COST Action TU1402: 1st Workshop on Quantifying the Value of Structural Health Monitoring
Lyngby. 04 – 05 May 2015

RISK REDUCTION THROUGH MONITORING OF ROAD BRIDGES

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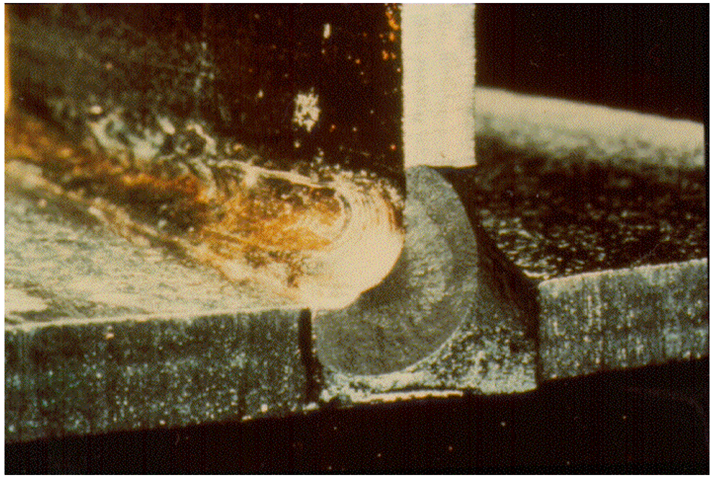
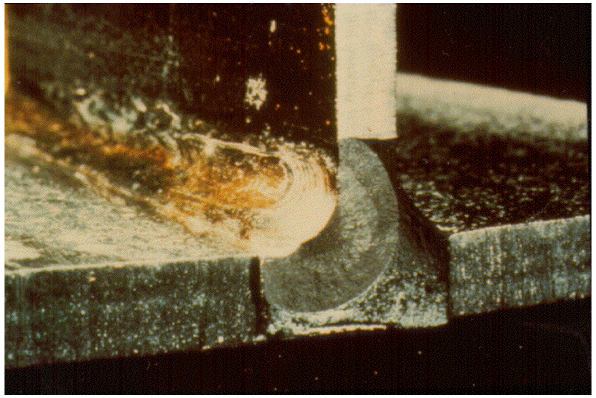
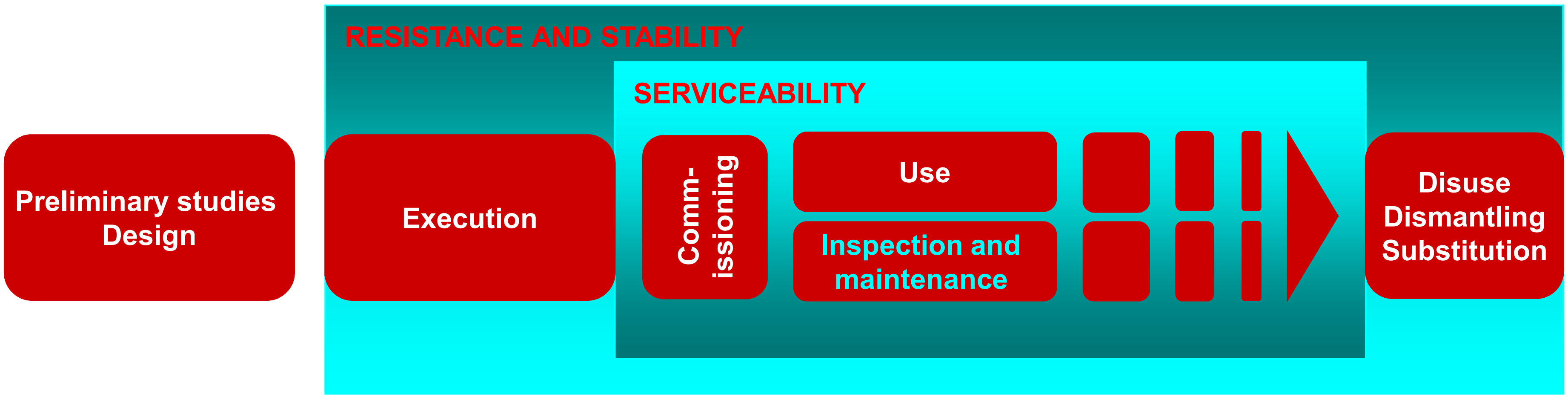


- **Inspections and basic requirements**
- **Monitoring plan**
- **Example**
- **Final remarks**



REQUIREMENTS

- Structures are to be designed, built, used and maintained in such a way that they
  - Remain fit for the use for which they are planned
  - Sustain all actions and influences likely to occur during execution and use
- Requirements can be achieved by adopting measures
  - Technical or organizational measures
  - Measures referring to all stages of the whole process
  - → E. g. risk control by means of inspections, warning systems, …



NON-COMPLIANCE OF REQUIREMENTS

– Different causes may lead to the non-compliance of any particular requirement

- Deviations from expected actions
- Geotechnical actions
- Environmental influences
- Dynamic actions
- Deviations from expected resistance
- Loss of load bearing capacity due to accidental actions
- Loss of resistance due to deterioration mechanisms such as corrosion or fatigue
- Others

→ Quantification of parameters related to such influences may provide evidence about the degree of compliance

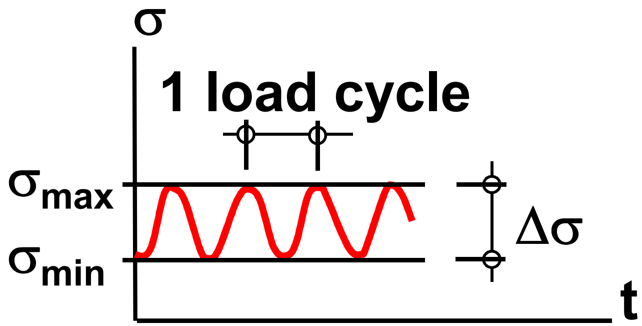
→ Indicators, in analogy with economy or medicine

FATIGUE AS AN EXAMPLE FOR DETERIORATION MECHANISMS

– Repeated variable loads on bridges

→ Initiation and propagation of fatigue cracks is possible

→



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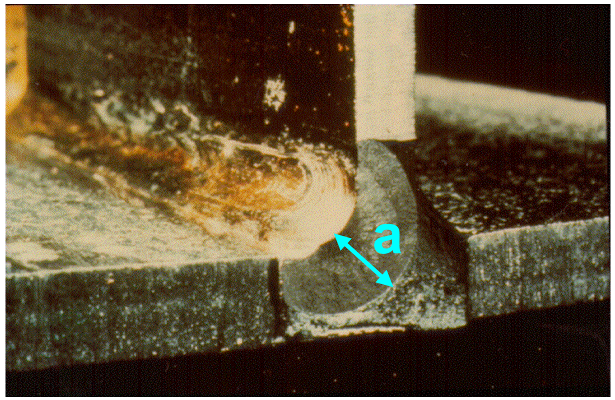

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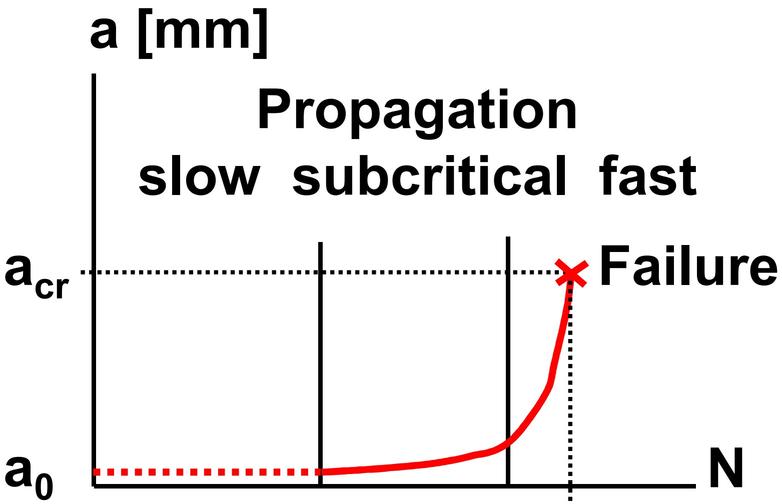
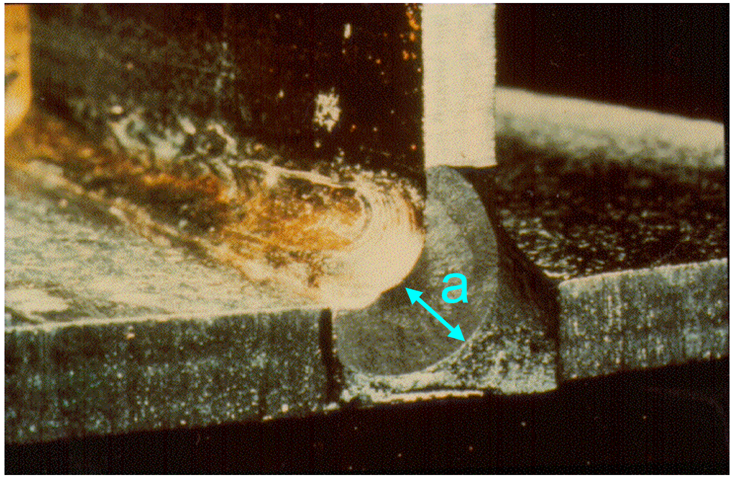


TWO CONDITIONS FOR FATIGUE FAILURE

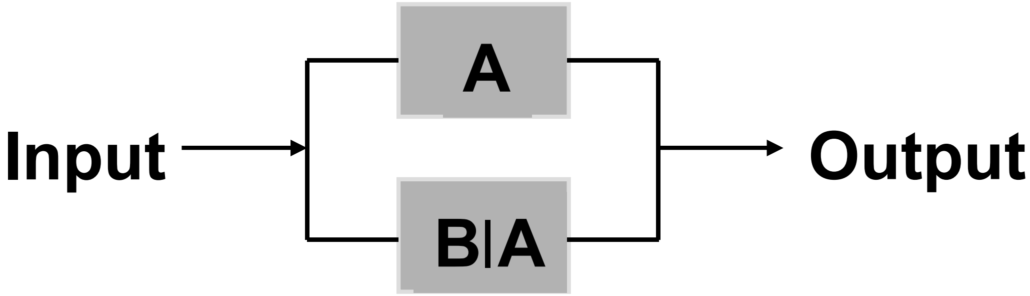
– Initiation and propagation of cracks

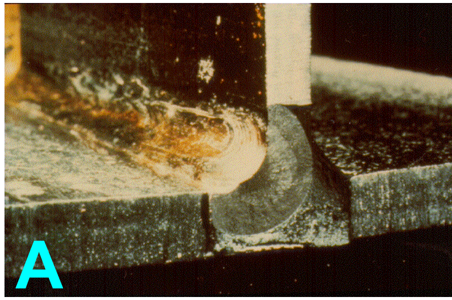


– Cracks undetected → no safety measures are adopted

TWO CONDITIONS FOR FATIGUE FAILURE

– Influence of inspections on probability of failure



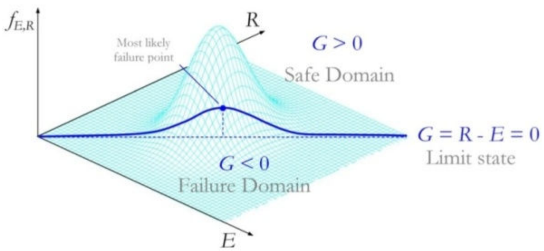


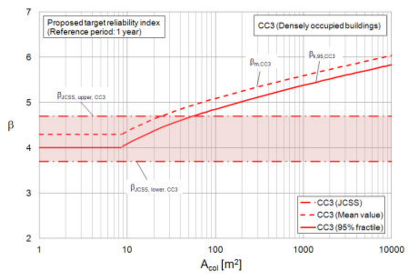
$$P_{f,insp} \approx P_f \cdot \left(1 - P_{\det}\right) \leq P_{f,adm}$$

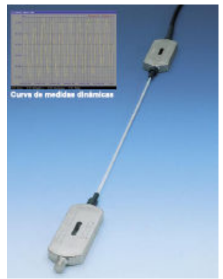
– P_f may be determined by applying probabilistic methods

– $P_{f,adm}$ is related with acceptable risks

– P_{det} depends on inspection strategy: technique, frequency







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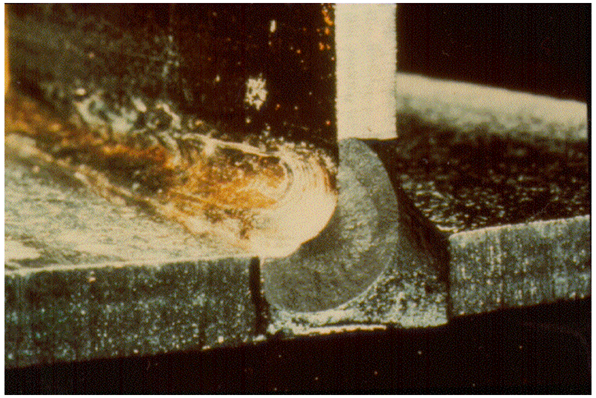
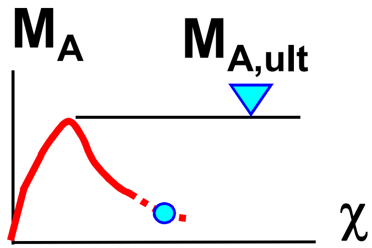
- Monitoring plan
- Example
- Final remarks



INDICATORS

– Quantification may refer to different system parameters related with
  - Geometry
  - Materials
  - Actions and influences
  - Structural behaviour

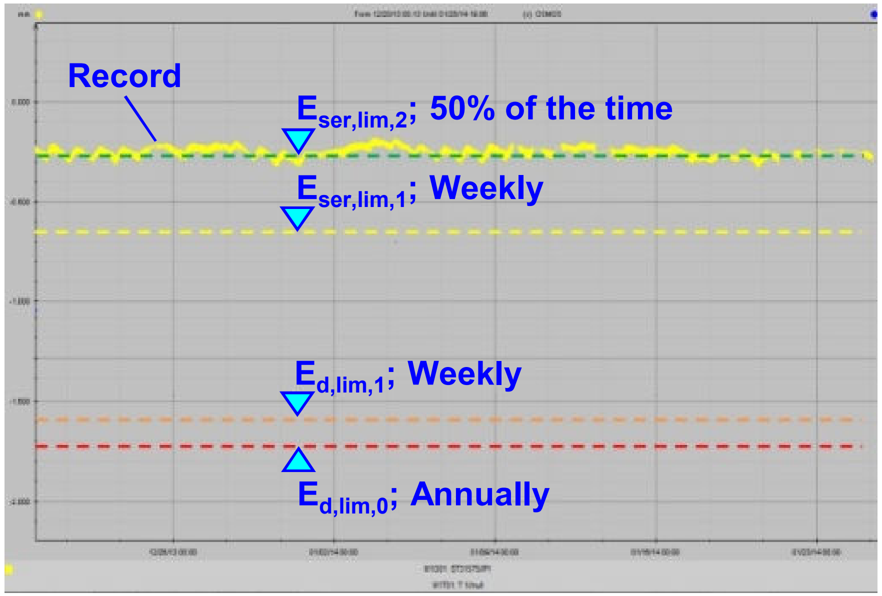


– Choice of parameters depending on the sensitivity of structural reliability to their variation

→ Most sensitive parameters depend on
  - Structural system and behaviour
  - Intended use of the structure
  - Exposure conditions
  - Materials
  - Available data acquisition system

PRACTICAL TOOLS FOR ROAD BRIDGES

- Definition of **indicators** related with different requirements
- Establishment of **threshold values** by applying normal structural analysis methods
- Determination of **admissible average frequencies** for outcrossing



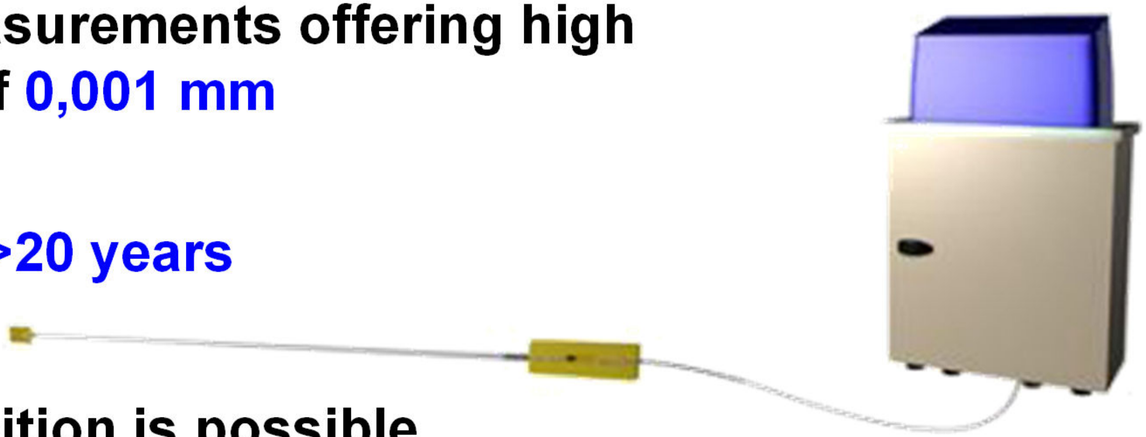
Appearance

Comfort of users

Safety of the structure
Safety of people

FIBER OPTIC SENSORS

- Developments originally intended for, but not limited to, monitoring by using fiber optic sensors
- Properties of sensors measuring the intensity of light
  - Excellent signal-to-noise ratio and no electromagnetic interference
  - Static and dynamic measurements offering high precision of the order of 0,001 mm
  - No loss of origin 0
  - Long service period of >20 years



→ Advantages
  - Continuous data acquisition is possible
  - Continuous comparison with threshold values
  - Alarm in case of outcrossing
  - Adoption of measures depending on the type of non-compliance

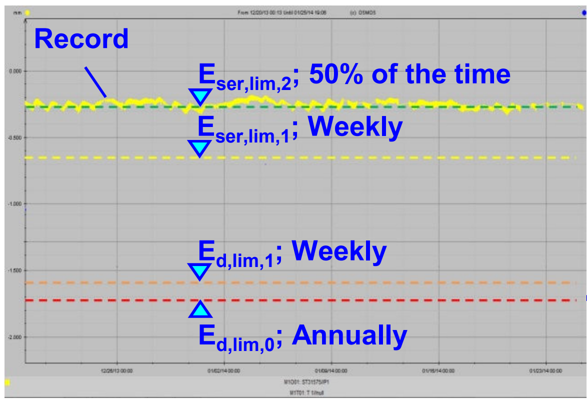
→ Automation is possible

REQUIREMENTS, INDICATORS AND THRESHOLD VALUES

- Developed criteria depending on the failure consequences
- Material independent requirements

	Demand	Consequences	Requirement	Indicator	Threshold		
					Value $E_{ser,lim}$; $C_{ser,lim}$		Mean frequency ω_{ser}
SLS	Appearance	Reversible	Deformations	Deflection	L/700 [1)]		50 % of time
SLS	Appearance	Reversible	Deformations	Strain	$E_{ser,lim,2}$		50 % of time
SLS	Comfort	Reversible	Deformations	Deflection	L/1000 [2)]		Weekly
SLS	Comfort	Reversible	Deformations	Strain	$E_{ser,lim,1}$		Weekly
SLS	Comfort	Reversible	Vibrations	Acceleration	a_v [3)]	a_h [3)]	
SLS	– Maximum				0,5	0,1	-
SLS	– Medium				1,0	0,3	-
SLS	– Minimum				2,5	0,8	-

	Demand	Consequences	Requirement	Indicator	Threshold	
					Value $E_{d,lim}$	Mean fr. ω_d
ULS	Structural reliability	Reversible	Safety of structure and facilities	Traffic loads [1)]	$E_{d,lim,1}$	Weekly
ULS	Structural reliability	Reversible	Safety of structure and facilities	Strain	$E_{d,lim,1}$	Weekly
ULS	Structural reliability	Irreversible	Safety of people	Traffic loads [1)]	$E_{d,lim,0}$	Yearly
ULS	Structural reliability	Irreversible	Safety of people	Strain	$E_{d,lim,0}$	Yearly



THRESHOLD VALUES RELATED WITH STRUCTURAL SAFETY

– Quantified parameters **indicate acceptable reliability** if

$$E_{mon} \leq E_{d,\lim}$$

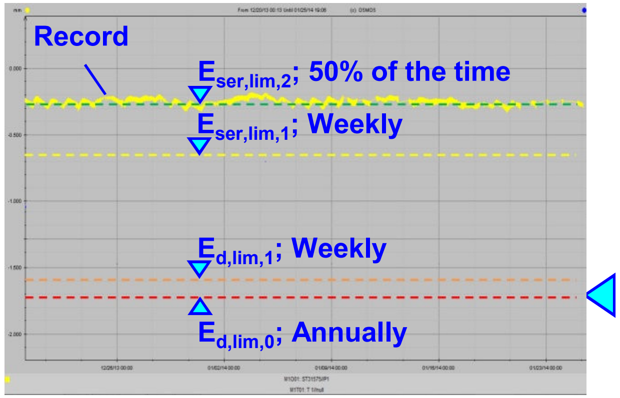
or

$$E_{mon} > E_{d,\lim} \text{ with } \omega_{mon} < \omega_d$$

– Example

$$E_{d,\lim,0} = E\left(\sum_{j\geq 1} \gamma_{G,j} \cdot G_{k,j} \text{"+"} \gamma_P \cdot P \text{"+"} \gamma_{Q,1} \cdot \psi_{0,1} \cdot Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \cdot \psi_{1,i} \cdot Q_{k,i}\right)$$

ω_d : annually



→ Threshold values depend on stage when monitoring starts

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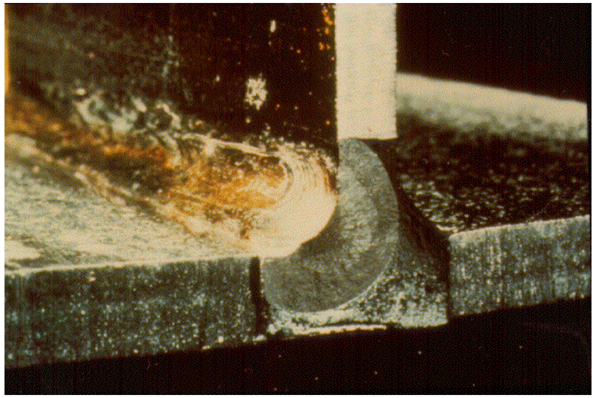
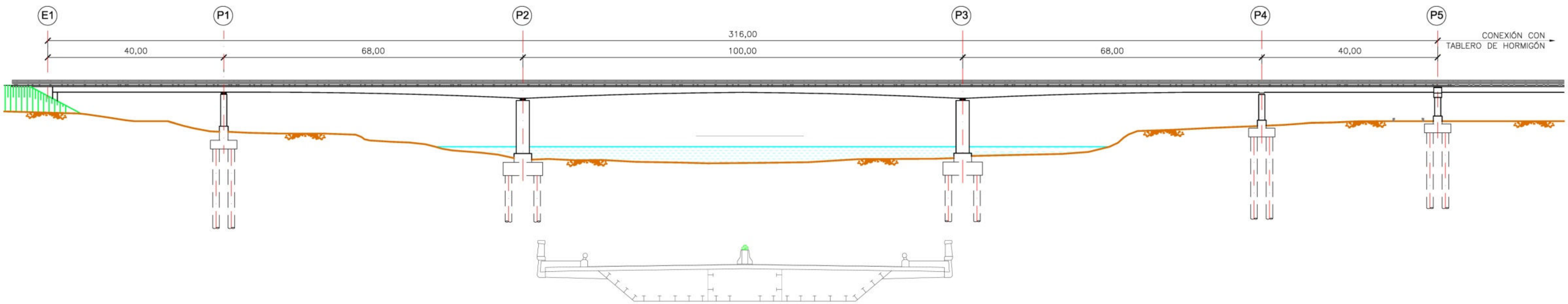


Example

IMPLEMENTATION OF A MONITORING AND ALARM SYSTEM

- Doubts about structural safety of an existing bridge
- Deck constituted by continuous five-span composite girder
  - Total length 316 m: 40 – 68 – 100 – 68 – 40 m
  - Deck width: 30,1 m
  - Tricellular steel box girder of varying height: 2250 mm to 4550 mm
  - 0,22 m deep reinforced concrete slab with prestressing over piers
  - Cantilevers rest on composite ribs
  - Deck supported by 4 piers and 2 abutments



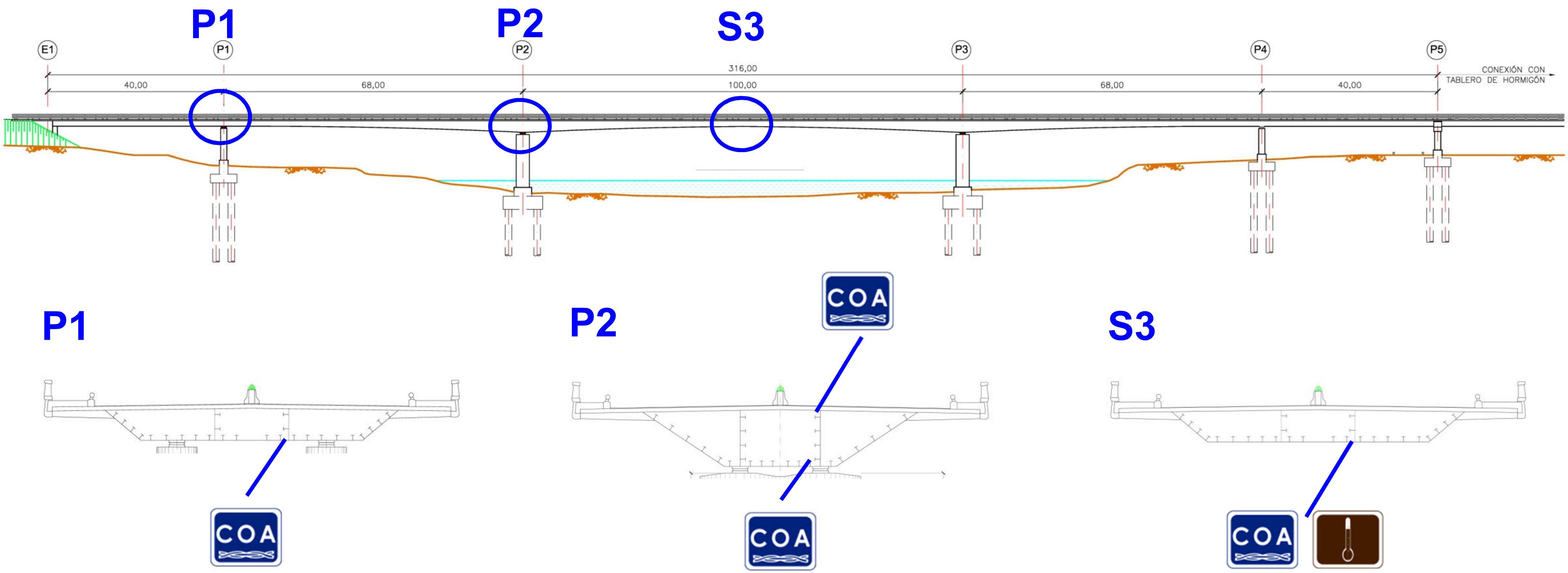
Example

INSTRUMENTATION

– Installation of fiber optic sensors in 3 cross-sections: COA

→ Indicator: strains

– In addition, temperature measurement in the box girder:

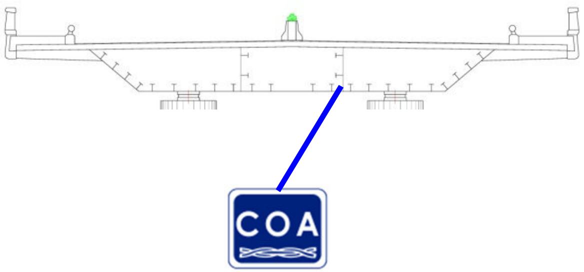


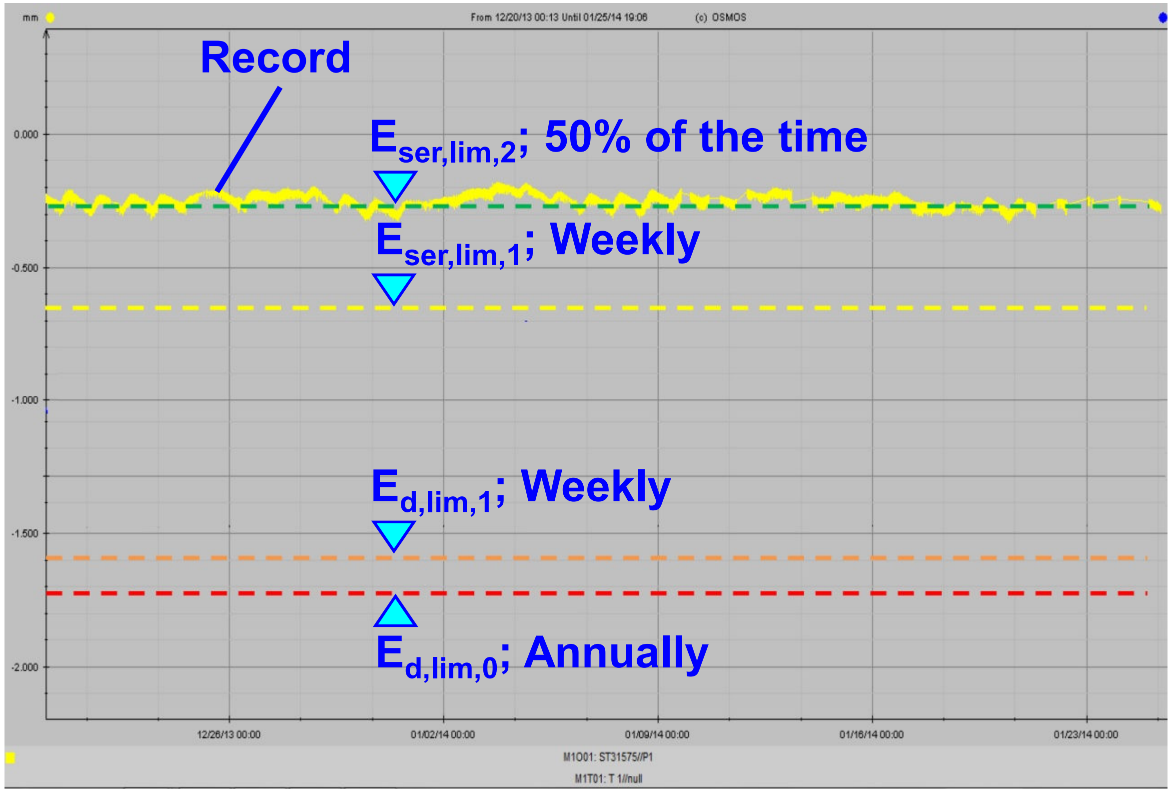
RESULTS

- For illustration purposes, consider results for the bottom flange over pier P1 → negative sign for compression
- Continuous record since 20/12/2013

→ Green signal

P1





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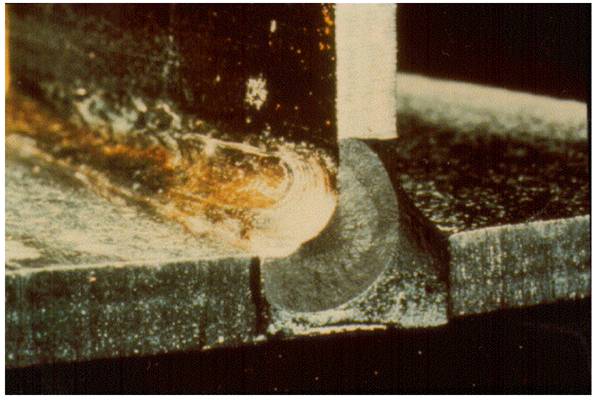

FINAL REMARKS

- Rational tool for risk control
- Contributes to the optimization of operation costs for infrastructures, new or existing
  - Instrumentation cost for the considered example — 55.700.- €
  - Expected number of fatalities in case of collapse of S3 — 9 fatalities
  - → Investment in preventing premature death — 6.190.- €

→ Comparison: in Western countries, life saving costs of the order of 3.000.000.- € are deemed reasonable

→ Saved resources are available for different purposes