

Long-Term Field Assessment of EC2 and MC 2020 Models for Creep and Shrinkage

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Abstract

Accurate prediction of concrete creep and shrinkage remains challenging owing to the significant variability of influencing parameters, particularly environmental factors such as temperature, relative humidity, and rainfall. Reliable prediction of these time-dependent phenomena is essential for modelling the long-term behaviour of concrete structures. Over recent decades, prediction models have undergone successive refinements, culminating in the fib Model Code 2020 and the forthcoming second generation of Eurocode 2, scheduled for implementation in 2027.

This study assesses the predictive capability of these models using long-term experimental results obtained over more than 15 years from 45 shrinkage and 13 creep specimens installed on a reinforced concrete bridge over the Douro River, in Portugal. The comparison between measured and predicted values provides insight into the models' accuracy and suitability for representing the behaviour of concrete under real environmental exposure conditions.

Keywords: concrete creep, shrinkage, long-term behaviour, predictive models, on-site study.

1. Introduction

Predicting concrete creep and shrinkage is affected by significant uncertainty arising from the wide variability of influencing parameters, particularly environmental factors such as temperature, relative humidity, and rainfall. These uncertainties must be adequately represented in predictive models to ensure an accurate description of time-dependent behaviour in structural analysis. In large structures, especially those experiencing notable configuration changes during construction, such as bridges erected by the cantilever method, the effects of time-dependent concrete behaviour become pronounced, making in-situ investigations highly advisable to reduce these uncertainties.

The National Laboratory for Civil Engineering (LNEC) has accumulated an extensive record of monitoring the long-term performance of prestressed concrete bridges in Portugal. Over several decades, LNEC has developed systematic methodologies that combine direct structural measurements with complementary monitoring of creep and shrinkage using specimens installed *in situ*.

This paper presents a concise overview of the EC2/MC2020 predictive models for shrinkage and creep. It then introduces the selected bridge case study and describes the experimental procedure used in the *in situ* study of concrete shrinkage and creep. The predicted values obtained using only information available during construction, as the average compressive strength, are compared with the measured results. Subsequently, the paper discusses the application of the adjustment procedure proposed in EC2, in which shrinkage and creep models are calibrated to experimental data through a least-squares fitting method to determine the adjustment parameters. Finally, the main conclusions are summarised.

2. MC2020 and EC2 prediction models

2.1. General remarks

The fib Model Code 2020 (MC2020) and the Eurocode 2 (EC2) provide analytical models for predicting the time-dependent behaviour of concrete, namely shrinkage and creep. The shrinkage and creep prediction models developed within the MC2020 framework were largely adopted in the revised EC2 (EN 1992-1-1:2023), with only minor differences, mainly in notation and certain code-oriented parameter choices. Both formulations account for material properties, environmental exposure, member size, concrete age, and mix characteristics. EC2 integrates these models into the EN 1992-1-1:2023 design framework, introducing revised calibration factors and codified parameters, whereas MC2020 presents them within a more mechanistically based, research-oriented context, offering greater flexibility and updated environmental functions.

The main components of the EC2 model are presented below, following the expressions given in the 2023 revision of EC2. For clarity, each expression is accompanied by the corresponding EC2 reference number [B.x] and the equivalent MC2020 reference [14.10-x], enabling a direct comparison between the two standards.

To improve the performance of these models by leveraging available experimental data, both MC2020 and EC2 introduce fitting parameters ξ , which are determined by a least-squares fit of the model functions to the experimental results. The formulas presented herein explicitly include these parameters.

2.2. Shrinkage

Both EC2 and MC2020 define total shrinkage strain (ε_{cs}) as the sum of basic shrinkage (ε_{cbs}) and drying shrinkage (ε_{cds}). Using EC2 notation, this may be written as:

$$\varepsilon_{cs}(t, t_s) = \xi_{bs1} * \varepsilon_{cbs}(t) + \xi_{ds1} * \varepsilon_{cds}(t - t_s) \quad [\text{B.37 / 14.10-22}] \quad (1)$$

Here, ξ_{bs1} and ξ_{ds1} are adjustment factors applied to the asymptotic values of autogenous and drying shrinkage, respectively, introduced to improve the fit of the model to experimental data.

According to EN1992-1-1:2023 and MC 2020, the **basic shrinkage** is calculated by the following expression:

$$\varepsilon_{cbs}(t) = \varepsilon_{cbs, fcm} * \beta_{bs, t} \quad [\text{B.24 / 14.10-23}] \quad (2)$$

where $\varepsilon_{cbs, fcm}$ is the asymptotic basic shrinkage strain, given by:

$$\varepsilon_{cbs, fcm} = \alpha_{bs} \left(\frac{f_{cm, 28}}{60 + f_{cm, 28}} \right)^{2.5} * 10^{-6} \quad [\text{B.26 / 14.10-25}] \quad (3)$$

and $\beta_{bs, t}$ is the time-development function governing the evolution of basic shrinkage from the reference age t_0 :

$$\beta_{bs, t} = 1 - \exp(-0.2 * \xi_{bs2} * \sqrt{t}) \quad [\text{B.38 / 14.10-26}] \quad (4)$$

The parameter ξ_{bs2} adjusts the rate at which autogenous shrinkage develops over time, based on experimental values.

The development of the **drying shrinkage** follows from formula (5):

$$\varepsilon_{cds}(t) = \varepsilon_{cds, fcm} * \beta_{RH} * \beta_{ds, t-t_s} \quad [\text{B.25 / 14.10-24}] \quad (5)$$

where $\varepsilon_{cds, fcm}$ is the notional drying shrinkage coefficient (6), β_{RH} is a coefficient to consider the effect of relative humidity on drying shrinkage (7) and $\beta_{ds, t-t_s}$ is a function to describe the time development of drying shrinkage (8):

$$\varepsilon_{cds, fcm} = (200 + 110\alpha_{ds}) * \exp(-0.012f_{cm,28}) * 10^{-6} \quad [\text{B.28 / 14.10-27}] \quad (6)$$

$$\beta_{RH} = \begin{cases} -1.55 \left[1 - \left(\frac{RH}{RH_{eq}} \right)^3 \right] & 20\% \leq RH \leq RH_{eq} \\ -1.55 \left[1 - \left(\frac{RH}{RH_{eq}} \right)^2 \right] & RH_{eq} \leq RH \leq 100\% \\ -1.55 \left[1 - \left(\frac{RH}{RH_{eq}} \right)^2 \right] + 0.25 & RH = 100\% \end{cases} \quad [\text{B.29 to B.31 / 14.10-28}] \quad (7)$$

$$\beta_{ds, t-t_s} = \sqrt{\frac{(t - t_s)}{0.035 * \xi_{ds2} * h_n^2 + (t - t_s)}} \quad [\text{B.39 / 14.10-29}] \quad (8)$$

The parameter ξ_{ds2} adjusts the rate of drying shrinkage development, based on experimental values.

2.3. Creep

The EN1992-1-1:2023 standard determines the creep coefficient over time $\varphi(t, t_0)$ as the sum of two components, basic creep $\varphi_b(t, t_0)$ and drying creep $\varphi_d(t, t_0)$, accounting separately for moisture-independent and drying-induced contributions:

$$\varphi(t, t_0) = \xi_{bc1} * \varphi_{bc}(t, t_0) + \xi_{dc1} * \varphi_{dc}(t, t_0) \quad [\text{B.34 / 14.10-7}] \quad (9)$$

ξ_{bc1} and ξ_{dc1} are factors for adjustment to asymptotic values of the basic creep and drying creep.

The **basic creep** $\varphi_{bc}(t, t_0)$ is calculated by using the following expression, where the parameter ξ_{bc2} adjusts its rate of time development:

$$\varphi_{bc}(t, t_0) = \beta_{bc, fcm} * \beta_{bc, t-t_0} \quad [\text{B.6 / 14.10-8}] \quad (10)$$

$$\beta_{bc, fcm} = \frac{1.8}{(f_{cm,28})^{0.7}} \quad [\text{B.7/14.10-9}] \quad (11)$$

$$\beta_{bc, t-t_0} = \ln \left(\left(\frac{30}{t_{0,adj}} + 0.035 \right)^2 \frac{(t - t_0)}{\xi_{bc2}} + 1 \right) \quad [\text{B.35 / 14.10-10}] \quad (12)$$

The **drying creep** $\varphi_{dc}(t, t_0)$ is calculated by the following expression, where the parameter ξ_{dc2} controls its rate of development:

$$\varphi_{dc}(t, t_0) = \beta_{dc, fcm} * \beta_{dc, RH} * \beta_{dc, t_0} * \beta_{dc, t-t_0} \quad [\text{B.9 / 14.10-11}] \quad (13)$$

$$\beta_{dc, fcm} = \frac{412}{(f_{cm,28})^{1.4}} \quad [\text{B.10 / 14.10-12}] \quad (14)$$

$$\beta_{dc,RH} = \frac{1 - \frac{RH}{100}}{\sqrt[3]{0.1 \frac{h_n}{100}}} \quad [\text{B.11 / 14.10-13}] \quad (15)$$

$$\beta_{dc,t-t_0} = \left[\frac{(t - t_0)}{\beta_h * \xi_{dc2} + (t - t_0)} \right]^{\gamma(t_0, \text{adj})} \quad \begin{matrix} [\text{B.36 /} \\ 14.10-14 \text{ \& 16}] \end{matrix} \quad (16)$$

3. Case study: Miguel Torga Bridge

The Miguel Torga Bridge spans the Douro River valley near Peso da Régua at a height of approximately 90 m (Figure 1). With a total length of 900 m, it features a main span of 180 m over the river (Figure 2). The curved-in-plan-and-elevation structure supports a 26-m-wide deck via a continuous single-cell prestressed concrete box girder of variable height.



Figure 1. Miguel Torga Bridge



Figure 2. Plan and elevation of Miguel Torga Bridge

Transversely, the deck includes two webs, 0.60 m thick and increased to 0.70 m over the 180-m span and adjacent spans. It is prestressed longitudinally and transversely, with provisions for future strengthening via external unbonded or internal bonded tendons. The deck was cast *in situ* using the balanced cantilever method, with 5-m segments erected successively from each pier.

The piers comprise tubular shafts of constant cross-section, with the main piers reinforced by four variable-depth ribs at their bases for added stiffness. Pot bearings support the deck at the abutments and piers P1–P6, while it is monolithically connected to the remaining piers. Due to shallow bedrock, foundations use near-surface direct footings.

Completed in 1997, the bridge was monitored by LNEC during and after its construction.

4. Experimental procedures

The in-situ study of concrete time-dependent behaviour on the Miguel Torga Bridge began during deck construction in 1997.

Shrinkage and creep specimens were cast using the same concrete mix as the bridge and stored under identical environmental conditions, inside and outside the deck. The location of the five sections where the study took place is marked in Figure 2.

These prismatic specimens measured typically $0.3 \times 0.3 \times 0.6 \text{ m}^3$ for shrinkage and $0.3 \times 0.3 \times 0.7 \text{ m}^3$ for creep, with two opposite faces sealed against evaporation. Each prism contained an embedded vibrating wire strain gauge. Shrinkage specimens remained unloaded, exposed only to environmental conditions. Creep specimens were subjected to constant axial loads via hydraulic jacks to maintain target stress levels (Figure 3).



Figure 3. Shrinkage and creep specimens stored inside the deck

In each section, test specimens were placed inside the box and on the tray. Table 1 provides an overview of the distribution of the specimens considered in this study across the various sections. For each section, the table reports the casting date, the average 28-day compressive strength of the concrete mix, and the number of shrinkage and creep specimens stored under outdoor and indoor environmental conditions. Further details on the procedures are presented in Santos, Virtuoso and Fernandes (2001) and Santos, Xu and Vieira (2018). The average compressive strength of the concrete at 28 days was 53.8 MPa.

Table 1. Information on shrinkage and creep specimens

Section	S3	S4	S5	S6	S7	Total
Concrete cast date	1997-07-24	1997-01-16	1997-09-17	1997-03-18	1997-08-29	–
$f_{cm,28}$ (MPa)	47.2	57.5	53.2	55.7	55.6	53.8*
Shrinkage (Outside)	6	6	6	6	6	30
Shrinkage (Inside)	6	2	2	2	3	15
Creep (outside, 7 days)	–	3	3	–	–	6
Creep (inside, 7 days)	–	3	2	–	–	5
Creep (inside, 21 days)	–	–	2	–	–	2

* Average value

5. Application of EC2 prediction models

5.1. Shrinkage

The EC2 shrinkage prediction model was applied to the specimen concrete using only information available during construction, as the respective value of f_{cm} (Table 1) and the history of local climatic conditions (Table 2).

The EC2 model was applied to the concrete specimens based on the specific strength values of each section. The parameters presented in Table 3 correspond to the average compressive strength of 53.8 MPa. The corresponding curves for each section are presented in Figure 4, together with the experimental results. It is important to remark, that the final shrinkage values predicted by EC2 are strongly dependent on the concrete strength adopted in the model, as shrinkage increases when the concrete strength decreases.

Figure 4 indicates that, across the different sections, the specimens kept inside the box girder exhibit greater shrinkage strains than those placed on the deck, again emphasizing the strong influence of environmental conditions on shrinkage development. The figure also shows considerable variability in this behavior among the various graphs, even under similar exposure conditions. Finally, it is clear that the prediction model overestimates the magnitude of the shrinkage strains, as also indicated in Table 4.

Figure 5 presents the shrinkage curves for each section (S3 to S7), adjusted according to the approach proposed in EC2, based on the experimental measurements obtained from the internal specimens. The overall curve, derived from the average of the individual section curves, is also shown. As observed, the shrinkage stabilizes from the 10th year onwards.

Table 2. Environmental conditions

	Min	Average	Max
HR (%)	19	63	97
Temperature air (°C)	4.5	17.9	31.1

Table 3. Parameters used in the concrete shrinkage prediction model

h_0 (mm)	HR (%)	RH_{eq} (%)	β_{RH}	$\beta_{bs,t0}$	$\epsilon_{cbs,fc,m}$ (10 ⁻⁶)	$\epsilon_{cds,fc,m}$ (10 ⁻⁶)	t_s (days)
300	65	94.83	1.051	0.293	92.204	461.426	3

Table 4. Long-term shrinkage strains according to EC2 prediction model and adapted model of EC2 (8000 days)

Model	Section S3	Section S4	Section S5	Section S6	Section S7	Average
Original	601	551	570	559	559	568
Adapted	508	461	388	448	355	431

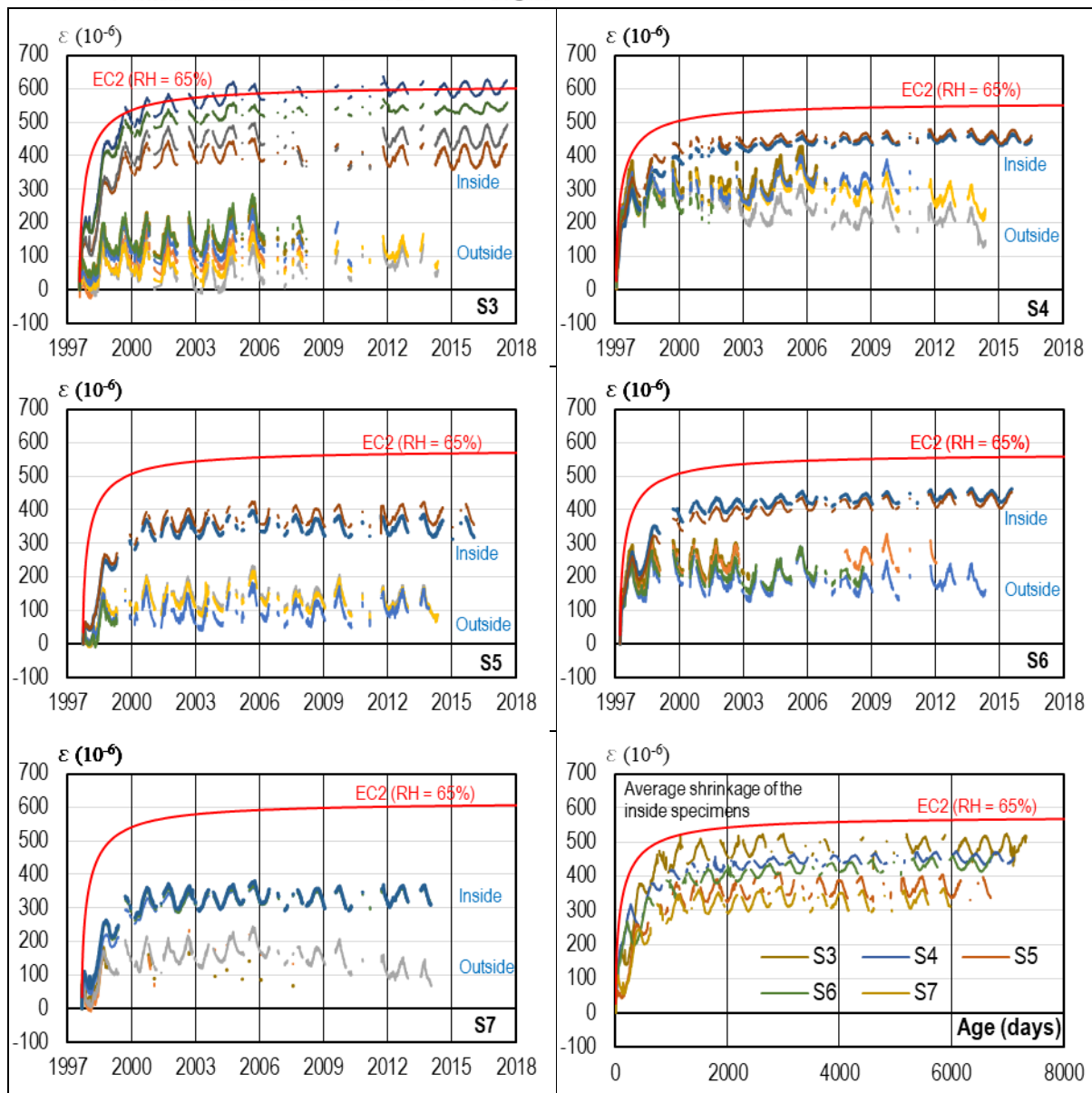


Figure 4. Shrinkage strains measured *in situ*

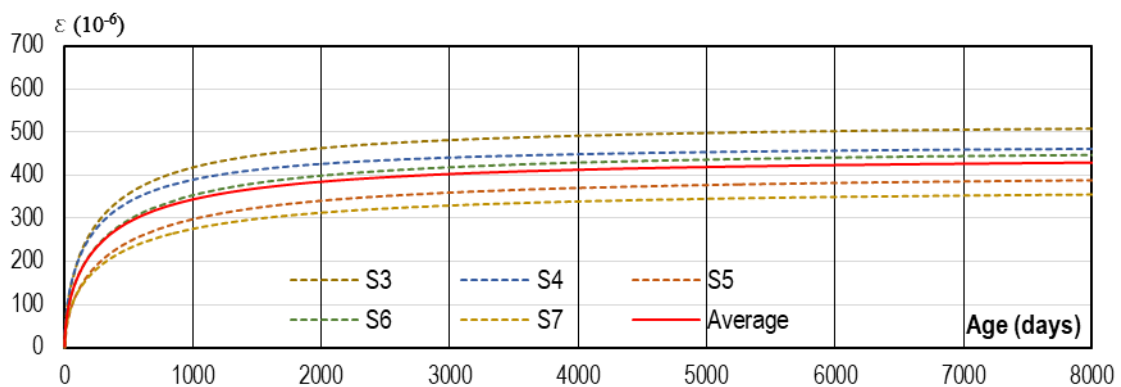


Figure 5. Shrinkage EC2 model adapted from the experimental results.

5.2. Creep

The creep coefficient is the ratio between the additional strain that occurs progressively over time and the initial elastic strain $\varepsilon(t_{0j})$ produced by the applied stress at the age of loading t_{0j} (Figure 6, Figure 7):

$$\varphi(t, t_{0j}) = \frac{\varepsilon(t) - \varepsilon(t_{0j})}{\varepsilon(t_{0j})} \quad (17)$$

The EC2 creep prediction model was applied to the specimen concrete using only information available during construction, namely the strength value corresponding to each section (Table 1) and the history of local climatic conditions (Table 2). The parameter values given in Table 5 are derived from the average concrete compressive strength of 53.8 MPa.

The corresponding curves, along with the experimental results, are shown in Figure 6 for the specimens kept inside the box girder and in Figure 7 for the specimens placed on the deck. In both cases, two graphs are presented for each section: the left graph includes the strains measured in the creep specimens together with the average strains recorded in the shrinkage specimens of that section; the right graph presents the creep coefficients calculated from the creep strains (after subtracting the shrinkage strains).

From Figure 6 and Figure 7, it can be observed that the EC2 prediction model underestimates the long-term creep coefficient, as also indicated in Table 6. It is further noted that the variability of the creep coefficient is smaller among specimens from the same section but becomes significant between specimens from different sections.

Table 5. Parameters used in the concrete creep prediction model

h_0 (mm)	HR (%)	$\beta_{bc, fcm}$	β_h	$\beta_{dc, fcm}$	$\beta_{dc, RH}$	$\beta_{dc, t0}$	γ	t_0 (days)
300	65	0.111	651.6	1.555	0.523	0.635	0.276	7

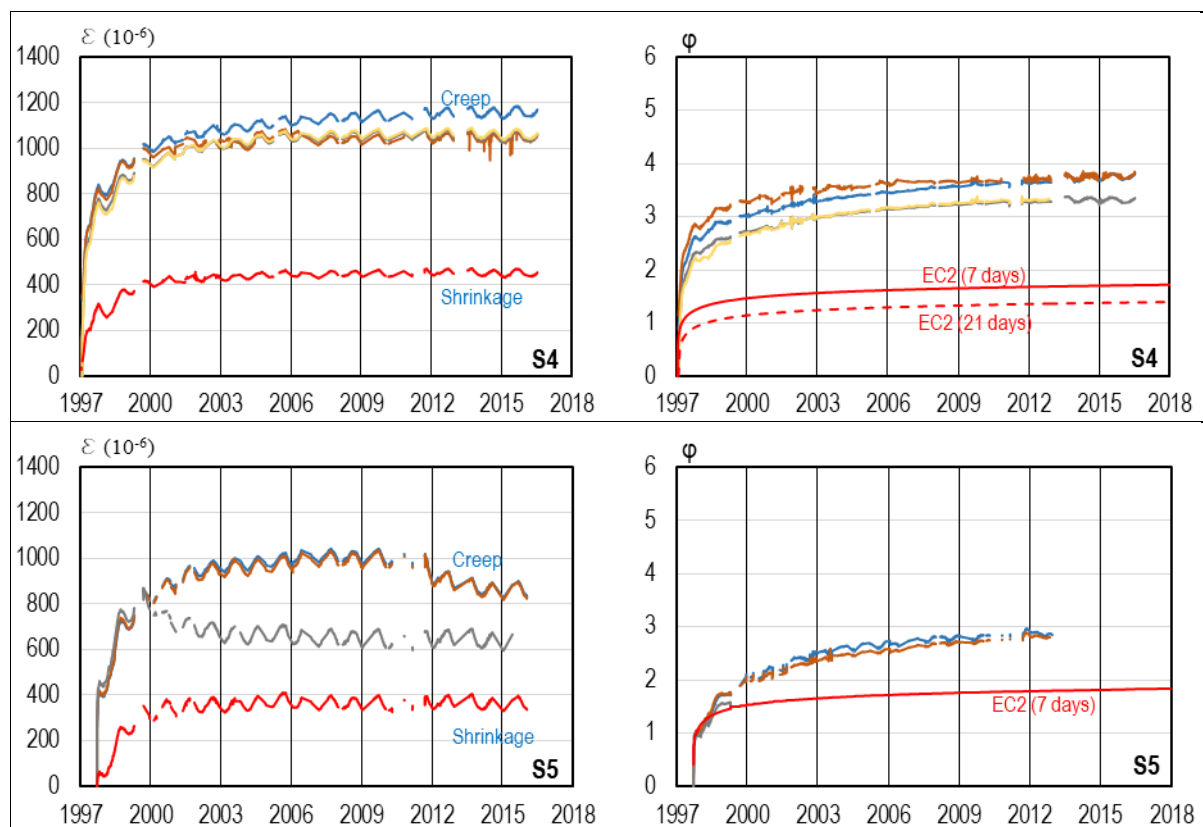


Figure 6. Creep coefficient determined experimentally (interior environment)

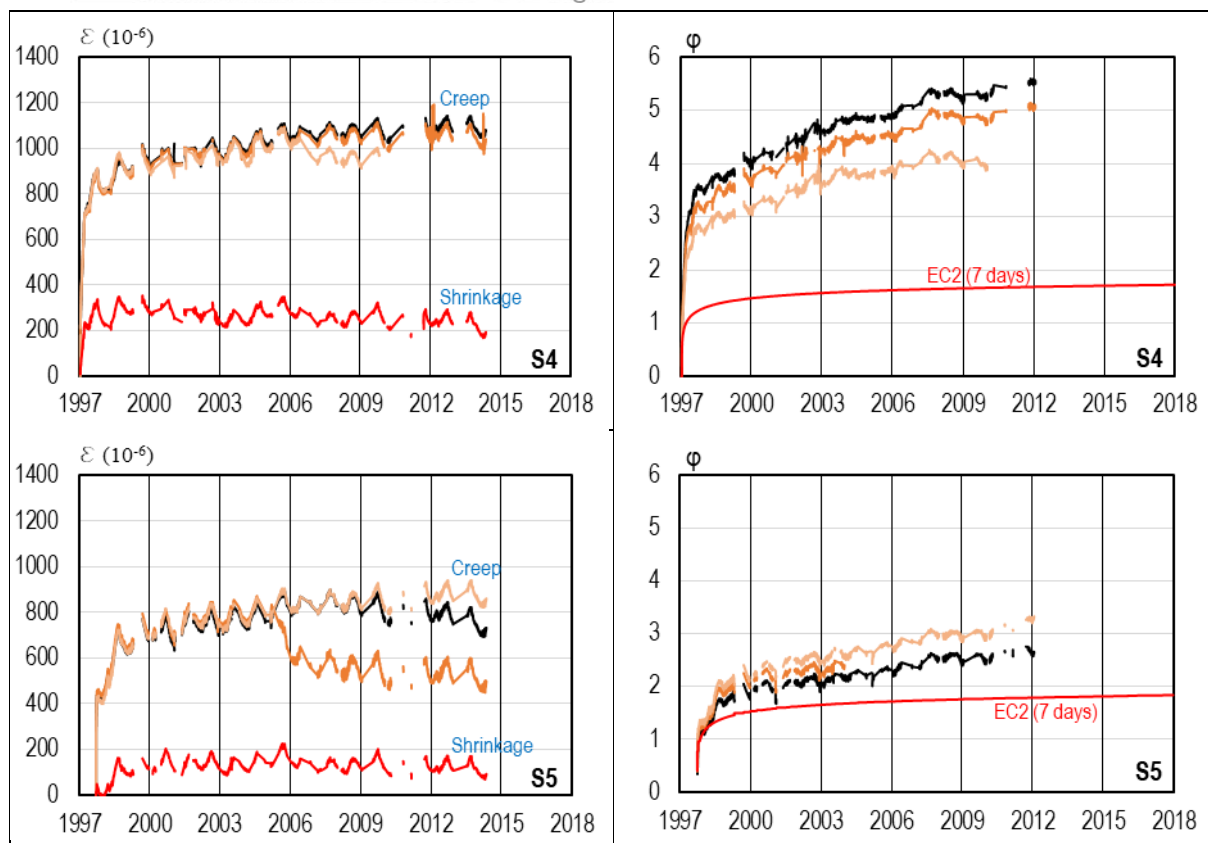


Figure 7. Creep coefficient determined experimentally (outdoor environment)

Table 6. Long-term creep coefficient according to prediction model and adapted model of EC2 (8000 days)

Model	Section S4	Section S4	Section S5	Average
Load ages (days)	7	21	7	7
Original model	1.725	1.401	1.841	1.822
Adapted model	3.821	3.315	3.046	3.501

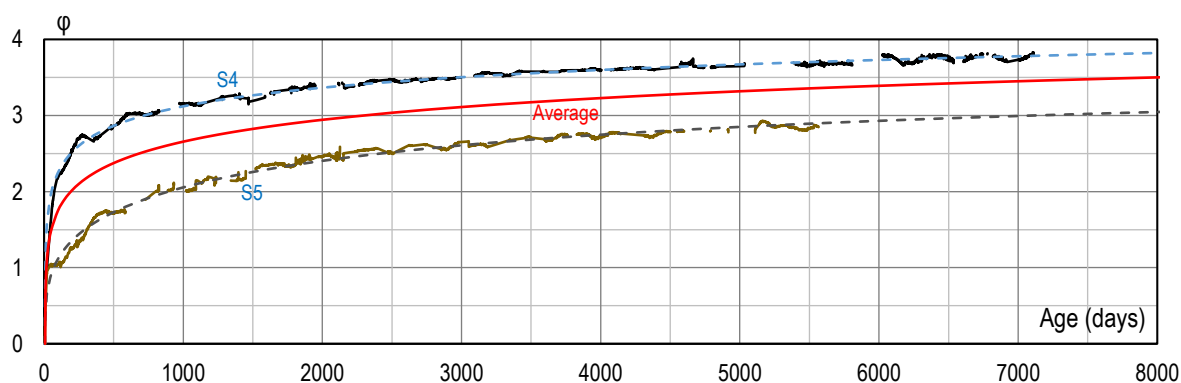


Figure 8. EC2 creep model adapted from the inside specimens

Figure 8 shows the average creep coefficients determined experimentally from the strains measured on the specimens kept inside the deck (sections S4 and S5). The procedure proposed in EC2 was applied to these average values to adapt the creep model to the experimental data, resulting in the two curves also shown in this figure. Finally, applying the same procedure to these two curves yielded the average curve, which is also represented in the figure.

This figure shows that the adapted EC2 creep model curves fit the set of experimental values very well, while a significant difference is also observed between the values obtained at the two sections. The experimental results indicate that the creep process continued beyond the monitoring interval, diverging from the behavior predicted by the EC2 model. The duration of the experimental work required to provide an accurate prediction of creep and shrinkage development has been the objective of other studies, including a Bayesian approach (Sousa, Santos and Chryssanthopoulos, 2017, 2019).

6. Conclusions

The long-term on-site measurements, covering more than 15 years and comprising 45 shrinkage and 13 creep specimens installed on the Miguel Torga Bridge, confirm that environmental actions and construction-related variability have a decisive influence on the time-dependent behaviour of concrete.

When applied using only information available at the time of construction, the EC2 shrinkage prediction model overestimates the final shrinkage strains of the studied concrete, whereas the EC2 creep model underestimates the corresponding long-term creep coefficients for the same material and environment.

The adjustment procedure proposed in EC2, based on least-squares fitting of model parameters to in-situ specimen data, significantly improves the agreement between predicted and measured shrinkage and creep, both at the level of individual sections and for the overall behaviour.

The results show that the variability of shrinkage is significant even between specimens subjected to the same local conditions and within the same section, whereas the variability of the creep coefficient remains relatively small within a section but becomes significant between different sections, underscoring the need to represent these distinct sources of uncertainty in structural analyses and reliability assessment.

The study demonstrates that combining EC2/MC 2020 prediction models with targeted long-term monitoring of in-situ specimens provides a robust framework for calibrating time-dependent concrete behaviour in major bridges, thereby reducing modelling uncertainties and supporting more reliable serviceability and durability verifications over the structure's lifetime.

Acknowledgements

The authors acknowledge Infraestruturas de Portugal and Norscut for enabling the dissemination of the study's findings.

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