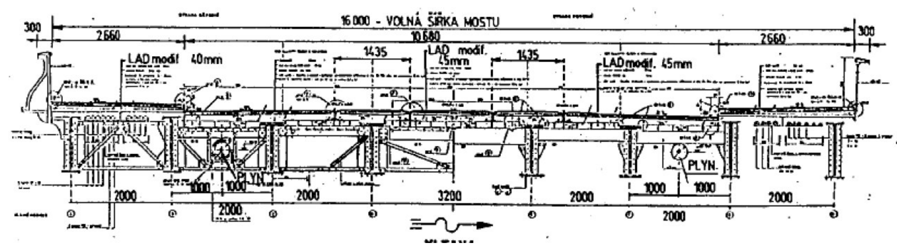
1. Overview of Ĉechův Bridge

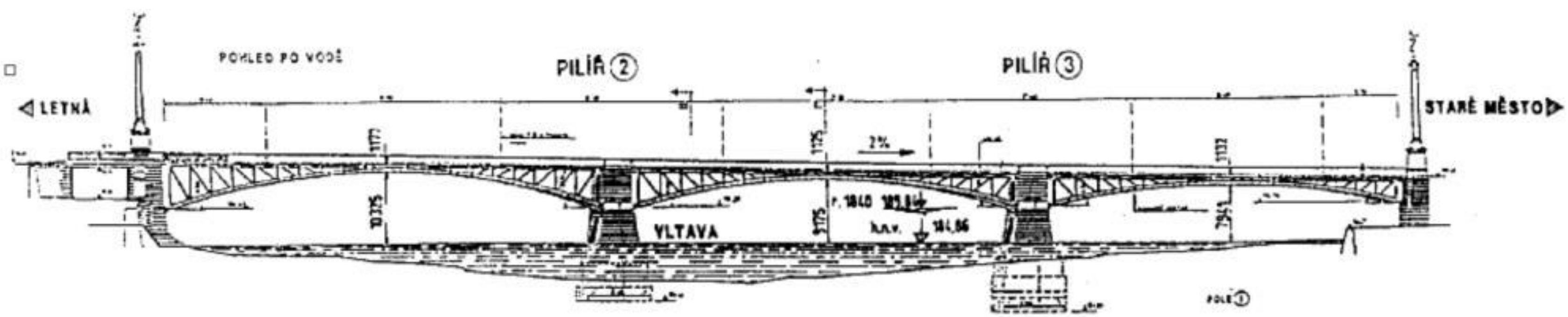
- Ĉechův bridge located in Prague 1
- Three span steel bridge constructed in 1909



1. Overview of Ĉechův Bridge

- Total Bridge Length: 182.5m
  - Span 1: 58.5m
  - Span 2: 52.4m
  - Span 3: 47.6m
- Bridge Width: 16m





1. Overview of Ĉechův Bridge

- Total Bridge Length: 182.5m
  - Span 1: 58.5m
  - Span 2: 52.4m
  - Span 3: 47.6m
- Bridge Width: 16m

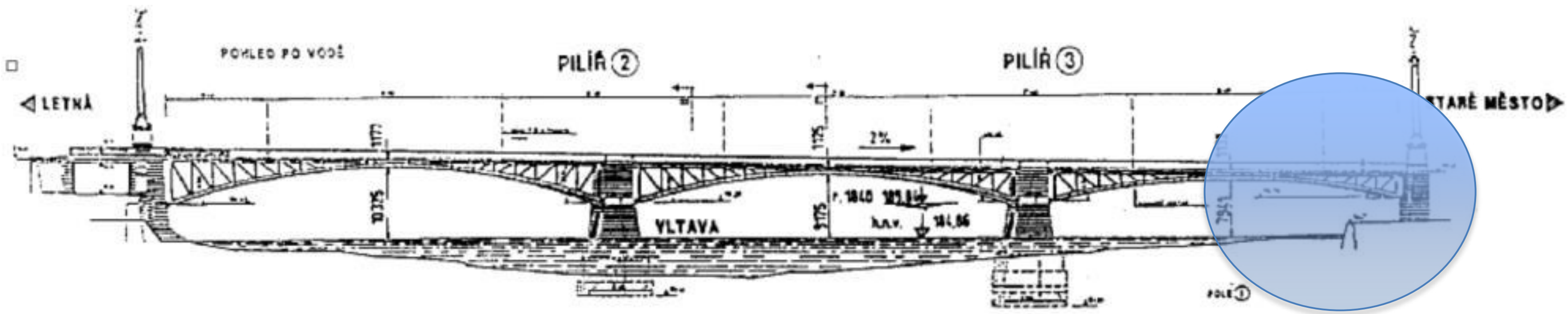
- ADT

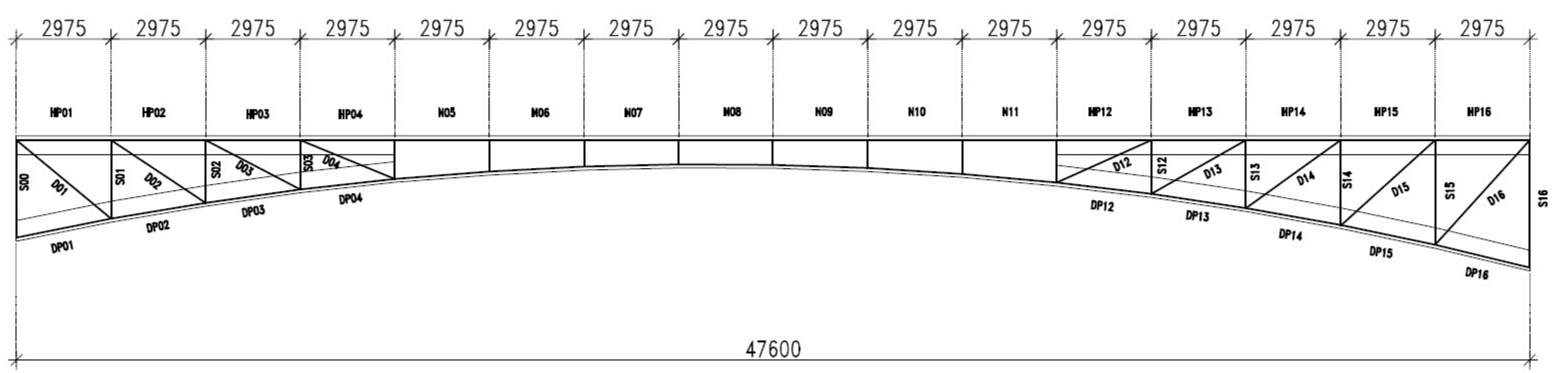
Trucks:	300 cars/24h
Pers. Cars	13600 cars/24h
Tram	450 cars/24h
Summary:	14350 cars/24h

- Refurbished in 2002

2. Condition Assessment of Bridge

- Condition assessment focused on one span of bridge





2. Condition Assessment of Bridge

- Assessment of Bridge Included
  - **Superstructure**
  - **Pavement**
  - **Substructure**
  - **Bearings**
  - **Parapet**
  - **Communications (Cables/Pipes)**
  - **Edge Panels**

- Including:
  - Longitudinal Girders
  - Transverse Beams
  - Bracing
  - Deck
  - Drainage

2. Condition Assessment of Bridge

- Assessment of Bridge Included
  - **Superstructure**
  - **Pavement**
  - **Substructure**
  - **Bearings**
  - **Parapet**
  - **Communications (Cables/Pipes)**
  - **Edge Panels**

- Including:
  - Asphalt layer
  - Expansion Joint
  - Rails – joint connection
  - Waterproofing

2. Condition Assessment of Bridge

- Main Longitudinal Girders

2. Condition Assessment of Bridge

- Main Longitudinal Girders
  - Minor distortion of top flange

2. Condition Assessment of Bridge

- Transverse Beams

2. Condition Assessment of Bridge

- Transverse Beams
  - Mild Surface Corrosion





2. Condition Assessment of Bridge

- Vertical/ Horizontal/ Diagonal Bracing
  - Mild Surface Corrosion

2. Condition Assessment of Bridge

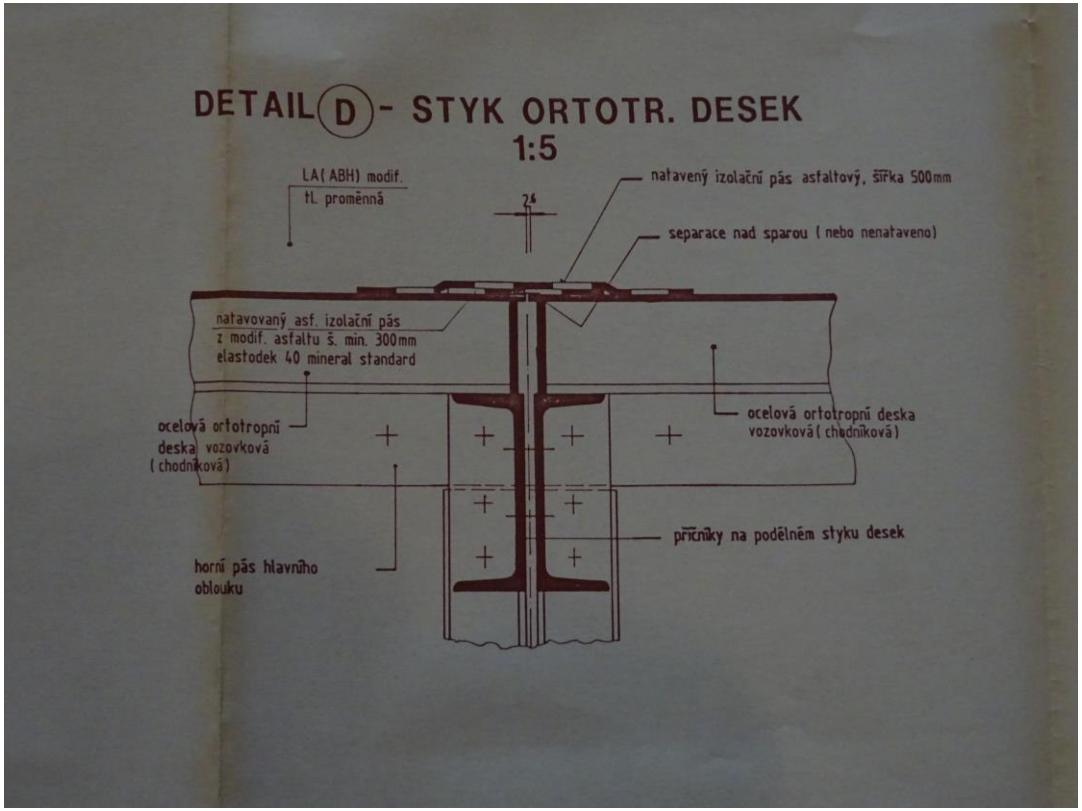
- Deck (Orthotropic Plates)
  - Crack in Welds

2. Condition Assessment of Bridge

- Deck (Orthotropic Plates)
  - – Liquid through joints

2. Condition Assessment of Bridge

- Deck (Orthotropic Plates)
  - Significant cracks in connection between panels



2. Condition Assessment of Bridge

- Deck (Orthotropic Plates)
  - Mild Surface Corrosion

2. Condition Assessment of Bridge

- Drainage System Elements:
  - Disconnecting / Missing Elements
  - Insufficient Length

2. Condition Assessment of Bridge

- Abutment
  - Water staining

2. Condition Assessment of Bridge

- Upper Bearings
  - Corrosion

2. Condition Assessment of Bridge

- Lower Bearings
  - Mild Surface Corrosion

2. Condition Assessment of Bridge

- Pavement: Asphalt layer
  - Generally in good condition, minor patch repairs evident

2. Condition Assessment of Bridge

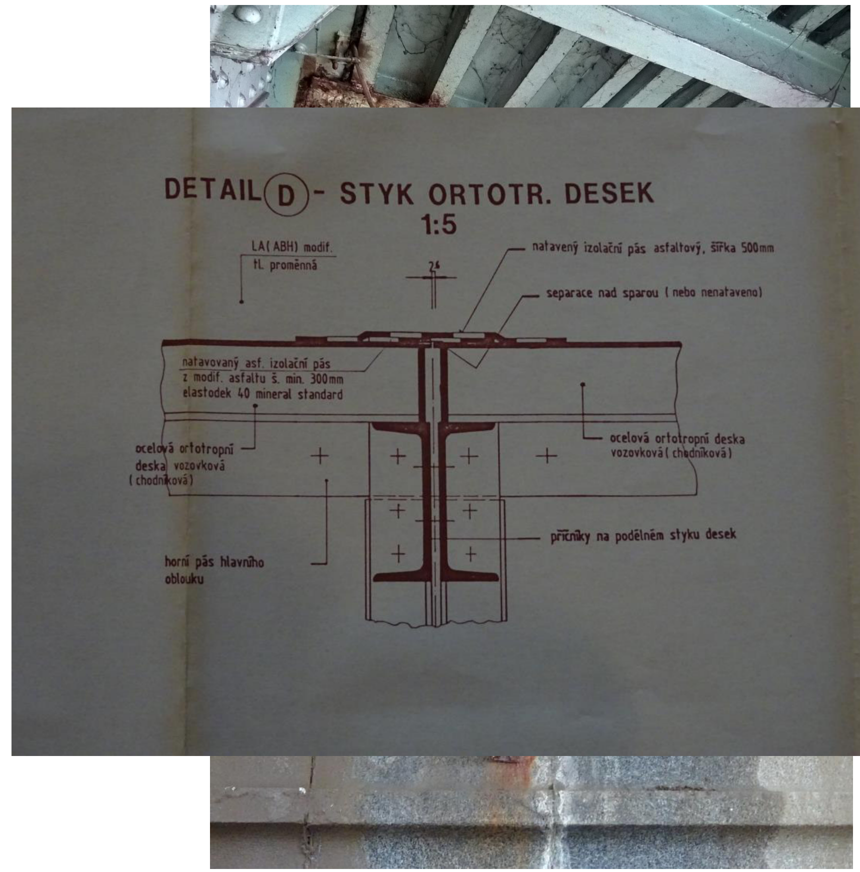
- Pavement: Expansion Joint
  - Gaps
  - Excess vibrations

2. Condition Assessment of Bridge

- Pavement: Rails – joint connection
  - Inappropriate design for switch device

2. Condition Assessment of Bridge

- Pavement: Waterproofing Layer
  - Excess water leakage
  - Poor design type



2. Condition Assessment of Bridge

- Railings
  - Corrosion

2. Condition Assessment of Bridge

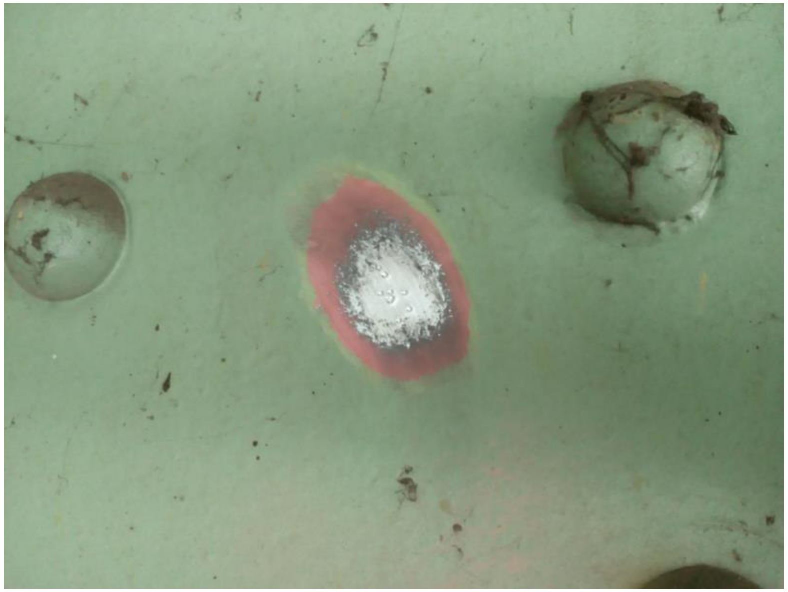
- Communications (Cables/ Pipes)
  - Corrosion
  - Loss of section

2. Condition Assessment of Bridge

- Edge Panels
  - Corrosion
  - Loss of section

3. Material Testing of Bridge

- Hardness Test
- Thickness



3. Material Testing of Bridge

- Hardness Test
  - Ultimate Strength = 390 MPa

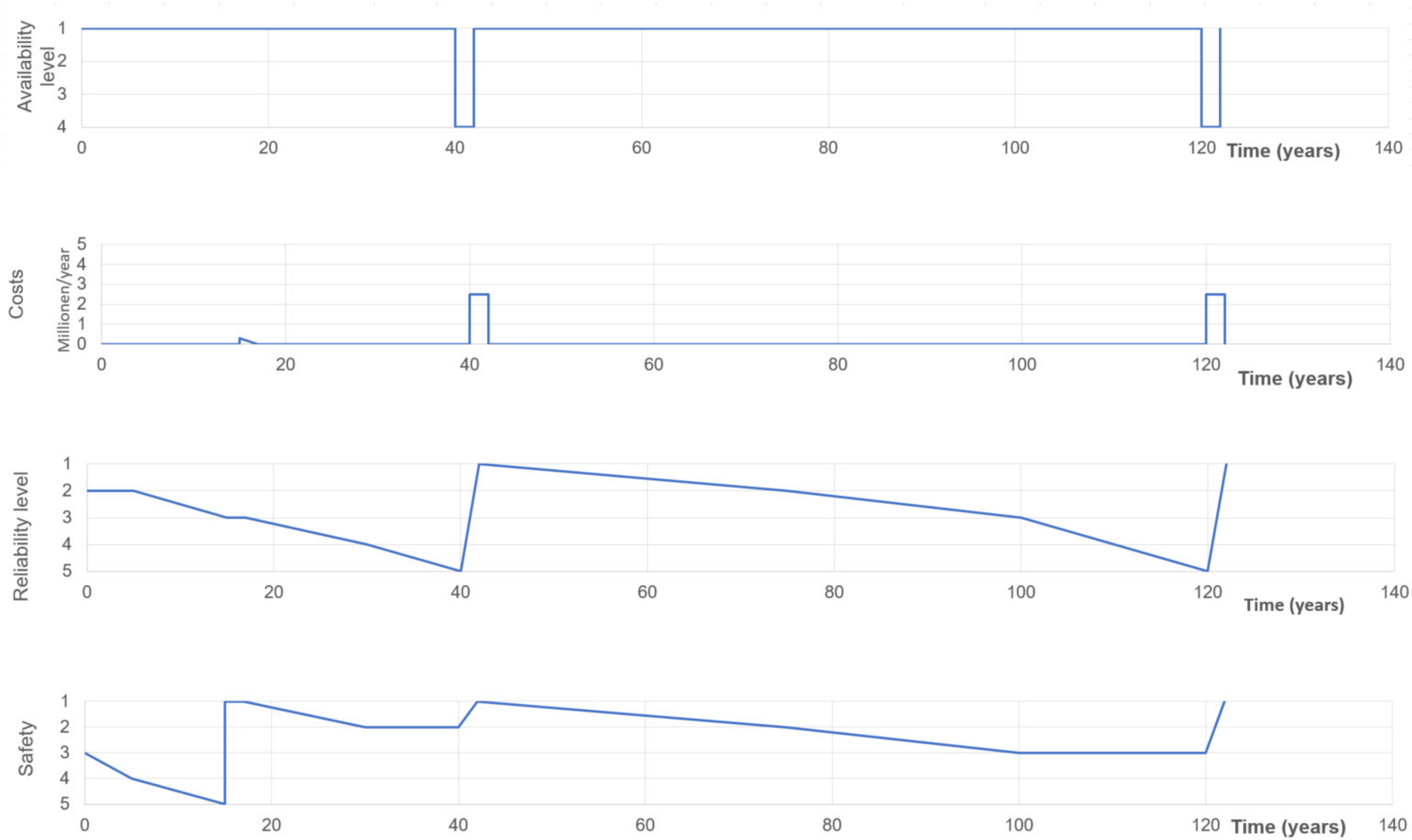
4. Assessment Table

structural superstructure	main arch girders	steel	1909	failure of cross section	moment & axial force	deformation of the top flange	**Reliability**	1	2	**40 years**	**2**
	transversal beam	steel	1909	failure of cross section	M & Shear force	corrosion		2			
	bracings - vertical/horizontal	steel	1909	buckling	axial force	superficial corrosion		1			
	deck (orthotropic plate)	steel	2002	lack of support		cracks in the welds		2			
						liquids through joints		2			
						corrosion		2			
bearings	upper bearings	steel	1909		redistribution of forces	corrosion		3	2		
	lower bearings	steel	1909		redistribution of forces	superficial corrosion		2			
substructure	abutment wall face	concrete with stone cover	1909			water staining		2	2		
drainage elements	tubes/pipes	pipes	2002			disconnetion		4	4	**15 years**	
	tubes/pipes					missing / insufficiant lenght		4			
pavement	asphalt layer	asphalt 2x5cm	2002			pot holes (few places)		2			
	expansion joints	elastomeric BAKOR 990-25	2002			material degradation		4			
	rail joint connection	steel	2002			blocked movement		4			
	water proofing layer		2002			not working		4			

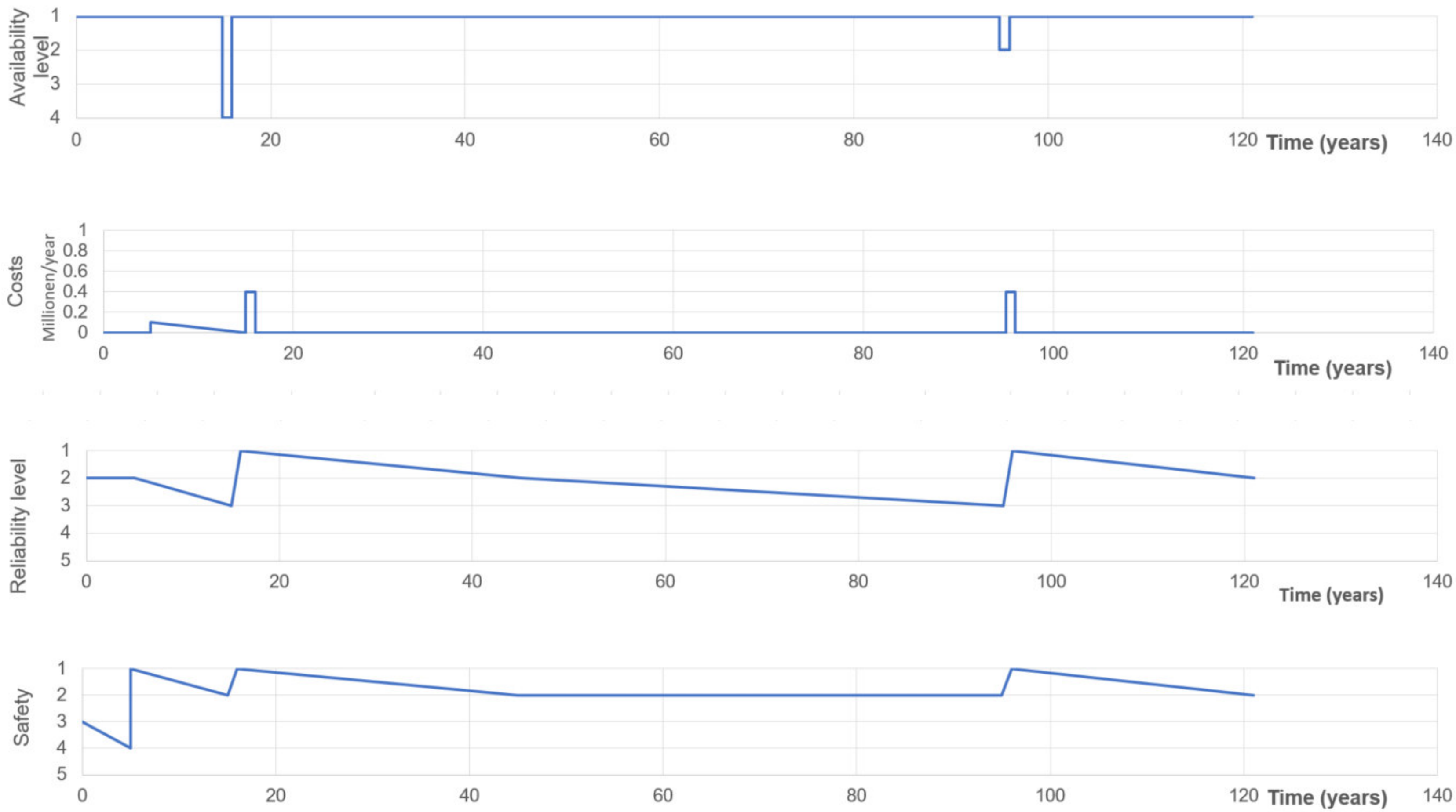
4. Assessment Table

railings	railings	steel	1909	falling of the bridge		corrosion	Safety	3	3	15 years	3
	scepters			falling of the bridge		cracks in the scepters		3			
edge panels	edge panels	steel	1909	falling of the bridge		corrosion		4	4	5 years	
	edge panels					lack of support		4			
comunication cables/pipes	cables	cables/ pipes	2002			not fixed		2	2	5 years	
	cables					protection elements corrupted		2			

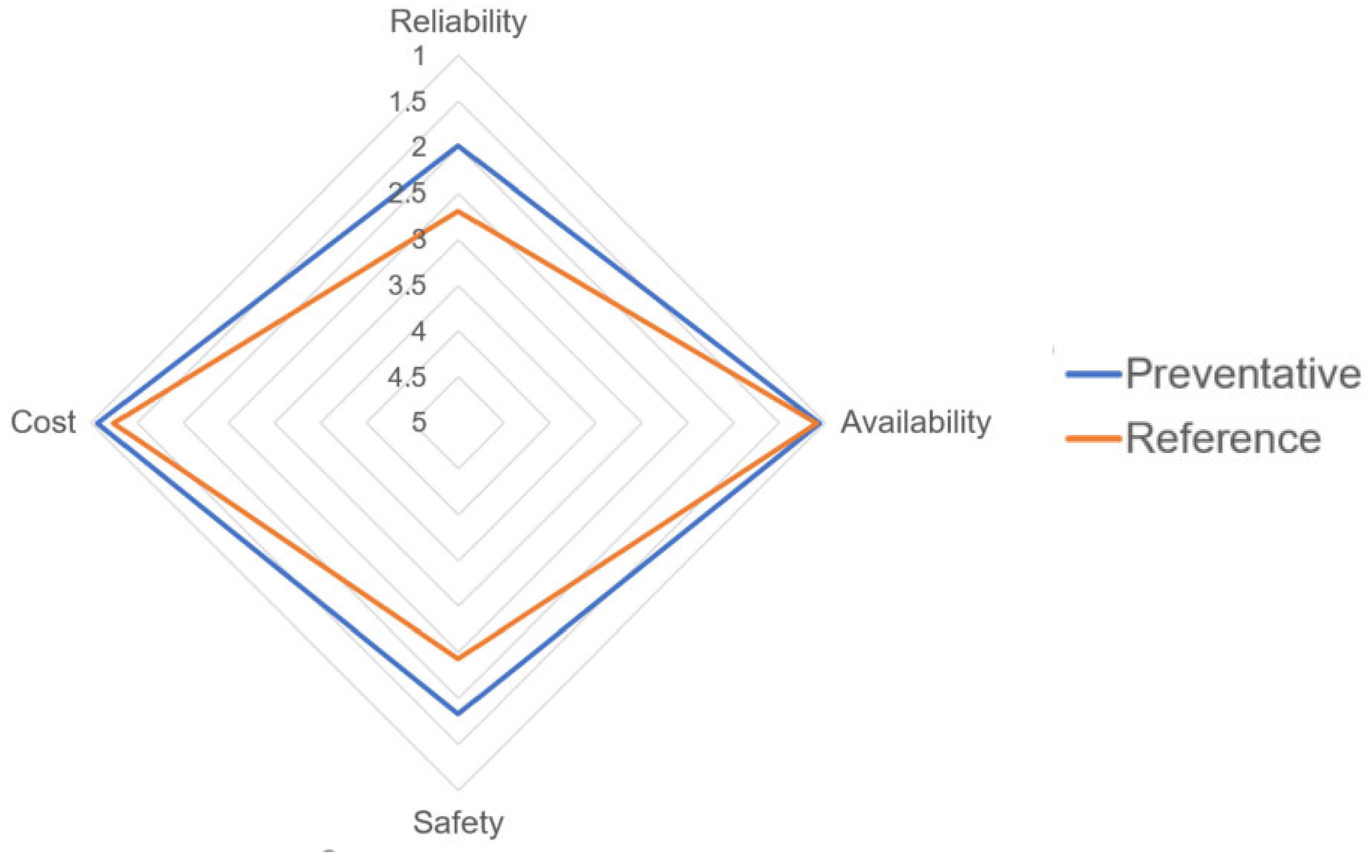
5. Maintenance : Reference Scenario



5. Maintenance : Preventative Scenario



5. Maintenance : Comparison



6. Conclusions

- Bridge is in Good condition.
- Structural elements show no major defects.
- Expansion joints are in poor condition.
- Lack of waterproofing and deck design leading to water leakage.
- Preventative Maintenance provides better reliability, safety and availability.

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Assessment of Čechův Bridge

STUDENT INFORMATION

Student	Alexander Jiponov Aron Bjarnason Patryk Mazur Sérgio Pereira	Kerstin Lang Mariano Angelo Zanini Paul Cahill
Date	September 28, 2017	

CONTENTS

1. INTRODUCTION

Figure 1.1.1. Čechův bridge

1.1. ČECHŮV BRIDGE

Čechův bridge [Figure 1.1.1] is a three span steel bridge, located in Prague 1, Czech Republic [Figure 1.1.2]. The bridge was constructed in 1909 and has an overall bridge length of 182.5m. The length of the three spans are 58.5m, 52.4m and 47.6, for Spans 1, 2 and 3 respectively. The bridge underwent significant refurbishment in 2002, with the entire deck of the bridge being repaired, along with steel members requiring replacement.

The bridge is located on one of the primary transportation routes of the city, and supports both vehicle traffic and tram traffic, with a total vehicle traffic of 14,350 individual vehicles per day. A breakdown of the average daily traffic which passes the bridge per vehicle classification is provided in Table 1.1.

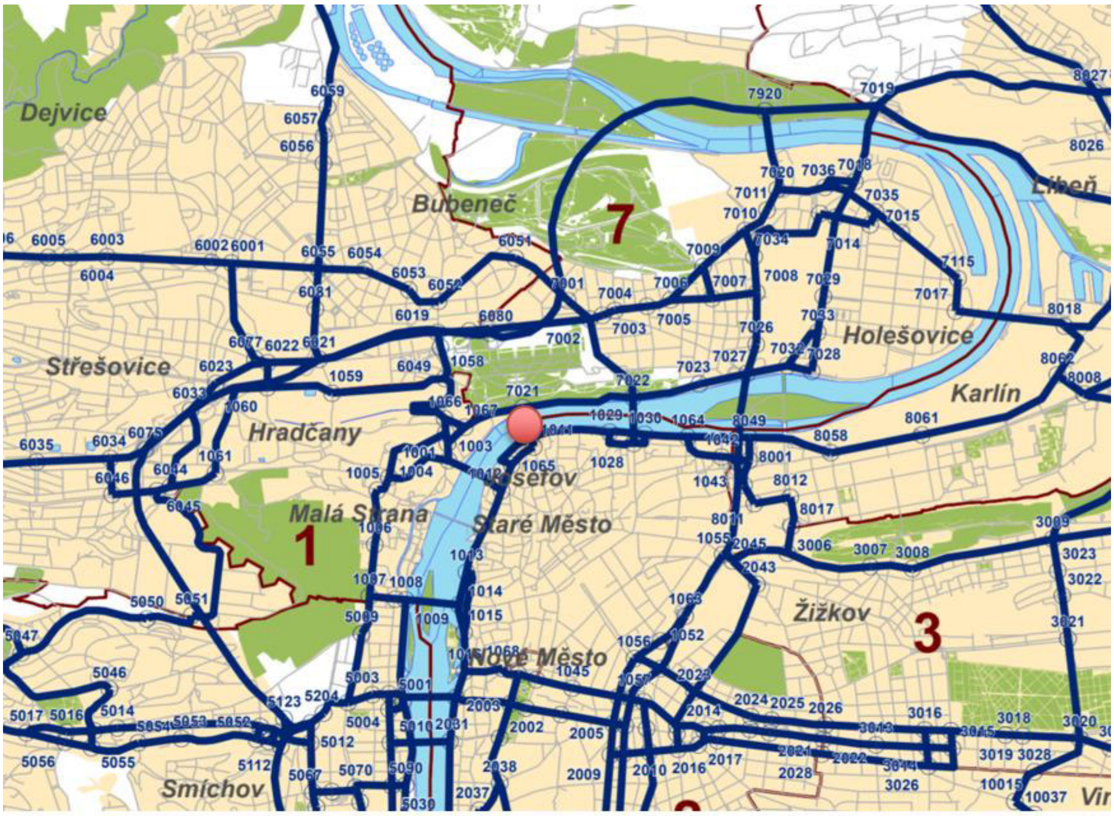

Figure 1.1.2. Location of Čechův bridge

Vehicle Type	Number
Trucks	**300 cars/24hrs.**
Pers. Cars	**13600 cars/24hrs.**
Trams	**450 cars/24hrs.**
Summary	**14350 cars/24hrs.**

Table 1.1. Average Daily Traffic (ADT) of Čechův bridge

2. CONDITION ASSESSMENT INSPECTION

2.1. INTRODUCTION TO INSEPCTION

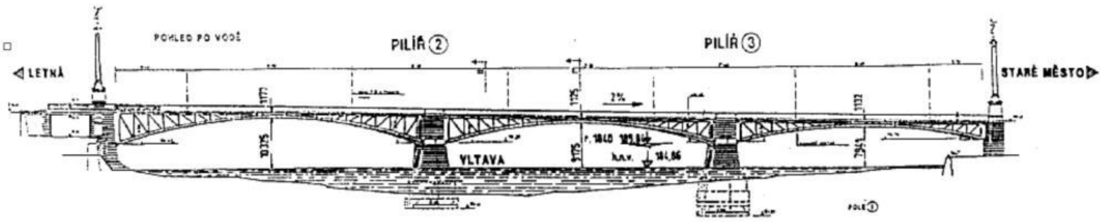

Figure 2.1.1. Elevantion of Čechův bridge

The condition assessment of the bridge consisted of an inspection of the Southern span of the bridge [Figure 2.1.1], with a detailed elevation of the span inspected provided in Figure 2.1.2.

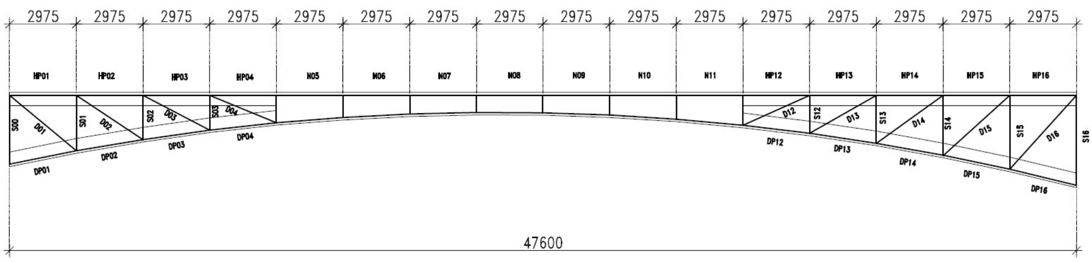

Figure 2.1.2. Detailed elevantion of inpected span 3

All elements of the span were inspected, with the following elements being classified together as part of the inspection:

1. Superstructure
    a. Longitudinal Girders
    b. Transverse Beams
    c. Bracing
    d. Deck
    e. Drainage
2. Pavement
    a. Asphalt layer
    b. Expansion Joint
    c. Rails – joint connection
    d. Waterproofing
3. Substructure
4. Bearings
5. Parapet
6. Communications (Cables/Pipes)
7. Edge Panels

2.2. LONGITUDINAL GIRDERS

2.2.1. SUMMARY

The longitudinal girders were found to be in good condition, with intact protective coating and no corrosion observed. Single localized damage observed on upstream girder.

2.2.2. OBSERVED DEFECTS

Figure. 2.2.1.
Minor Distorsion of upper flange observed on upstream edge girder

2.3. TRANSVERSE BEAMS

2.3.1. SUMMARY

The transverse beams were found to be in good condition. Evidence of mild surface corrosion observed at localized locations of the beams.

2.3.2.OBSERVED DEFECTS

Figure. 2.3.1
Mild surface corrosion observed

Figure. 2.3.2

Mild surface corrosion observed

Figure. 2.3.3
Mild surface corrosion observed

2.4. VERTICAL/ HORIZONTAL/ DIAGIONAL BRACING

2.4.1. SUMMARY

The vertical, horizontal and diagonal bracing are in good condition, with only mild surface corrosion observed in very localized locations.

2.4.2. OBSERVED DEFECTS

Figure. 2.4.1
Mild surface corrosion observed

Figure 2.4.2.
Mild surface corrosion observed

2.5. DECK

2.5.1. SUMMARY

The deck consists of orthotropic deck pates, supported by the transverse beams and welded together, with the design drawings of the deck provided in Figure 2.5.1. It was observed that the deck lacks an effective waterproofing layer, with water seepage occluding to the transverse beams below. The welds between the plates are contributing to this seepage, with cracks between the welds. Mild surface corrosion was also observed.

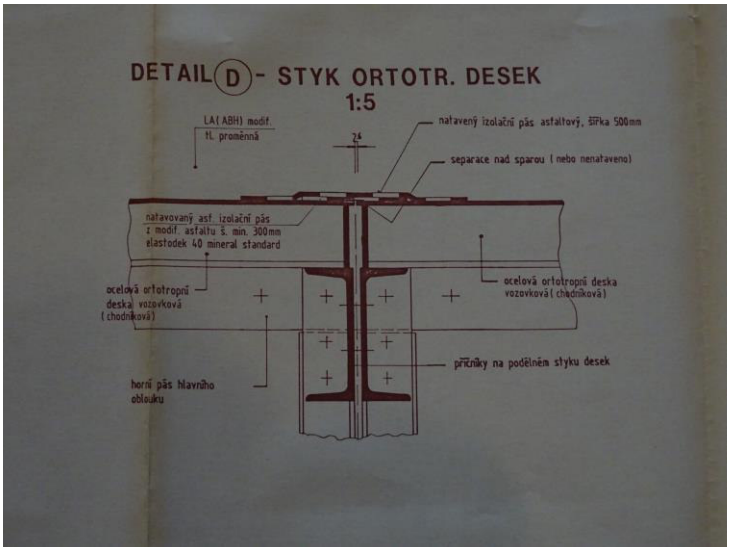

Figure 2.5.1. Details of orthotropic deck plates

2.5.2. OBSERVED DEFECTS

Figure 2.5.2
Cracks in welds detected

Figure 2.5.3
Cracks in welds detected

Figure 2.5.3
Liquid seepage through the deck

Figure 2.5.4
Mild surface corrosion

2.6. DRAINAGE SYSTEM

2.6.1. SUMMARY

The drainage system was found to be in poor condition, with missing and miss sized elements observed.

2.6.2. OBSERVED DEFECTS

Figure 2.6.1
Insufficient length

Figure 2.6.2
Disconnected and missing elements

2.7. ABUTEMENTS

2.7.1. SUMMARY

The abutments are in good condition, with only water seepage and staining observed.

2.7.1. OBSERVED DEFECTS

Figure 2.7.1
Water staining

2.8. BEARINGS

2.8.1. SUMMARY

The upper bearings are corroded, with corrosion present on all elements. The lower bearings are in good condition, with mild surface corrosion observed.

2.8.2. OBSERVED DEFECTS

Figure 2.8.1
Corrosion of upper bearing

Figure 2.8.2
Mild surface corrosion of lower bearing

2.9. ASPHALT LAYER

2.9.1. SUMMARY

The asphalt layer was generally in good condition, with minor patch repair evident.

2.9.2. OBSERVED DEFECTS

Figure 2.9.1
Asphalt layer in good conidtion, with patch repair evident.

2.10. EXPANSION JOINTS

2.10.1. SUMMARY

The expansion joints of the bridge are in poor condition, with gaps and excess vibrations present at each joint.

2.10.2. OBSERVED DEFECTS

Figure 2.10.1
Gaps in expansion joints

Figure 2.10.2
Defunct expansion joints

2.11. WATERPROOFING LAYER

2.11.1. SUMMARY

The waterproofing is the insufficient and defunct throughout the bridge, leading to water leakage throughout the entire bridge structure.

2.11.2. OBSERVED DEFECTS

Figure 2.11.1
Excess water leakage

Figure 2.11.2
Water staining due to indufficient waterproofing

2.12. RAILINGS

2.12.1. SUMMARY

The railings throughout the bridge are corroded, but are structurally intact.

2.12.2. OBSERVED DEFECTS

Figure 2.12.1
Corroded Railing

2.13. COMMUNICATIONS (CABLES/PIPES)

2.13.1. SUMMARY

The communications cables and pipes on the structure are in poor condition, with corrosion of elements and loss of section observed.

2.13.2. OBSERVED DEFECTS

Figure 2.13.1
Corroded communications pipes

Figure 2.13.2
Loss of section

2.14. EDGE PANELS

2.14.1. SUMMARY

The edge panels of the bridge are severely corroded and significant loss of section observed.

2.14.2. OBSERVED DEFECTS

Figure 2.14.1 Corroded edge plates and loss of section

3. MATERIAL TESTING OF THE BRIDGE

3.1. HARDNESS TEST

A hardness test was performed on the steel members of the bridge. It was found that an Ultimate Strength of 390 MPa was obtained.

Figure 3.1.1
Hardness test of
steel elements

4. ASSESSMENT TABLE FROM INSEPCTION ASSESSMENT

structural superstructure	main arch girders	steel	1909	failure of cross section	moment & axial force	deformation of the top flange	**Reliability**	1	2	**40 years**	**2**
	transversal beam	steel	1909	failure of cross section	M & Shear force	corrosion		2			
	bracings - vertical/horizontal	steel	1909	buckling	axial force	superficial corrosion		1			
	deck (orthotropic plate)	steel	2002	lack of support		cracks in the welds		2			
						liquids through joints		2			
						corrosion		2			
bearings	upper bearings	steel	1909		redistribution of forces	corrosion		3	2		
	lower bearings	steel	1909		redistribution of forces	superficial corrosion		2			
substructure	abutment wall face	concrete with stone cover	1909			water staining		2	2		
drainage	tubes/pipes	pipes	2002			disconnection		4	4	**15 years**	
	tubes/pipes					missing / insufficient length		4			
pavement	asphalt layer	asphalt 2x5cm	2002			pot holes (few places)		2			
	expansion joints	elastomeric BAKOR 990-25	2002			material degradation		4			
	rail joint connection	steel	2002			blocked movement		4			
	water proofing layer		2002			not working		4			

Table 4.1. Assessment Table of Reliability of Čechův bridge

railings	railings	steel	1909	falling of the bridge		corrosion	Safety	3	3	15 years	3
	scepters			falling of the bridge		cracks in the scepters		3			
edge panels	edge panels	steel	1909	falling of the bridge		corrosion		4	4	5 years	
	edge panels					lack of support		4			
communication	cables	cables/ pipes	2002			not fixed		2	2	5 years	
	cables					protection elements corrupted		2			

Table 4.2. Assessment Table of Safety of Čechův bridge

5. MAINTENANCE

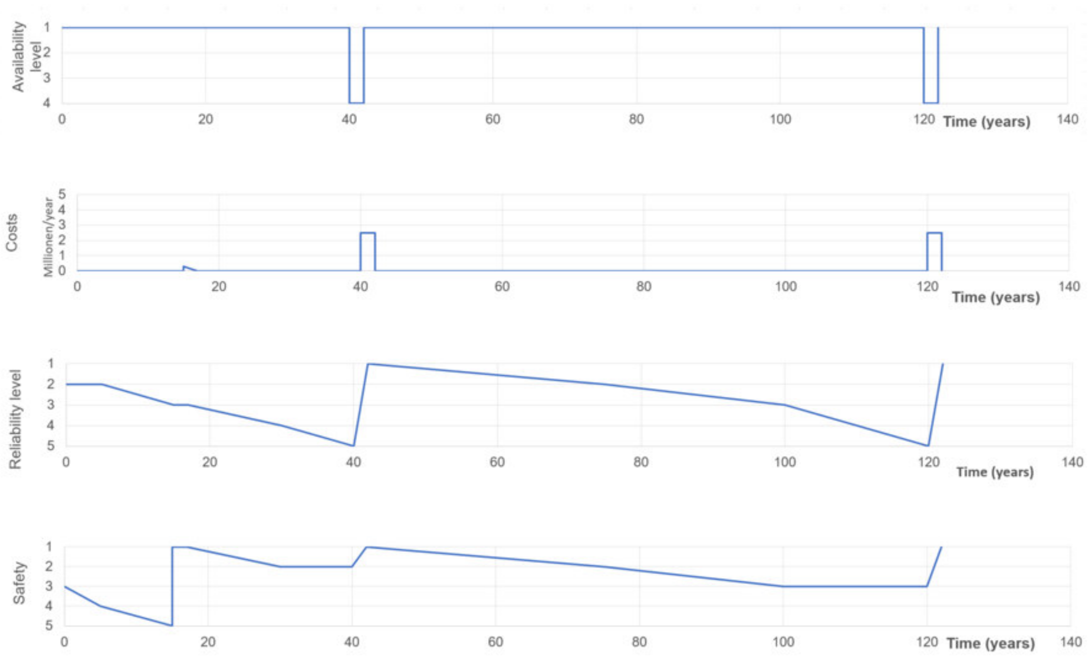

Table 5.1.1. Benchmark maintenance scenario

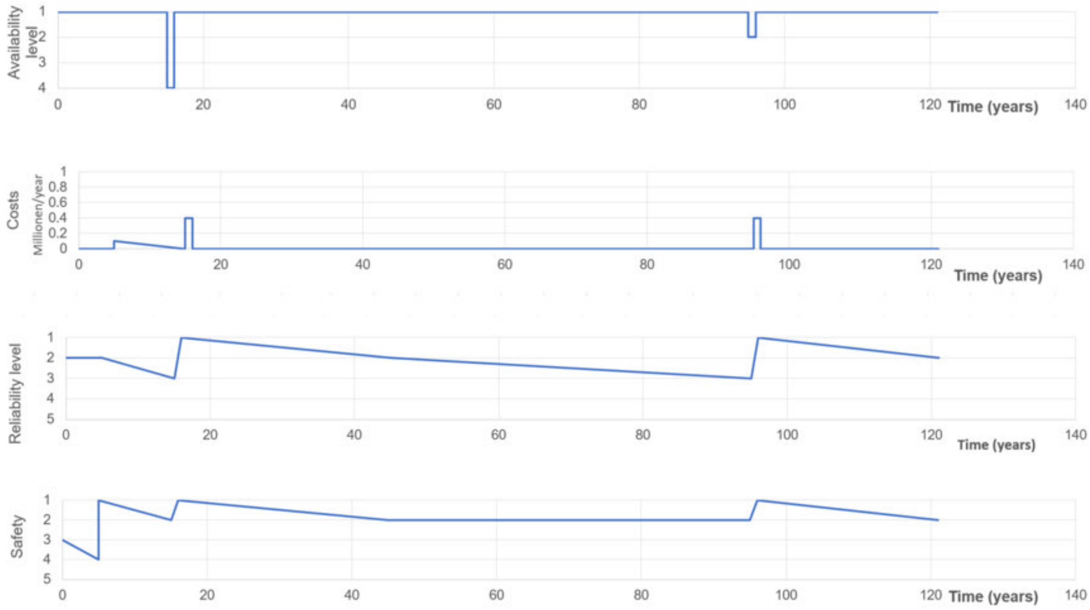

Table 5.1.2. Preeventative maintenance scenario

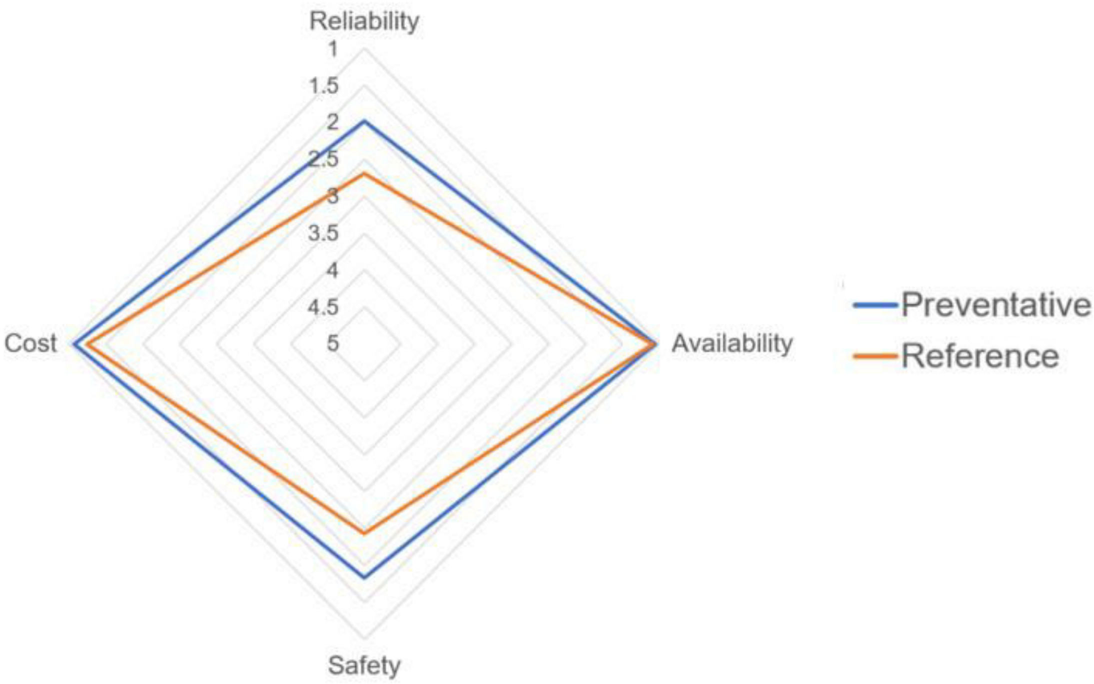

Table 5.1.3. Comparison of maintenance scenarios

6. CONCLUSIONS

The bridge is in good condition. Some minor damage is evident to individual elements but the bridge is structurally sound. Attention should be given to the expansion joints and the waterproofing system on the bridge, which are deficient and may lead to future problems. Using a preventative maintenance strategy will lead to improved reliability, safety and availability over the life time of the bridge.

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