# Extrapolation of creep and shrinkage of concrete bridges measured *in situ*

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## Summary

The main propose of this paper is to assess the minimum duration of *in situ* measured data to be use in creep and shrinkage models in order to obtain sufficient accuracy in long-time predictions.

A brief description of the experimental procedure used to measure creep and shrinkage in field conditions is done. A methodology to analyse the evolution of experimental data, including its variability is also presented. This methodology is then applied to initial sets of measured data with different duration.

**Keywords**: concrete bridges, creep, extrapolation, regression analysis, shrinkage, time dependent behaviour.

## 1. Introduction

Beside the uncertainty due to the random variability of the concrete proprieties – which results from the process of mixing, casting and curing of concrete – the concrete creep and shrinkage prediction is strongly associated with a great uncertainty due to the variability of many parameters, namely those connected with the *in situ* environment conditions, such as temperature, humidity or rainfall. This uncertainty is reflected in the prediction models of creep and shrinkage, so the use of experimental procedures is the most accurate way of known the creep and shrinkage evolution.

In order to improve long-term predictions, several authors [1], [2] have used initial sets of laboratory experimental data. However, as these studies were done using experimental data obtained with constant humidity and temperature it was not taken into account the uncertainties due to environment conditions.

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

The main propose of this paper is to assess the minimum duration of *in situ* measured data to be use in creep and shrinkage models in order to obtain sufficient accuracy in long-time predictions. All of the specimens used in this study were made with concrete applied in the construction of bridges and keep in the same environmental conditions of the bridge.

A brief reference is made to the experimental procedure and to the methodology applied to experimental data, which includes the identification of the specimen's strains due to seasonal effects, the statistical evaluation of the experimental data and the use of a non-linear regression to fit MC90 [3] models to experimental data. This methodology is then applied to the initial sets of measured data with different duration.

## 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 (Fig. 1).

Specimens from four different bridges were used.

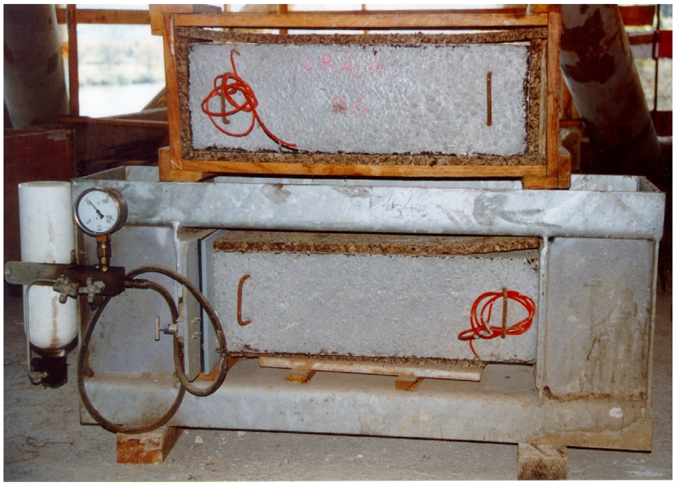

*Fig. 1 – A shrinkage and a creep specimen*

The concrete specimens are placed in several sections over the deck and inside the box girder. In Miguel Torga Bridge some of the creep and shrinkage specimens were kept in laboratory. Table 1 shows 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 [4], [5]

*Table 1 – Number of specimens used 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 | – |
| Mig. Torga | 5 | 32 | 15 | 6 | 2 | 6 | 9 | 6 |
| Total | 24 | 47 | 48 | 6 | 14 | 10 | 36 | 6 |

## 3. Non linear regression analysis

In order to adjust the MC90 expressions to the experimental data, two parameters (C1 and C2) were introduced in the referred expressions:

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

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

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

where $\varepsilon_{cs}$ is the total shrinkage strains, $\varepsilon_{cs0}$ is the ultimate value of the total shrinkage strain, $\beta_s$ is the coefficient that describes the development of shrinkage as function of drying time and $f_{cm}$ is the mean compressive strength of concrete at age of 28 days (MPa).

To obtain a best fit between the expressions to the experimental data, a non-linear regression analysis was performed, as presented in [5] and [6].

Seasonal effects affect the measure of shrinkage in field conditions. With the purpose of take into account these effects the non-linear regression model used includes a sinusoidal function:

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

Creep results were treated in a similar way as shrinkage, introducing two parameters ($C_3$ and $C_4$) in the MC90 expressions:

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

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

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

where $\phi$ is the creep coefficient, $\phi_0$ is the notional creep coefficient, $\beta_c$ is the coefficient to describe the development of creep with time and $t_0$ is the age of concrete at loading (days).

## 4. Extrapolation of experimental data

The measurement of creep and shrinkage in field conditions demonstrated that experimental values can be very different from those computed by prediction models. The present methodology is applied to a initial set of measure data with different duration in order to relate the accuracy in long term predictions with the duration of in situ data measurement.

The proposed methodology is illustrated in Fig. 2, where it is applied to strains measured in shrinkage specimens of one section of S. João bridge, using the initial sets of one year, two years three and four years.

Applying the same procedures to the experimental data obtained from the different sections of this bridge is possible to predict, from short initial sets of experimental data, the mean values of shrinkage evolution of the bridge concrete, as illustrated in Fig. 3.

In fact, this figure presents the shrinkage evolution of S. João bridge concrete, extrapolated from sets of 1, 2 and 3 years.

Experimental data from four bridges: S. João, a railway bridge, with a main span of 250 m; Guadiana bridge, a cable-stayed bridge with a main span of 324 m; Freixo bridge, a multi-span bridge (main span of 150 m); Miguel Torga bridge, a curve box-girder bridge, with a main span of 180 m were used in this study. The years of completion of these bridges were 1991, 1991, 1995 and 1998, respectively.

The application of the presented procedures to the shrinkage strains measured in all specimens of the four bridges allowed to predict its values at an age of 50 years. These results are presented in Fig. 4 and 5. As the differences in behaviour between inside and outside shrinkage specimens are very significant the experimental data obtained from each environment was analysed and presented separately.

These figures show that only after three years it is possible to have sufficient accuracy in long-term prediction of the average value and the coefficient of variation of shrinkage strains.

It is also interesting identify the significant difference between shrinkage strains in specimens placed inside and outside the box girder.

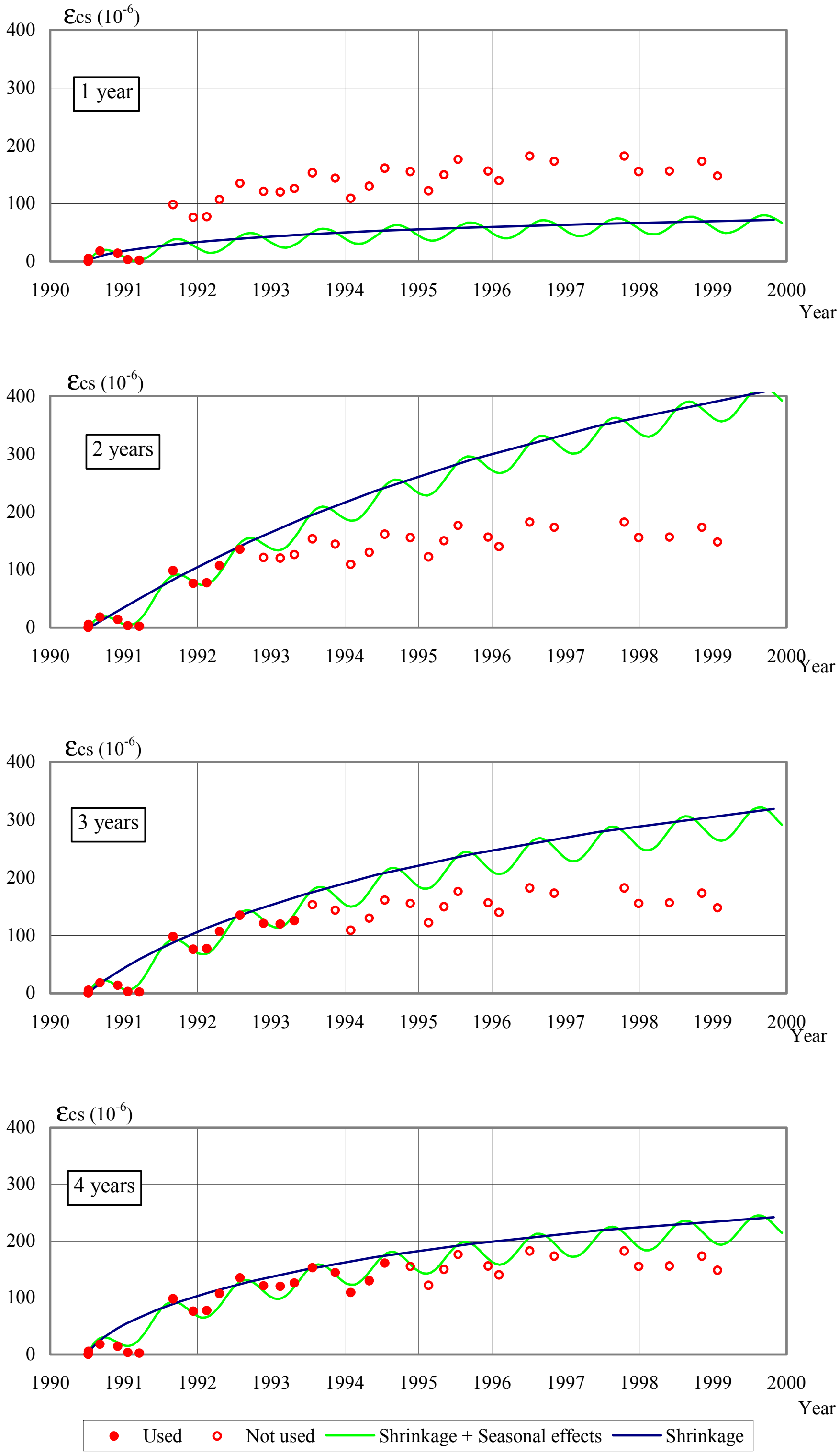

*Fig. 2 – S. João Bridge: shrinkage extrapolation using 1, 2, 3 and 4 years initial sets of experimental data obtained from one section*

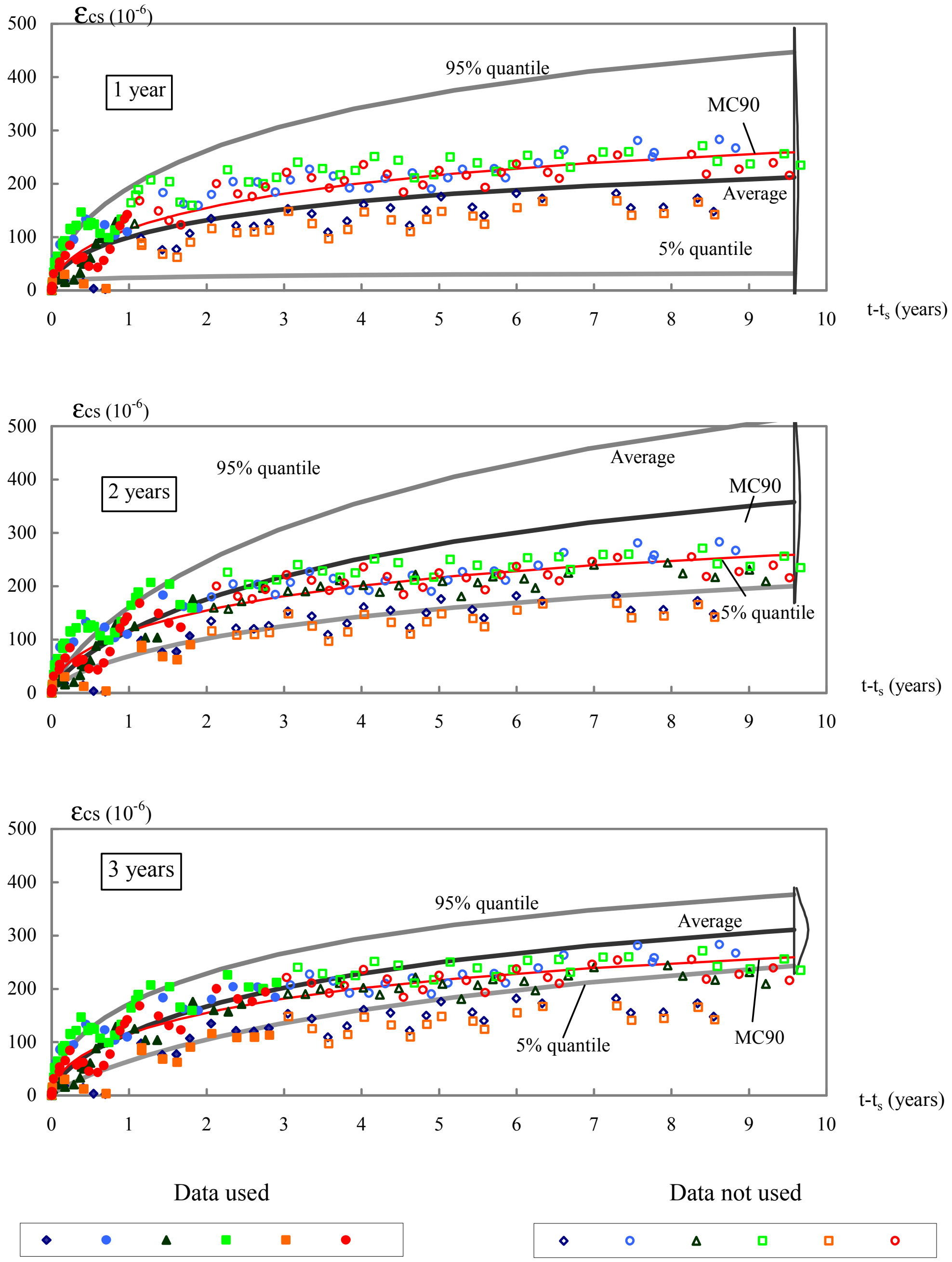

*Fig. 3 – S. João Bridge: shrinkage extrapolation using 1, 2 and 3 years initial sets of experimental data from different sections*

The application of the same procedure to creep coefficients is presented in Fig. 6, where the creep coefficients are extrapolated form data obtained from different sections of S. João bridge. The creep coefficients are related to the tangent modulus of elasticity at 28 days and to a age of load of 7 days. Initial sets of three months, 1 year and 3 years were used in the charts presented in this figure. The comparison of these charts shows a significant difference between the first and the other two.

With the extension of the presented methodology to experimental data of the four bridges it was possible to extrapolate the average value of creep coefficient for an age of 50 years, as well its coefficient of variation.

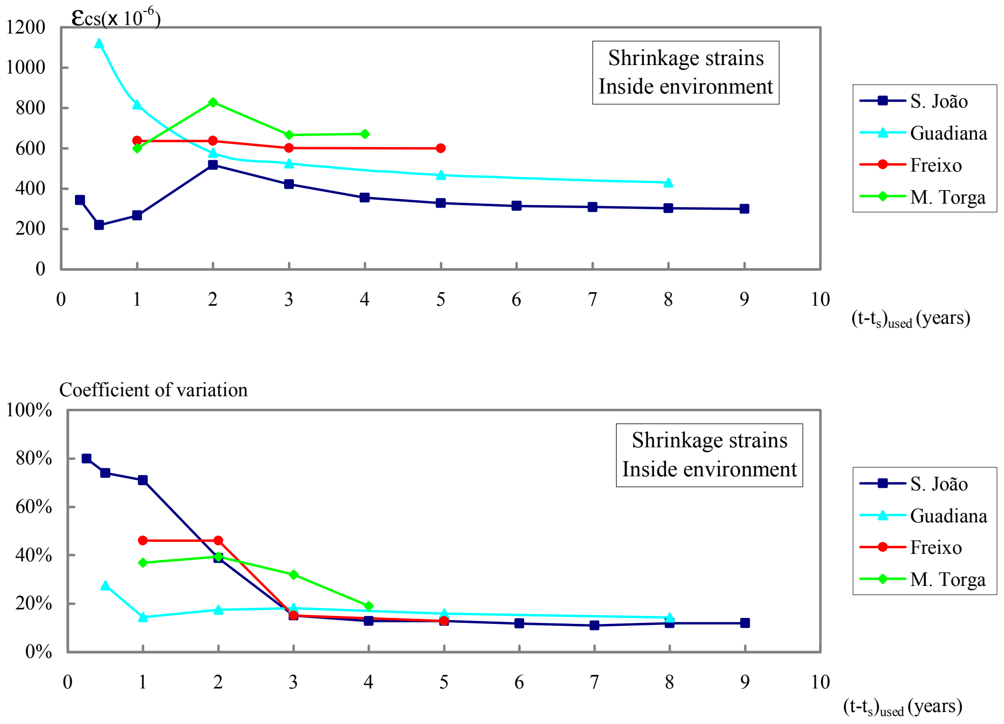

*Fig. 4 – Inside shrinkage extrapolation at 50 years: evolution of average and coefficient of variation according to the initial set of experimental data used*

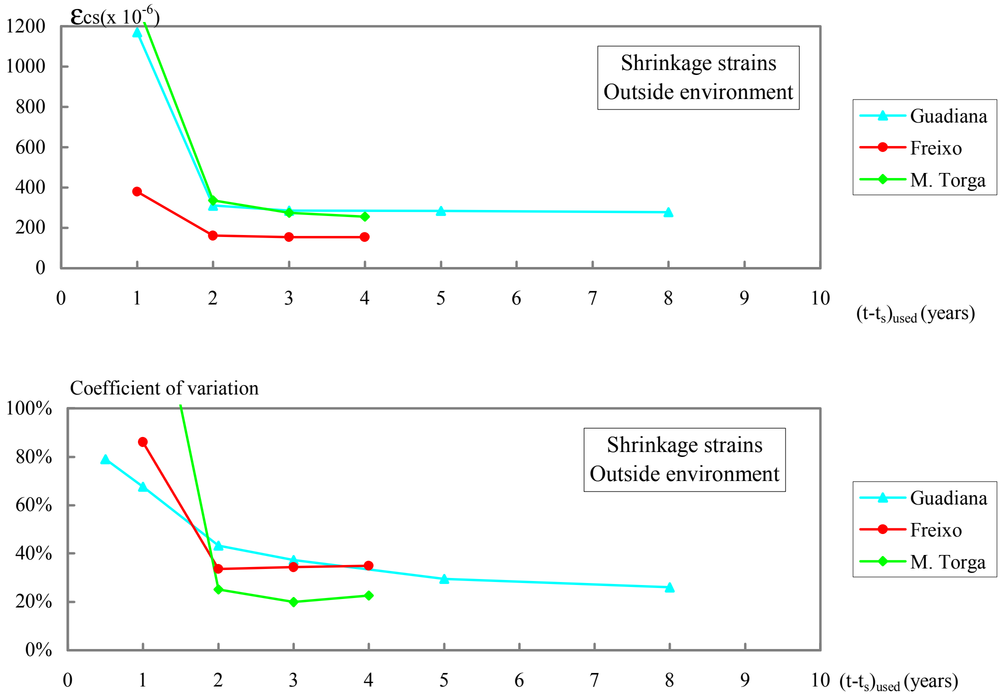

*Fig. 5 – Outside shrinkage extrapolation at 50 years: evolution of average and coefficient of variation according to the initial set of experimental data used*

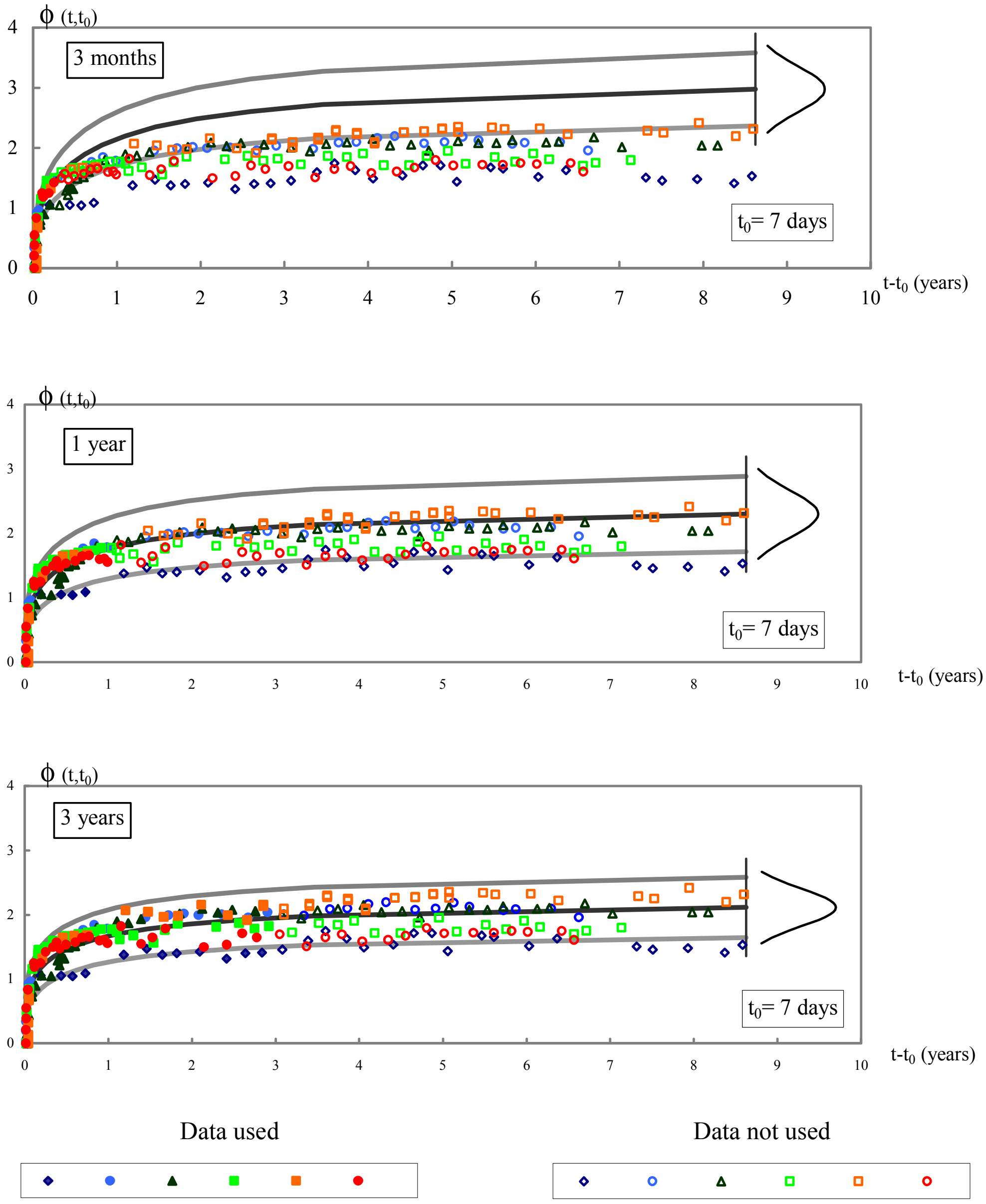

*Fig. 6 – S. João Bridge: creep coefficient extrapolation using 3 months, 1 year and 3 years initial sets of experimental data from different sections*

Fig. 7 presents the evolution of these values in function of initial set of experimental data used. This figure shows that satisfactory accuracy can be attained for average value after one-year period. An accurate prediction of the coefficient of variation takes, at least, two years.

## 5. Conclusions

Although a small number of cases were analysed it can be concluded that the prediction models referred can be used to extrapolate experimental data. In order to obtain an accurate long-term prediction of shrinkage and creep, it is necessary to use initial sets of, at least, three years for shrinkage and one year for creep. The need of larger initial sets of experimental data to obtain an accurate long-term prediction of shrinkage is probably related to seasonal effects, which are quite relevant at early ages.

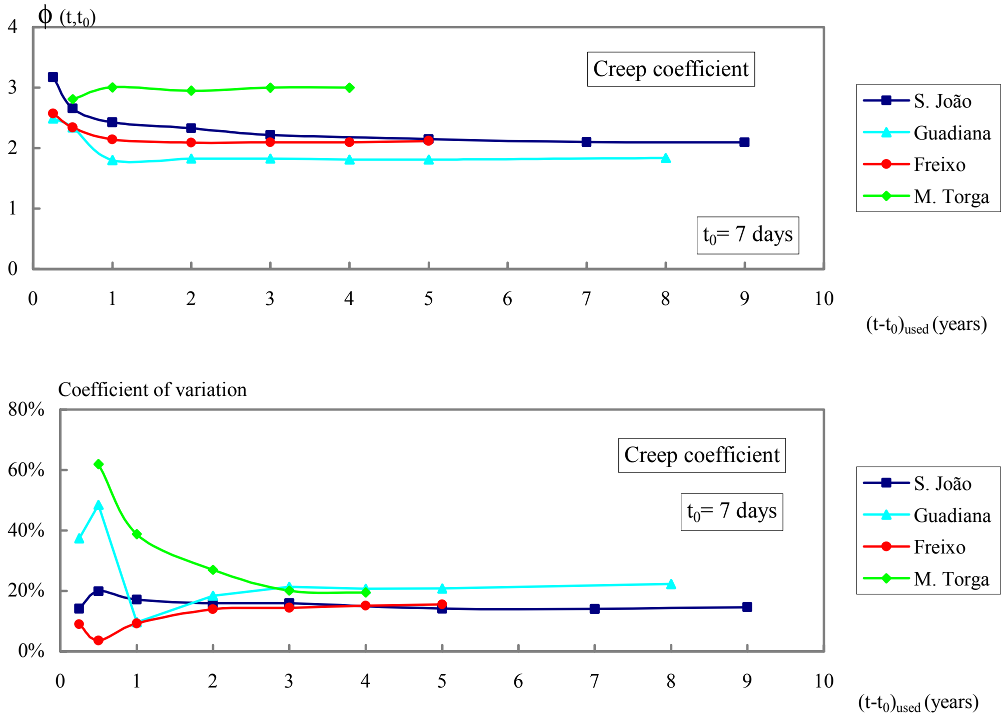

*Fig. 7 – Creep coefficient extrapolation at 50 years: evolution of average and coefficient of variation according to the initial set of experimental data used*

Previous studies [5], [6] has demonstrated that initial evolution of creep and shrinkage is higher than the one predicted by MC90. This explain the higher values predicted with short initial sets of experimental data

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