In situ measured creep and shrinkage of concrete bridges

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After a brief description of the experimental procedure to measure creep and shrinkage of concrete in field conditions, the methodology for the characterization of variability of the experimental data is presented and applied to the results obtained from four bridges built in Portugal.

1. INTRODUCTION

The prediction of concrete creep and shrinkage is deeply associated with a great uncertainty due to the variability of many parameters, namely those related with environmental conditions. In structural analysis of the time dependent behaviour this uncertainty should to be taken into account in the modelling of creep and shrinkage.

The National Laboratory for Civil Engineering (LNEC) has a long experience of monitoring the long-term behaviour of prestressed concrete bridges. The usually adopted procedure used includes, besides measurements in the structure, the measurement of the creep and shrinkage of concrete in specimens placed over the deck and inside the box girder, in several sections.

A brief description of the experimental procedure is made and a methodology for the characterization of the variability of the data measured in those specimens is presented and applied to the results obtained from four bridges built in Portugal. This methodology includes the identification of the specimens deformation due to seasonal effects, the statistical evaluation of the experimental data and the use of a non-linear regression to fit EC2[1] / MC90[2] models to that data.

2. EXPERIMENTAL PROCEDURES

The specimens were made with the same concrete of the bridge and maintained in the same environmental conditions of the structure. They are prismatic, usually, with $0.3\times0.3\times0.6\ m^3$ for shrinkage and with $0.3\times0.3\times0.7\ m^3$ for creep. In order to prevent evaporation two opposite faces are sealed. Inside of each prism a vibrating wire gauge is placed to measure concrete strain. The shrinkage specimens are not loaded, subject only to environmental conditions. The creep specimens are subject to a constant axial load imposed by hydraulic jacks, which maintain the pressure level (Figure 1).

The concrete specimens are placed in several sections over the deck and inside the box girder. In Miguel Torga Bridge two of the shrinkage specimens were placed outside the deck but under the outside flanges and some of the creep and shrinkage specimens were kept in laboratory. Table 1 indicates the distribution of the specimens involved in this study and the number of sections studied. More details about the experimental procedures, which include the determination of strength and modulus of elasticity by laboratory tests, have been presented in [3,4].

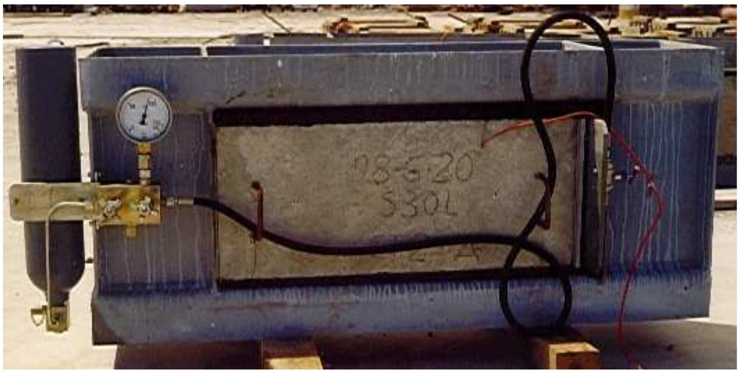

Figure 1. A creep specimen

Table 1 – Number of specimens involved in this study

Bridge	Shrinkage				Creep			
	No sections	Outside	Inside	Lab.	No sections	Outside	Inside	Lab.
S. João	6	–	15	–	6	–	15	–
Guadiana	4	7	6	–	2	4	4	–
Freixo	8	8	12	–	4	–	8	–
M. Torga	5	32	15	6	2	6	9	6
Total	24	47	48	6	14	10	36	6

3. SHRINKAGE AND CREEP VARIABILITY

Two parameters (C1 and C2) were introduced in EC2 shrinkage expressions in order to allow the fitting of these expressions to experimental results:

$$\varepsilon_{cs}(t-t_s) = \varepsilon_{cs0} \cdot \beta_s(t-t_s) \qquad (1)$$

$$\varepsilon_{cs0} = C_1 \cdot \varepsilon_s(f_{cm}) \cdot \beta_{RH} \qquad (2)$$

$$\beta_s(t-t_s) = \left(\frac{t-t_s}{0{,}035\, h_0^2 + (t-t_s)} \right)^{0{,}5C_2} \qquad (3)$$

Seasonal effects, namely the temperature, affect the measure of shrinkage in field conditions. In order to take into account these effects, the non-linear regression model used includes a sinusoidal function:

$$\Delta\varepsilon_{csT}(t-t_s) = \varepsilon_{cs0} \cdot \beta_s(t-t_s) + A_1 \left[\cos\left(\frac{2\pi(t-t_s)}{365} \right) - 1 \right] + A_2\, sen\left(\frac{2\pi(t-t_s)}{365} \right) \qquad (4)$$

Figure 2 presents strains measured in shrinkage specimens located in the outside environment in one section of Miguel Torga Bridge and the curves obtained by the described approach. In specimens located under flanges strains are much higher then the strains in the specimens located over the deck. This difference is, probably, due to rainfall, as it was already suggested by Sato and Ujike[5].

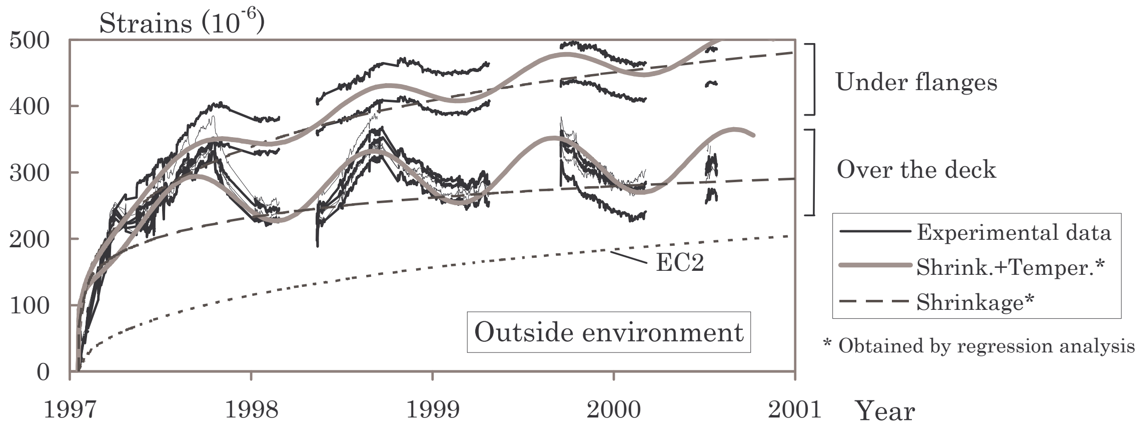

Figure 2. Shrinkage strains in specimens of section S4 of Miguel Torga Bridge

With shrinkage strains already identified, the average and standard deviation of experimental data of specimens maintained in the same environmental conditions were calculated at different ages. Assuming a normal distribution it is then possible to fit, by non-linear regression, EC2 curve to several values of the same quantile at different ages

The strains measured in inside environment of different sections of Freixo Bridge are presented in Figure 3. In this figure the EC2 curve and the curves of 5%, 50% and 95% quantile, obtained by the described methodology are also presented.

Creep results were treated in the same way as shrinkage, introducing two parameters (C_3 and C_4) in the EC2 expressions:

$$\phi(t,t_0) = \phi_0 \cdot \beta_c(t-t_0) \tag{5}$$

$$\phi_0 = C_3 \cdot \phi_{RH} \cdot \beta(f_{cm}) \cdot \beta(t_0) \tag{6}$$

$$\beta_c(t-t_0) = \left(\frac{(t-t_0)}{\beta_H + (t-t_0)} \right)^{0,3\,C_4} \tag{7}$$

4. COMPARISON OF RESULTS FROM DIFFERENT BRIDGES

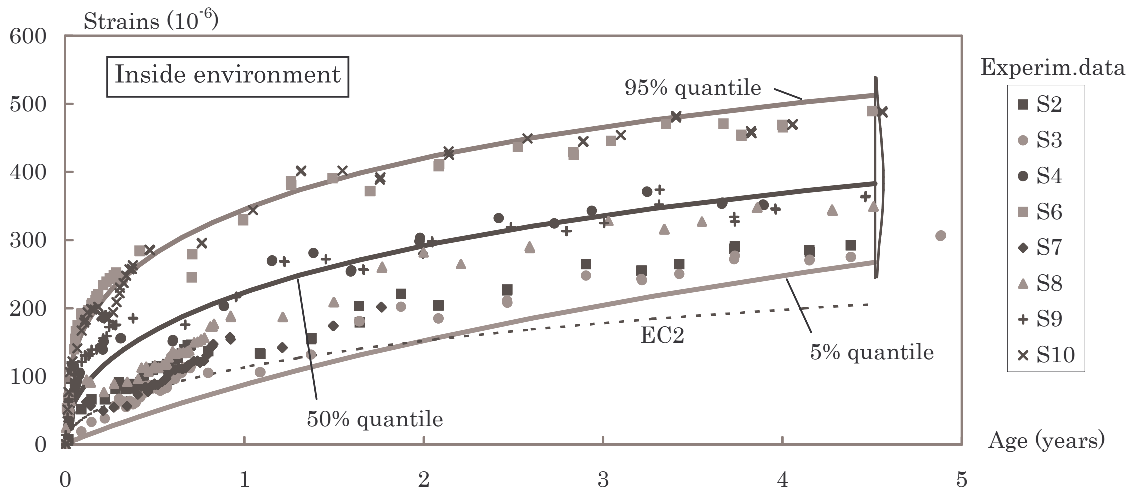

Figure 3. Shrinkage strains in specimens inside box-girder of Freixo Bridge

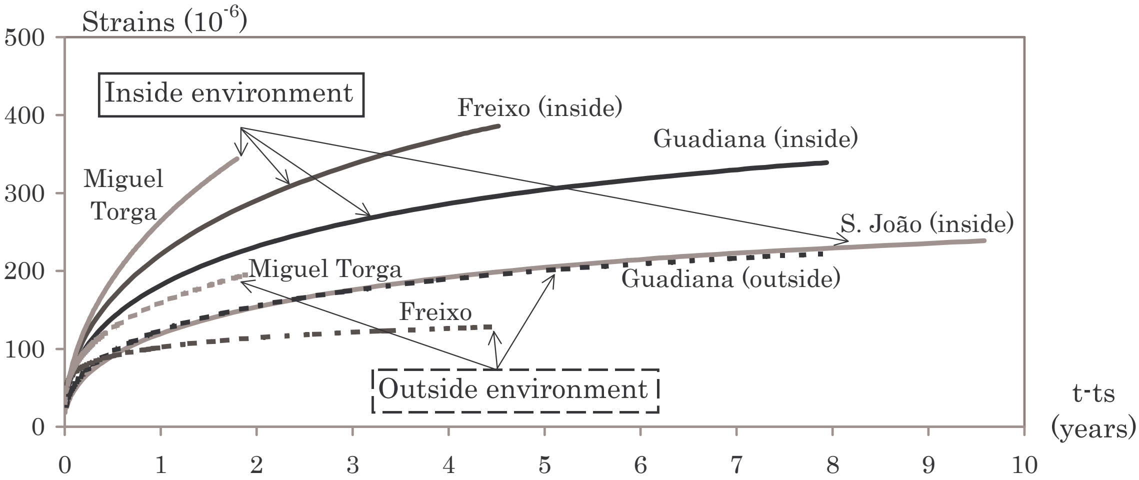

Figure 4. Shrinkage strains: average values

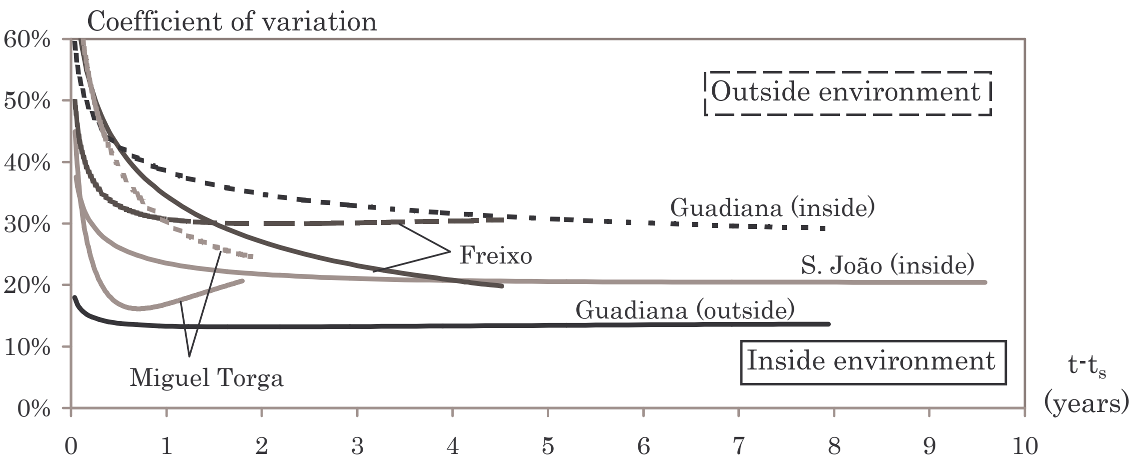

Figure 5. Shrinkage strains: coefficient of variation

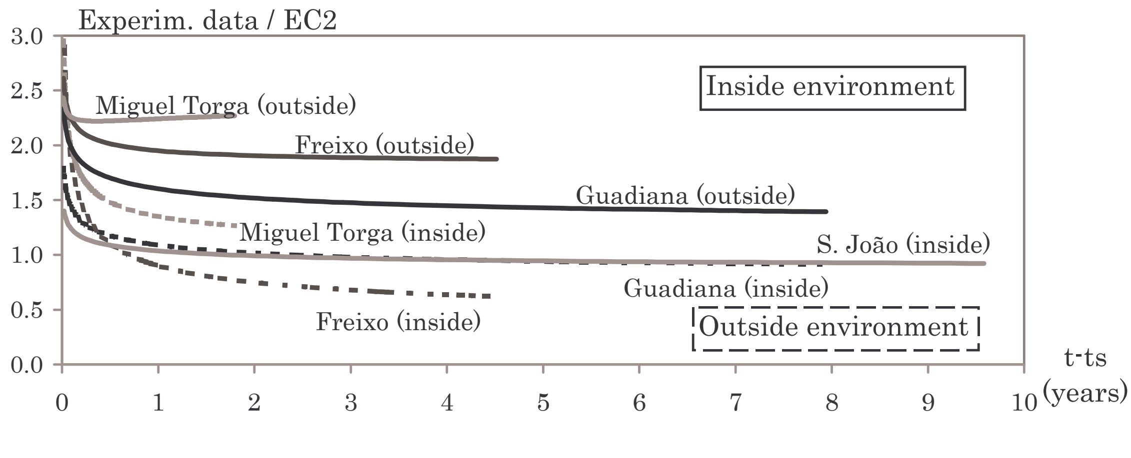

Figure 6. Shrinkage strains: relation between measured and predicted values

Shrinkage evolution of the four bridges studied is presented in Figures 4 to 6. As the differences found between creep coefficients of inside and outside specimens were not so significant as for shrinkage [3], creep evolution presented in Figures 7 to 9, is the average of inside and outside specimens. Figures 4 to 9 includes for both shrinkage and creep the evolution of the average, the coefficient of variation and the relation between experimental and predicted values.

In shrinkage figures the differences between behaviour of inside and outside specimens are

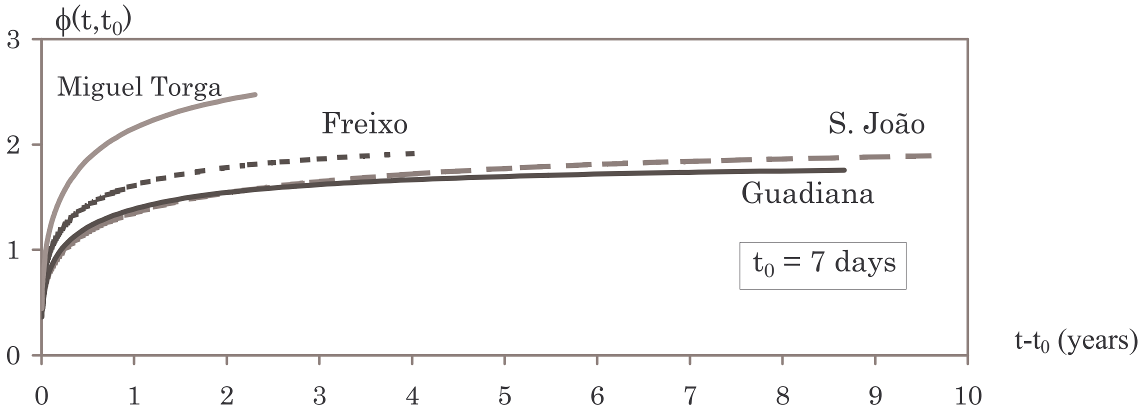

Figure 7. Creep coefficient: average values

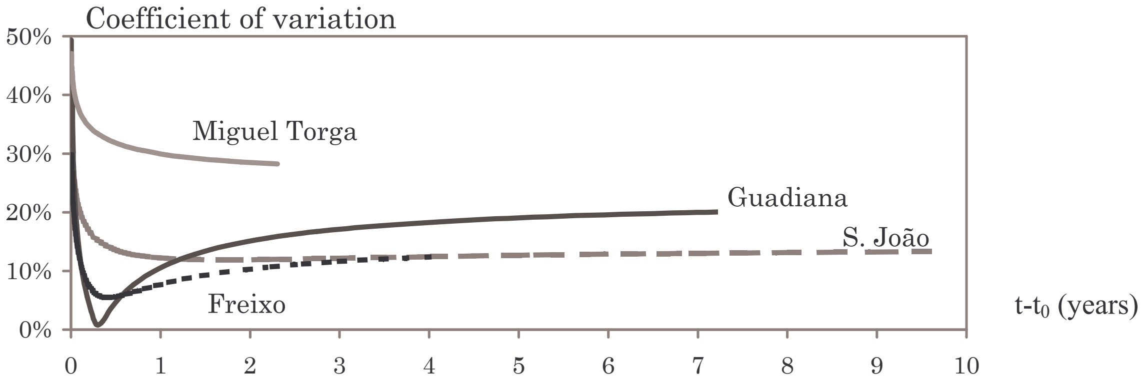

Figure 8. Creep coefficient: coefficient of variation

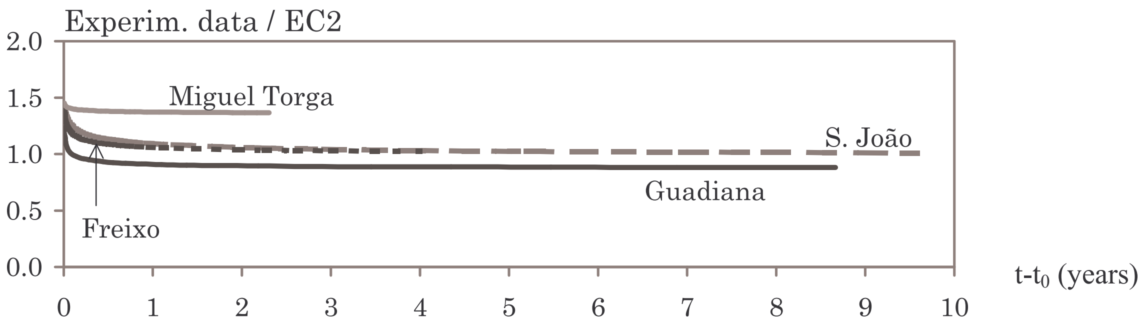

Figure 9. Creep coefficient: relation between measured and predicted values

obvious: the evolution of shrinkage in specimens inside the box girder is much higher, with lower variability (V = 10% to 20%), than for those placed outside (V = 20% to 30%). The relation between measured and predicted values (Figure 6) ranges from 0.6 to 1.3 for outside specimens and from 0.9 to 2.2 for inside specimens.

Creep behaviour is similar for three of the studied bridges with a long-term creep coefficient close to 2, a coefficient of variability that ranges from 10% to 20% and a relation between experimental and predicted values near to 1. Creep coefficient of Miguel Torga Bridge is higher with upper variability.

5. CONCLUSIONS

A methodology for the characterization of variability of the shrinkage and creep measured *in situ* was presented and applied to experimental data from four bridges built in Portugal in last 10 years. The presentation of the obtained results gives an overview about the variability of time dependent behaviour of concrete exposed to environmental conditions and focuses on the following aspects: the significant difference between shrinkage deformations in specimens placed inside and outside the box girder; this difference is not so significant in creep evolution; shrinkage variability ranges from 10% to 20% for inside specimens and from 20% to 30% for outside specimens.

Finally, results show that the initial evolution of creep and shrinkage is higher than the one predicted by EC2. They also show the accuracy of a long-term prediction of outside shrinkage; inside shrinkage is higher than predicted; EC2 creep curve is similar of the experimental curves, but in some cases, as in Miguel Torga Bridge, significant differences were found.

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