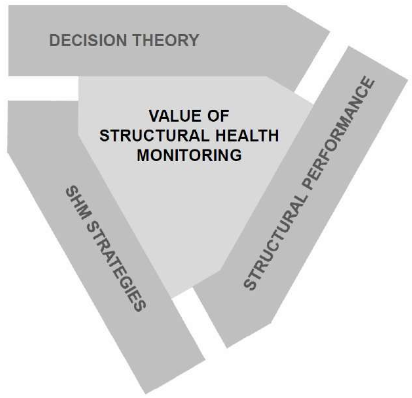


Long-term performance of prestressed concrete bridges

Helder Sousa

Brisa
UNIVERSITY OF SURREY

Luís Oliveira Santos

LNEC
LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

4th Workshop of the COST Action TU1402

Guildford, Surrey, United Kingdom, 18th of April, 2016

INDEX

- Introduction
- Long-term observation and assessment of prestressed concrete bridges
- Performance indicators for the long-term assessment
- Value of SHM from in-situ characterization of creep and shrinkage
- Conclusions

1. Introduction

- Time-dependent behaviour of prestressed concrete
  - increase of deformations
  - losses of prestress
  - redistribution of stresses
- Creep and shrinkage effects
  - Depend on concrete composition and environmental conditions
  - No agreement between the different code formula
  - Code formulae shows limitations for bridge assessment
- High uncertainty
  - Creep and shrinkage uncertainty might lead to underestimation of deflections
  - Potential loss of serviceability and durability

2. Long-term observation and assessment of prestressed concrete bridges

1st part: Monitoring the long-term behaviour – what to measure

- Parameters clustered in three main categories: (i) structural measurements, (ii) specimen measurements, (iii) environmental measurements

- Specimen measurements ⇨ quantify creep and shrinkage deformations

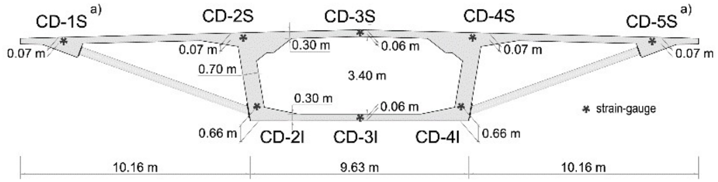
- Environmental measurements ⇨ quantify deformations mainly due to temperature variations

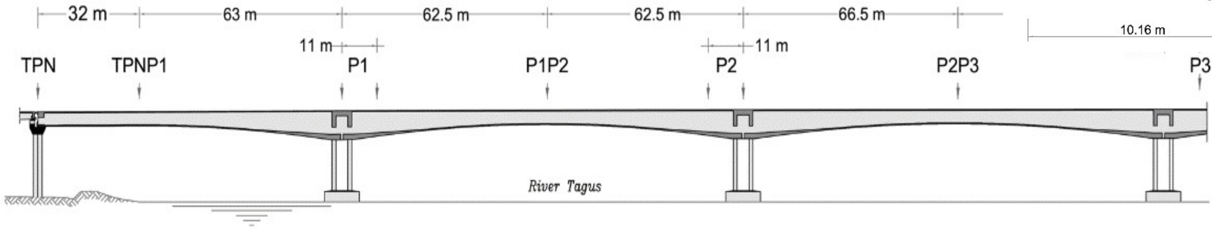
Category	Parameter	SHM technology (sensors)
Structure	Vertical displacement	Hydrostatic levelling system
	Bearing/Joint displacement	LVDTs
	Rotation	Inclinometers
	Strain	Strain-gauges
	Support reaction	Load cells
Specimens	Creep	Strain gauges
	Shrinkage	Strain gauges
Environment	Temperature	PT100
	Relative Humidity	Capacitive RH sensor

2. Long-term observation and assessment of prestressed concrete bridges

1st part: Monitoring the long-term behaviour – where to measure

- ❑ Objective is to capture, as best as possible, the long-term deflection of the bridge
- ❑ Sensors located where it is expected that they will record the maximum expected amplitude, among all the possible locations
- ❑ Priori knowledge about the structure behaviour in order to identify the critical sections





	TPN	TPNP1	P1	P1P2	P2	P2P3	P3
VERTICAL DISPLACEMENT		✓		✓		✓	
BEARING DISPLACEMENT	✓						
ROTATION			✓		✓		
STRAIN		✓	✓	✓	✓	✓	✓

Example: Monitoring plan of Lezíria Bridge

2. Long-term observation and assessment of prestressed concrete bridges

2nd part: Assessment of the long-term behaviour

- ❑ Structural models (e.g. FE models) are normally used to get reliable estimations ⇨ reference information
- ❑ Reliability of those estimations depends on the assumptions made for the structural models
- ❑ Collect, as much as possible, real information related to the monitored bridge ⇨ reduce uncertainty. Models which use real information from the bridge are called as *updated structural models*
- ❑ Real information grouped in main five categories:
  - ❑ material characterization
  - ❑ environmental conditions
  - ❑ loading
  - ❑ time-history

3. Performance indicators for the long-term assessment

- Assessment of the long-term performance of prestressed concrete bridges based on periodical inspections.

- SHM technologies provides an important improvement in the assessment through the measurement of selected structural parameters and its comparison with values predicted by structural models

- PI is an abstraction of superior level related to a bridge characteristic, which enables to identify the condition of a bridge

- PI as a dimensionless index (e.g. as a relation between a measured value and a reference value)

- For the definition of PI, the bridge is seen as a composition of two main components:

    - bearing and expansion joints and
    - the prestressed concrete structure

3. Performance indicators for the long-term assessment

Bearings and expansion joints

- Bearing or joint displacement is ultimately restricted by the maximum range of the bearing or joint device
- Maximum range of a bearing/joint device and the measured displacement used to define the PI
- Ratio between measured and reference value is proposed

$$PI_{bearing/joint} = \mathrm{f}(\text{displacement}, \text{maxi}mum\ range)$$

Prestressed concrete structure

- Several parameters that can be related to the definition of a PI (e.g. vertical displacement, rotation or strain)
- Reference values set by the bridge designer is proposed to be adopted
- An alternative approach is to use the stress level installed on the bridge (obtained based on the updated structural model that is able to best match the collected measurements)

$$PI_{concrete} = \mathrm{f}(\sigma_c\,, f_{ctk}\,, f_{ck})$$

4. Value of SHM from in-situ characterization of creep and shrinkage

- Creep and shrinkage effects are perhaps the ones with highest uncertainty.
- Long-term predictions differ significantly from the observed response
- Although the majority of shrinkage and creep models are relative recent and comprehensive, there are systematic deviations and a lack of consensus in their utilisation (mainly thought for design proposes rather assessment)
- Best approach to reduce uncertainty associated with creep and shrinkage effects is through long-term observation supported on SHM systems
- Bridge owner/operator benefits in employing SHM systems (i.e. overall, the operational costs decrease)

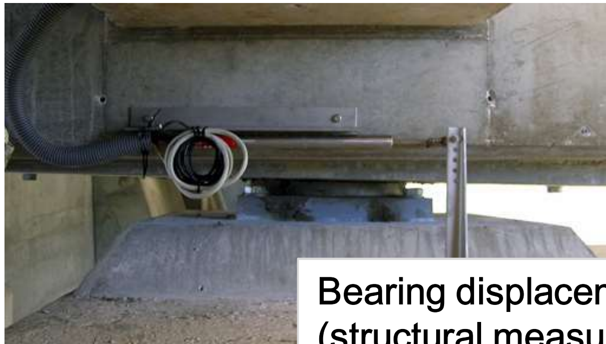
$$V = B_1 - B_0\,, \qquad \begin{cases} B_0 = Life\ cycle\ benefit\ without\ SHM \\ B_1 = Life\ cycle\ benefit\ utilizing\ SHM \end{cases}$$

4. Value of SHM from in-situ characterization of creep and shrinkage

Lezíria Bridge – a case study

- Comprehensive case study available in the literature
- Monitoring data collected since the beginning of construction
- Real data related to materials, geometry, and loading
- FE modelling approach based on a full model of the bridge, including a detailed time-step analysis from the beginning of construction

Creep and shrinkage (specimen measurements)

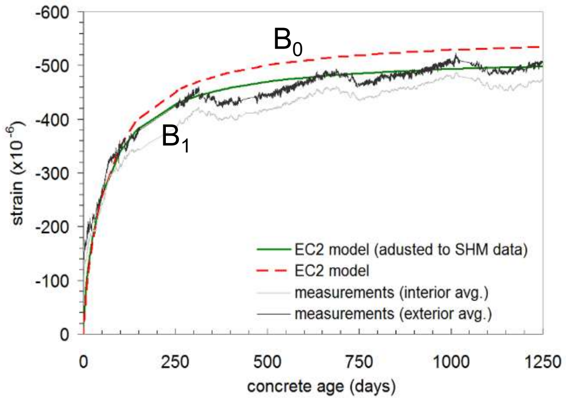


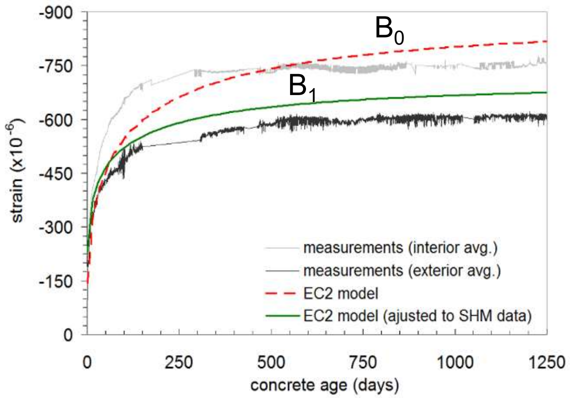
Bearing displacement (structural measurements)

4. Value of SHM from in-situ characterization of creep and shrinkage

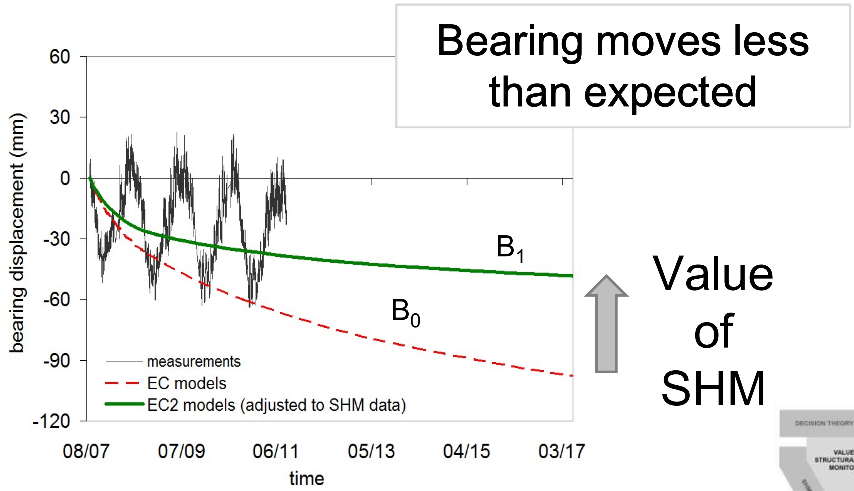
Lezíria Bridge – a case study

Creep and shrinkage (specimen level)





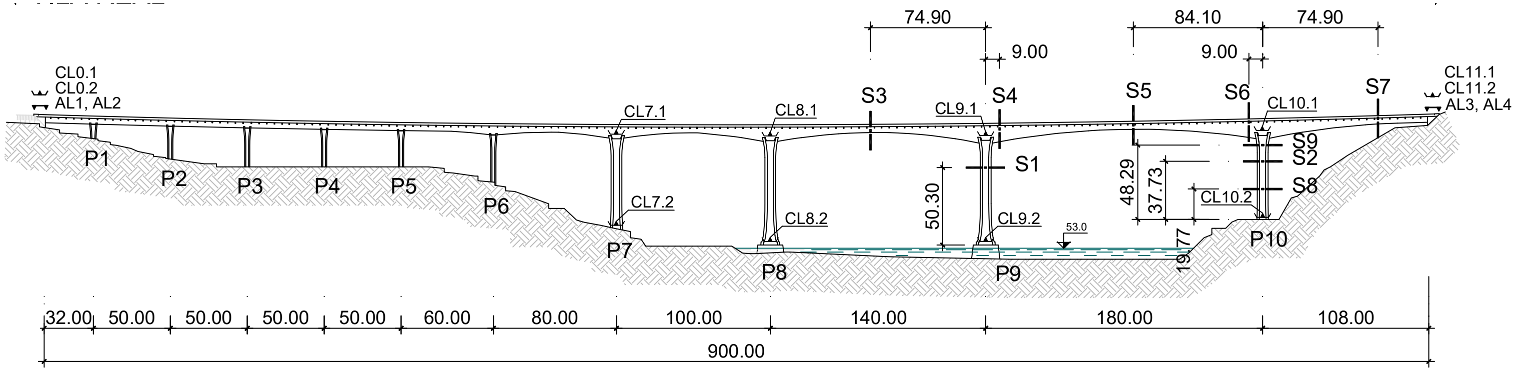
Bearing displacement (structural level)



B_0 – prediction without monitoring
B_1 – prediction with monitoring

4. Value of SHM from in-situ characterization of creep and shrinkage

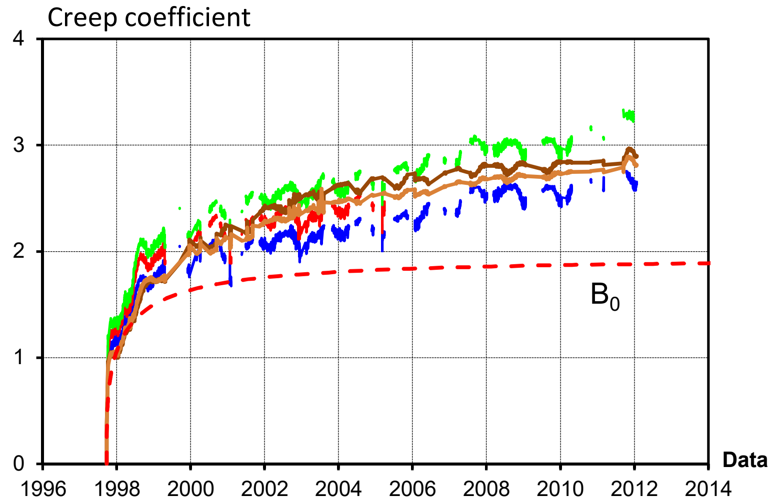
Miguel Torga Bridge



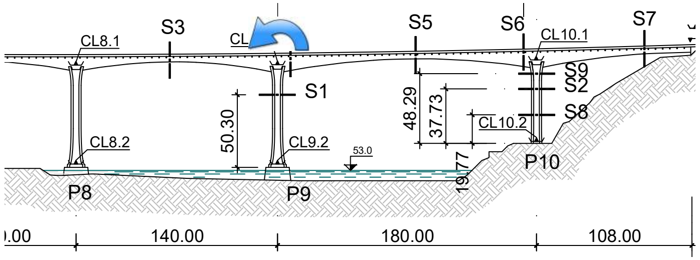
4. Value of SHM from in-situ characterization of creep and shrinkage

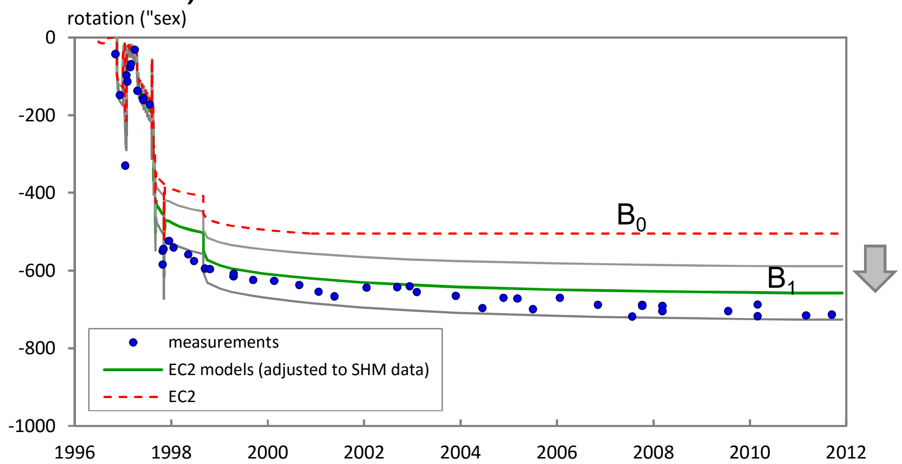
Miguel Torga Bridge – a case study

Creep and shrinkage (specimen level)



Rotation at the top of P9 (structural level)





Value of SHM

B_0 – prediction without monitoring
B_1 – prediction with monitoring

5. Conclusions

- Long-term performance of prestressed concrete bridges is highly dependent on creep and shrinkage effects

- Generally, available code formulae are not suitable to be used for bridge assessment

- Definition of PI depends on the component of the bridge: (i) bearings and joint devices and (ii) prestressed concrete structure

- Comprehensive monitoring systems installed on the bridge + updated structural models crucial for reliable long-term assessment of the bridge with benefit in the reduction of operational costs from the perspective of the bridge owner/operator

References

American Concrete Institute Committee 209 (ACI). (2008). Guide for modeling and calculating shrinkage and creep in hardened concrete. ACI Rep. 209.2R-08, ACI, Farmington Hills, MI.

Bažant, Z., Yu, Q., and Li, G. (2012a). Excessive Long-Time Deflections of Prestressed Box Girders. I: Record-Span Bridge in Palau and Other Paradigms. Journal of Structural Engineering, 138(6):676-686.

Bažant, Z. P., Yu, Q., and Li, G. H. (2012b). Excessive long-time deflections of prestressed box girders. II: Numerical analysis and lessons learned. Journal of Structural Engineering, 138(6):687-696.

Bergmeister, K., Santa, U. (2001). Global monitoring concepts for bridges. Structural Concrete, the official Journal of the fib, 2 (1), 29-39.

European Committee for Standardization (2004). Eurocode 2 EN 1991-1-1 design of concrete structures part 1–1 general rules and rules for buildings. 2nd edition Brussels: CEN.

European Committee for Standardization (2005). Eurocode 2 EN 1992-2 - Design of concrete structures – Part 2: Concrete bridges - Design and detailing rules, Brussels: CEN/TC 250.

Goel R, Kumar R, Paul DK. (2007). Comparative study of various creep and shrinkage prediction models for concrete. Journal Materials Civil Engineering, 19:60-249.

Robertson I. (2005). Prediction of vertical deflections for a long-span prestressed concrete bridge structure. Engineering Structures, 27:7–1820.

Santos, L. O. (2001). Observation and analysis of the time dependent behavior of concrete bridges. Ph.D. thesis. Universidade Técnica de Lisboa, Lisbon, Portugal. (in Portuguese)

Santos, L.O., Virtuoso, F., Fernandes, J.A. (2001). In situ measured creep and shrinkage of concrete bridges, 6th International Conference on Creep, Shrinkage & Durability Mechanics of Concrete and other Quasi-Brittle Materials - ConCreep 6, MIT, Cambridge, USA.

References

Santos T. O. (2007). Concrete shrinkage in bridges: Observation and analysis. PhD thesis. LNEC, Lisbon, Portugal. (in Portuguese)

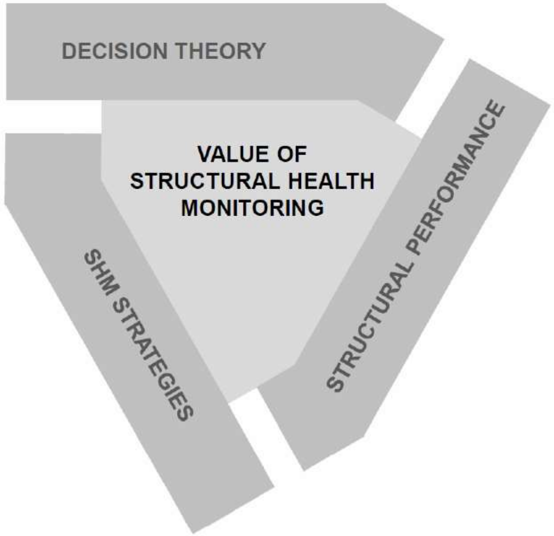
Sousa, H., Félix, C., Bento, J., Figueiras, J. (2011). Design and implementation of a monitoring system applied to a long-span prestressed concrete bridge. Structural Concrete. 12(2):82-93.

Sousa, H., A., Bento, J., Figueiras, J. (2013). Construction assessment and long-term prediction of prestressed concrete bridges based on monitoring data. Engineering Structures 52:26-37.

Sousa, H., A., Bento, J., Figueiras, J. (2014). Assessment and management of concrete bridges supported on monitoring data-based finite element modelling. Journal of Bridge Engineering, 19(6):05014002.

Thöns, S. and M. H. Faber (2013). Assessing the Value of Structural Health Monitoring. 11th International Conference on Structural Safety & Reliability (ICOSSAR 2013). New York, USA.

Thank you for your attention



Helder Sousa

Luís Oliveira Santos

Brisa

UNIVERSITY OF SURREY

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL