INTERNATIONAL JOURNAL OF OPTIMIZATION IN CIVIL ENGINEERING
Int. J. Optim. Civil Eng., 2020; 10(2):315-331

OPTIMUM DESIGN OF LONG-TERM DEFLECTION IN SEGMENTED PRESTRESS BRIDGES BY CONSIDERING THE EFFECTS OF CREEP AND SHRINKAGE

F. Rahmani[1], R. Kamgar[2*, †] and R. Rahgozar[3]
[1,3]*Department of Civil Engineering, Shahid Bahonar University of Kerman, Kerman, Iran*
[2]*Depatment of Civil Engineering, Shahrekord University, Shahrekord, Iran*

ABSTRACT

The purpose of this study is to evaluate the long-term vertical deformations of segmented pre-tensioned concrete bridges by a new approach. It provides a practical and reliable method for calculating the amount of long-term deformation based on creep and shrinkage in segmented prestress bridges. There are various relationships for estimating the creep and shrinkage of concrete. The analytical results of existing models can be very different, and the results are not reliable. In this paper, the different existing relationships are written in MATLAB software. After calculation, the values of the creep and shrinkage are stored. Then a sample bridge is simulated in the CSI-Bridge software, and different values of creep and shrinkage are allocated separately. Therefore, the data are analyzed, and its maximum deformation value is extracted at a critical span (D_{v-max}). Assigning different amount of creep and shrinkage to the model results in different values of D_{v-max}. In the next step, all D_{v-max} values resulting from the change in creep and shrinkage contents should be re-introduced to MATLAB code to perform the calculation of the failure curve, and extract the corresponding D_{v-max} values at 95% probability. In a new approach, fragility curves are used to obtain the corresponding creep and shrinkage values corresponding to the desired probability percentage. Thus, instead of simulating several models, only one model is simulated. The results of the analysis of a bridge sample in this study indicate acceptable accuracy of the proposed solution for the 95% probability.

Keywords: Segmented Prestress Bridges; Creep; Shrinkage; Long-Term Deformation; Concrete.

Received: 8 November 2019; Accepted: 29 February 2020

1. INTRODUCTION

[*]Corresponding author: Department of Civil Engineering, Shahrekord University, Shahrekord, Iran
[†]E-mail address: kamgar@sku.ac.ir (R. Kamgar)

Bridges play a key role as an infrastructure in every country and known as costly structures [1]. Bridges are made of concrete or steel, and in the field of concrete, researchers have done a great deal of research into the construction of concrete with different mechanical properties [2]. In this regard, the researchers have attempted to increase the shear and bending capacity of reinforced concrete members using FAR sheets, and post-tensioned technics [3, 4]. Keveh *et al*. [5] designed optimally the behavior of multi-span composite box girder bridges using the Cuckoo Search algorithm.

Using segmented prestress bridges has been known as a solution to decrease the cost and time of construction and increase the bridge span length [6]. There should be special sensivity in their design in order to have desirable serviceability in action; one way to achieve this is to have an accurate estimation of the future structural behavior of the bridges system to minimize the damages and maximizing the lifespan of the structural system [7]. Elongating the lifespan of the structural system, especially bridges, has a crucial impact both economically and environmentally [8]. To achieve this goal, we need to know both mechanical properties and future behavior of bridge structure, especially creep and shrinkage of concrete which is tedious work because they are not only time-dependent parameters but also depend on the curing process of concrete and the ratio of humidity, temperature, etc. [9]. There are various methods offered by different standards for estimating concrete creep and shrinkage rate. The methods investigate in this section are those proposed by AASHTO [10, 11], ACI/PCI [12-14], CEB-FIP [15], NCHRP[16], GL2000 [17], and Eurocode [18, 19]. The reason for choosing these methods in the present study is that among all the available methods, these methods are the most widely used and also have been used by previous researchers [20]. Although the general form of relationships provided by different standards are different, in most relationships, five parameters are used as inputs, the values of which are specified at the beginning of the design procedure. These parameters include compressive strength of concrete (f'_c), relative humidity (RH), assumed thickness (h_0), concrete age at application of pre-tensioning load (t_0), and time of observation (t).

Ghali *et al.* [21] in 2000 presented a part of an extensive research project on the Confederation Bridge in Canada in the form of an article. This article reports on observing the short and long term deformations of the mentioned bridge, and its purpose is to evaluate the conventional techniques for estimating the deformation of concrete structures and especially the sample bridge. For this purpose, bridge deformations are measured in a bridge site. Besides, finite element modeling of the bridge is performed. For more accurate modeling, the materials used in the bridge are tested separately in the site, and the results of tests such as concrete creep and shrinkage are presented. To observe long-term deformations, after the completion of the bridge construction process, deformations were read at specific times, the last reading presented in this article is 27 months after the bridge was completed. A comparison between the measured and calculated deformation values shows that methods used for estimating the deformation can have acceptable accuracy if the concrete creep and shrinkage values are correctly defined.

The results of a study on the Koror-Babeldaob Bridge in Palau show that the reason for underestimate deformation values in the bridge was the use of an old design code to estimate creep in concrete. For this reason, Bazant *et al.* [22] conducted a study on the mentioned bridge in 2011 to find the best creep calculation model for the bridge. The results show that using the B3 model, the value of underestimate long-term deformation is much lower than that used by ACI 209 [13], CEB-FIP [15], and GL2000 [17] models. In 2012, Bazant *et al.* [23, 24] conducted more extensive research on the Koror-Babeldaob Bridge and published the results in two articles. It should be noted that the bridge was built in 1977 and has a major span of 241 meters. After 18 years, the middle span of the bridge experienced about 1.6 meters of deformation, and the bridge performance confronts with a problem, and eventually, this span collapsed during maintenance program in 1996. The reason for the Bazant *et al*. research was to obtain the causes of the computational error of the bridge designing. The results showed that one of the sources of error was the use of old relationships to calculate concrete creep and shrinkage. Bazant et al. proposed that large-span bridges should be designed to be within 95% of the permissible deformation range.

In 2018, Huang *et al.* proposed a process that could improve the accuracy of numerical modeling of the long-term behavior of pre-tensioned segmented concrete bridges [25]. In this study, information on the Jiang Jin Bridge in China is used. The results show that the proposed method is accurate. The results of the parametric study show that concrete creep and pre-tension loss have the most effect on the vertical displacement of bridge.

2. FINITE ELEMENT MODELING

In the present paper, CSI-Bridge software is used for modeling. Following the conventional process of finite element modeling, samples from different references have to be selected, and after simulating them in software, the results of the analysis are compared with their laboratory results. If the analytical results are converged with the experimental results, it can be concluded that the adopted process for the modeling is adequate. This part of the finite element work is called the verification phase. Verification is typically more important for samples that experience nonlinear behavior. In the long-term behavior of the bridge deck, concrete creep and shrinkage and relaxation of prestressing tendons, define the time-dependent nonlinear behavior. Therefore, it is necessary to select samples for the validation phase in which the effect of these three characteristics is evident. For this purpose, the MSB1 specimen, which is a segmented pre-tensioned concrete bridge and built by a balanced-cantilever method, is selected from the study of Hedjazi *et al.* [26]. Fig. 1 shows the dimensions and arrangement of the pre-tensioned cables for this bridge.

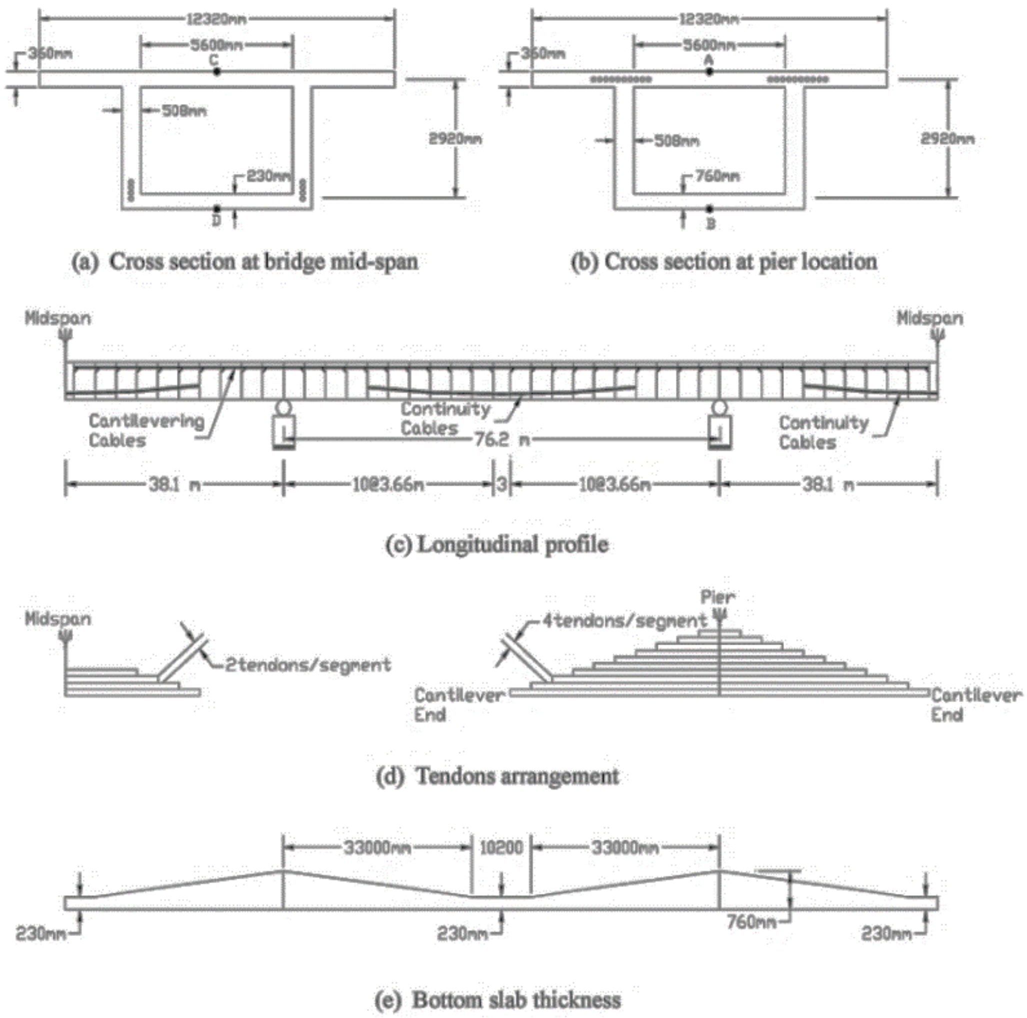

Figure 1. MSB1 bridge geometry. (a) Cross-section at pier location, (b) crosssection at mid-span for MSB1, (d) longitudinal profile, (e) arrangement of tendons [6].

The concrete strength (f'_c) is 35 MPa, maximum creep coefficient (ϕ_∞) is 3, maximum strain due to concrete shrinkage $(\varepsilon_{sh\infty})$ is 0.0008, and concrete density (ρ_c) is 2400 Kg/m^3. The modulus of elasticity (E_{ps}) and the ultimate strength of pre-tensioned cables (f_{us}) are 193 MPa and 1900 MPa, respectively. Fig. 1 depicts the beam used in the MSB1 is a single-celled concrete beam whose overall depth is fixed at a total length of 3.48 m. The amount of non-prestressed reinforcing steel in the cross-section is equal to 0.02% of the cross-section area. For more detailed information referred to Ref. [6]. Bridge construction is done in five general stages, including 1- Manufacturing prefabricated parts (days 0 to 20), 2- Fabricating of 10 cantilever segments and cables then stressing tendons at a desired frequency every other day. (days 20 to 40), 3- Concreting and curing the key segment in middle span (days 40 to 47), 4- Assembling prefabricated parts and related cables then apply pre-tensioning (days 47 to 50); 5- Do the pavement and apply a superimposed load (days 50 to 75) [6].

Several steps must be taken to simulate the sample in CSI-Bridge software. These include the definition of route geometry, defining material properties, the geometry and dimensions of the cross-sections, the pre-tensioned cable path, the boundary conditions, load application, finally, analysis. Relationships provided by CEB-FIP 1990 are used to define the time-dependent properties of the materials. Due to the symmetry in the balanced-cantilever method, only one span of the sample is modeled (right span) and analyzed for this purpose at the center of symmetry, the roller support is defined (see Fig. 2).

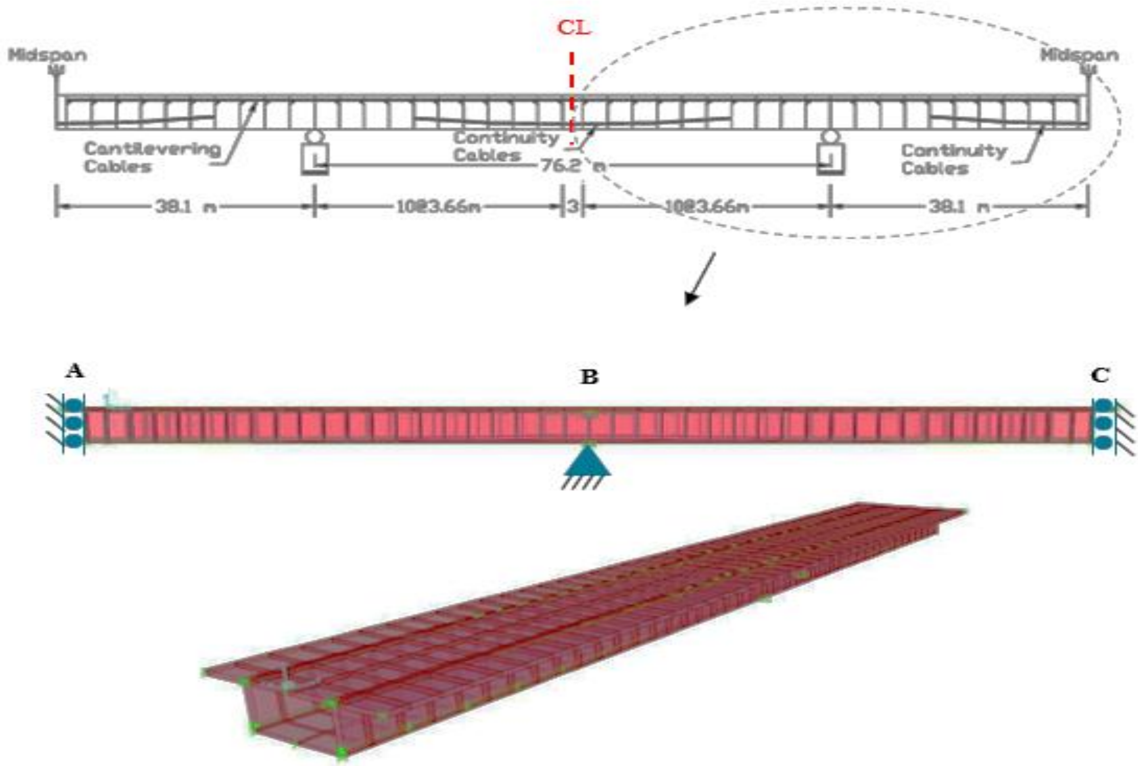

Figure 2. Geometry and boundary conditions of the understudy model

One of the essential parts of modeling is to introduce the sequence of sample construction, which mentioned and following the process outlined in Reference [26]. These general steps each have subcategories that have been introduced to the software in a total of 70 steps. After modeling and analyzing the model, to ensure the validity of the process, the analytical results are compared with those presented by Hedjazi *et al*. [26]. The results of this comparison at the times of 500, 1000, and 5000 days after construction of the bridge are shown in Fig. 3. The abscissa of the diagrams in this figure represents the horizontal distance from the center of the middle support (point B of Fig. 2), and the ordinate shows the vertical displacements of the deck. As can be seen in Fig. 3, as time passes the results in the primary part of the span (near-column stations) are closer to those presented in [26] on the other hand, results at middle span (stations after 25,000 mm) differs from the results presented by Hedjazi *et al.* [26]. However, this difference is minimal and can be ignored.

Therefore, with matching the present results and the results presented in [26], the validity of the modeling process in this study can be confirmed.

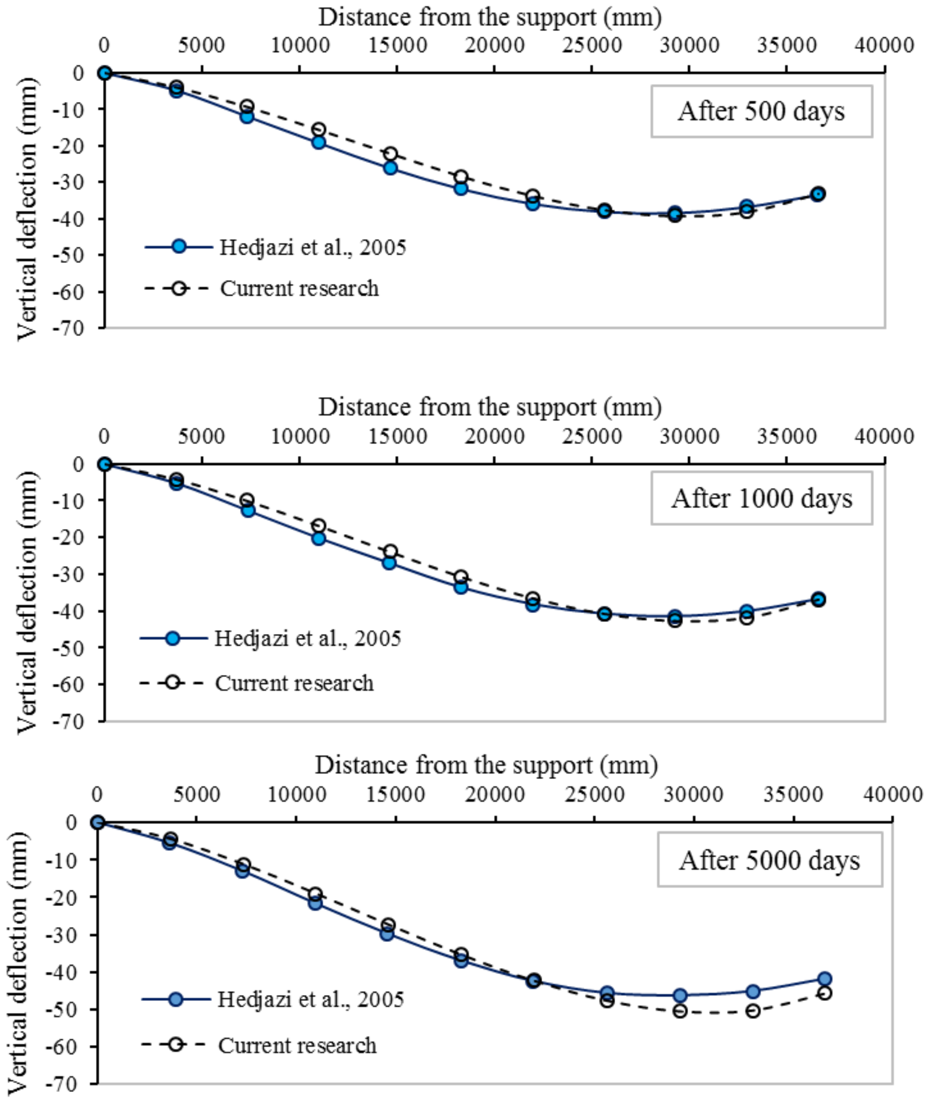

Figure 3. Existing relationships for estimating concrete creep and shrinkage on vertical deformation in the middle span

In this section, the values of the creep and shrinkage are obtained by using 7 different references (CEB-FIP1990 [15, 27], GL2000 [17], ACI [13], Eurocode [18, 19], NCHRP [16], and AASHTO [11]) and considered in bridge modeling. Regulations use a combination of five input parameters to calculate concrete creep and shrinkage (Table 1). Although the general form of relationships is different, the values of these parameters are the same.

Table 1: Demonstrate the input parameters in creep computation in the codes discussed in this study

Code	V/S	RH	f'_{c28}	t	t_0
AASHTO	x	x	x	x	x
ACI/PCI	x	x	x	x	x
CEB-FIP	x	x	x	x	x
GL2000	x	x	-	x	x
NCHRP	x	x	x	x	x
Eurocode	x	x	x	x	x

V/S = The volume-to-surface ratio RH = Relation humidity

f'_{c28} = Compressive strength of concrete at 28 days (MPa)

t = age of concrete t_0 = Age of concrete at initial loading in creep calculations (days).

3. RELATIONSHIP FOR CALCULATING CREEP AND SHRINKAGE ACCORDING TO DIFFERENT PREFERENCES

In this section, different relationships for calculating of concrete creep and shrinkage are discussed.

3.1. AASHTO[1]

One of the most commonly used AASHTO regulation is the bridge design based on the LRFD method. The latest available version of this code, is the sixth version [10, 11] published in 2012, is used in this study.

3.1.1. Creep

The creep coefficient value is significantly dependent on the concrete age at loading time, and it may be taken as:

$$\begin{aligned} &\phi(t,t_0) = 1.9 k_s k_{hc} k_f k_{td} t_0^{-0.118} \\ &k_s = \max\ (1.45 - 0.13(V/S),\ 1.0) \qquad k_{hc} = 1.56 - 0.008RH \\ &k_f = \frac{5}{1+f_c'} \qquad k_{td} = \frac{t}{61 - 4f_c' + t} \end{aligned} \tag{1}$$

where k_s, k_{hc}, k_f, k_{td} are volume-to-surface, humidity, concrete strength, and time-dependent factors, respectively.

3.1.2. Shrinkage

Calculations for concrete shrinkage depend on parameters such as time, relative humidity, and member dimensions.

[1] American Association of State Highway and Transportation Officials

$$\varepsilon_{sh}(t,t_s) = k_s k_{hs} k_f k_{td} \times 480 \times 10^{-6}$$
$$k_{hs} = 2 - 0.014RH \tag{2}$$

where k_s, k_f, k_{td} are assumed as previous. k_{hs} is known as humidity factor for shrinkage.

3.2. ACI[2]-209 and PCI[3] [12-14]

ACI-209 is specifically addressing the impact of creep and shrinkage on concrete, and PCI is mainly focused on developing the knowledge in the design, manufacturing, and installation of prefabricated concrete structures. Relationships of calculating the shrinkage and creep of concrete structures in PCI and ACI codes differ slightly. The relationships are defined under standard conditions. See Refs. [12-14] for more information.

3.2.1. Creep

The general form of the proposed relationship is used to calculate creep for concrete with a strength of 4 to 12 ksi.

$$\phi(t,t_0) = \left(\frac{(t-t_0)^{0.6}}{(12-0.5f_c^{'})+(t-t_0)^{0.6}}\right) \times (1.18 - 0.045f_c^{'}) \times 1.88 k_{la} k_{hc} k_s k_\alpha k_{sl} k_p$$
$$k_{la} = 1.25(t_0)^{-0.118} \qquad k_s = \frac{2}{3}(1 + 1.13e^{-0.54V/S}) \tag{3}$$
$$k_{hc} = 1.586 - 0.0084RH \qquad \text{for } 40 \le \text{RH} \le 100\%$$

where k_{la}, k_{hc}, k_s are correction factors for loading case, size of the member, and relative humidity, respectively. Also, k_α, k_{sl}, k_p parameters stand for existing air in concrete, concrete slump, and percentage of aggregate, respectively. If there is insufficient information for these parameters, their value is assumed to be one.

3.2.2. Shrinkage

The general form of shrinkage strain for a concrete sample at the age of *t* days ($\varepsilon_{sh}(t,t_s)$) is computed by Eq. (4) for a concrete sample with a strength of 4 to 12 ksi.

$$\varepsilon_{sh}(t,t_s) = \left(\frac{(t-7)}{(45-2.5f_c^{'})+(t-7)}\right) \times (1.2 - 0.05f_c^{'}) \times 545 \times 10^{-6} \times k_{cp} k_{hs} k_s k_c k_\alpha k_{sl} k_p$$
$$k_{hs} = 2 - 0.0143RH \qquad \text{for } 40 \le \text{RH} \le 80\% \tag{4}$$
$$k_{hs} = 4.286 - 0.0429RH \qquad \text{for } 80 \le \text{RH} \le 100\%$$
$$k_s = 1.2\, e^{-0.12(V/S)}$$

where k_{hs} is known as a correction factor for relative humidity. Also, k_{cp} is related to the curing period, and its values may be taken from Table (2).

---

[2] American Concrete Institute
[3] Precast/Prestressed Concrete Institute

Table 2: Demonstrate the correction factor k_{cp} for a curing period [12-14].

Moist curing period, days	Shrinkage factor, k_{cp}
1	1.20
3	1.10
7	1.00
14	0.93
28	0.86
60	0.79
90	0.75

where k_c is taken as a factor for the content of cement. Also, k_α, k_{sl}, k_p parameters are defined in the creep section. In the absence of specific shrinkage data above coefficient, they must be considered as one.

3.3. CEB-FIP[4] [15]

The effect of complex dependencies between input parameters enters in the relationships proposed by CEB-FIP.

The effect of complex dependencies between input parameters is the main reason for the difference between the relationships presented in the CEB-FIP and those of the other regulations.

3.3.1. Creep

$$\phi(t,t_0)=\phi_0\beta_c(t-t_0)\beta_E(t_0)$$

$$\phi_0=\phi_{RH}\beta(f_{cm})\beta(t_0) \qquad \phi_{RH}=1+\frac{1-\dfrac{RH}{100}}{0.46(\dfrac{h_0}{100})^{1/3}}$$

$$\beta(f_{cm})=\frac{5.3}{\sqrt{(f_{cm}/10)}} \qquad \beta(t_0)=\frac{1}{0.1+t_0^{0.2}} \qquad \beta_c(t-t_0)=\left(\frac{t-t_0}{t-t_0+\beta_H}\right)^{0.3} \tag{5}$$

$$\beta_H=\frac{150\times h_0}{100}(1+(0.012\text{RH})^{18})+250\leq 1500$$

$$\beta_E(t_0)=\frac{E_c(t_0)}{E_c(28)} \qquad h_0=\frac{2A_c}{p}$$

where β_c, β_E, β_H, $\beta(t)$, $\beta(f_{cm})$ are constant parameters depend on the type of cement, modulus of elasticity, relative humidity, concrete age, and mean concrete strength. Also, h_0, A_c and p parameters stand for assumed thickness, cross-section area, and perimeter of concrete.

[4] International Federation for Prestressing, European Committee for Concrete

$$\phi(t,t_0)=\phi_0\beta_c(t-t_0)\beta_E(t_0)$$

$$\phi_0=\phi_{RH}\beta(f_{cm})\beta(t_0) \qquad \phi_{RH}=1+\frac{1-\frac{RH}{100}}{0.46(\frac{h_0}{100})^{1/3}}$$

$$\beta(f_{cm})=\frac{5.3}{\sqrt{(f_{cm}/10)}} \qquad \beta(t_0)=\frac{1}{0.1+t_0^{0.2}} \qquad \beta_c(t-t_0)=\left(\frac{t-t_0}{t-t_0+\beta_H}\right)^{0.3} \tag{6}$$

$$\beta_H=\frac{150\times h_0}{100}(1+(0.012\text{RH})^{18})+250\leq 1500$$

$$\beta_E(t_0)=\frac{E_c(t_0)}{E_c(28)} \qquad h_0=\frac{2A_c}{p}$$

where $f_c^{'}$, f_{cm}, $E_c(28)$, $E_c(t)$ are shown the compressive and mean compressive strength of concrete, modulus of elasticity at the time of 28 days, and modulus of elasticity at the time of t, respectively.

3.3.2. Shrinkage

The following equation can be used to calculate the concrete shrinkage at any age.

$$\varepsilon_{sh}(t,t_s)=\varepsilon_{cs0}\beta_s(t-t_s)$$

$$\beta_s(t-t_s)=\left(\frac{t-t_s}{350(h_0/100)^2+(t-t_s)}\right)^{0.5}$$

$$\varepsilon_{cs0}=\varepsilon_s(f_{cm})\beta_{RH} \qquad \varepsilon_s(f_{cm})=\left(160+10\beta_{sc}\left(9-\frac{f_{cm}}{10}\right)\right)\times 10^{-6} \tag{7}$$

$$\beta_{RH}=-1.55\left(1-\left(\frac{RH}{100}\right)^3\right) \qquad \text{for} \quad 40\%\leq RH\leq 99\%$$

$$\beta_{RH}=0.25 \qquad \text{for} \quad RH\geq 99\%$$

where β_s, β_c, β_{RH} are constant depend on the time and relative humidity. Also, $\varepsilon_s(f_{cm})$ shows a parameter to consider the effect of concrete strength and type of cement on the amount of concrete shrinkage.

3.4. GLP2000 [17]

The GL 2000 method was developed in 2000 by Gardner and Lockman and can be used to calculate the concrete creep and shrinkage up to 12 ksi. Many researchers have used this method. It should be mentioned that this formula has been extracted and validated based on an extensive database**.**

3.4.1. Creep

$$\phi(t,t_0)=\phi(t_c)\left(\frac{(t-t_0)^{0.3}}{(t-t_0)^{0.3}+14}\right)\times\left(\frac{7}{t_0}\right)^{0.5}\left(\frac{t-t_0}{t-t_0+7}\right)$$
$$+2.5\left(1-1.0286\left(\frac{RH}{100}\right)^2\right)\left(\frac{t-t_0}{t-t_0+0.15(V/S)^2}\right) \quad (8)$$
$$\phi(t_c)=\left(1-\left(\frac{t-t_s}{t_0-t_s+0.15(V/S)^2}\right)^{0.5}\right)^{0.5}$$

The term $\phi(t_c)$ takes account of creep before loading.

3.4.2. Shrinkage

$$\varepsilon_{sh}(t,t_s)=\varepsilon_{shu}\beta(h)\beta(t)$$
$$\varepsilon_{shu}=1000K\left(\frac{30}{f_{cm}}\right)^{0.5}\times10^{-6}$$
$$f_{cm}=1.1f_c^{'}+5(MPa) \quad (9)$$
$$\beta(h)=1-1.18\left(\frac{RH}{100}\right)^4 \qquad \beta(t)=\left(\frac{t-t_0}{t-t_0+0.15(V/S)^2}\right)^{0.5}$$

where K, $\beta(h)$, and $\beta(t)$ are taken as an ultimate shrinkage strain, a correction factor based on the type of cement, humidity, and the shrinkage time. Also, ε_{shu} shows the ultimate shrinkage strain.

3.5. NCHRP[5] [15]

This reference helps designers to have a realistic estimate of the pre-tension creep values in prestressed bridges.

3.5.1. Creep

$$\phi(t,t_0)=1.9k_{td}k_{la}k_{hc}k_sk_fK_1K_2$$
$$k_{td}=\frac{t}{61-4f_c^{'}+t} \qquad k_{la}=t_0^{-0.118}$$
$$k_{hc}=1.56-0.008RH \qquad \text{for} \quad 30\% \le RH \le 80\% \quad (10)$$
$$k_s=\frac{1064-94V/S}{735} \qquad k_f=\frac{5}{1+f_c^{'}}$$

where k_{td}, k_{la}, k_{hc}, k_s, k_f, K_1 and K_2 are shown time-development, loading age, humidity, volume-to-surface ratio, concrete strength, aggregate type in predicting an average value, and aggregate type in predicting upper and lower bounds correction factors, respectively.

---

[5] National Cooperative Highway Research Program

3.5.2. Shrinkage

$$\begin{aligned} &\varepsilon_{sh}(t,t_s) = 480\times 10^{-6} k_{td} k_s k_{hs} k_f K_1 K_2 \\ &k_{hs} = 2 - 0.0143RH \qquad \text{for} \quad 30\% \le RH \le 80\% \end{aligned} \tag{11}$$

where k_{hs} is a humidity correction factor for shrinkage.

The sample of bridge investigated in this study is the MSB1 sample selected from the study done by Hedjazi et al. [26]; its details are given in the previous section. Firstly, the creep and shrinkage contents for each of these seven references are separately applied to the MSB1 bridge sample then analyze is done. Then, Long-term deformation values (after 30 years) are extracted from the software (see Fig. 4). According to ACI regulations, typically after about 30 years, the concrete creep reaches its maximum value and stops [25]. In this study, 30 years is assumed to be the desired number to investigate the long-term behavior of the investigated bridge.

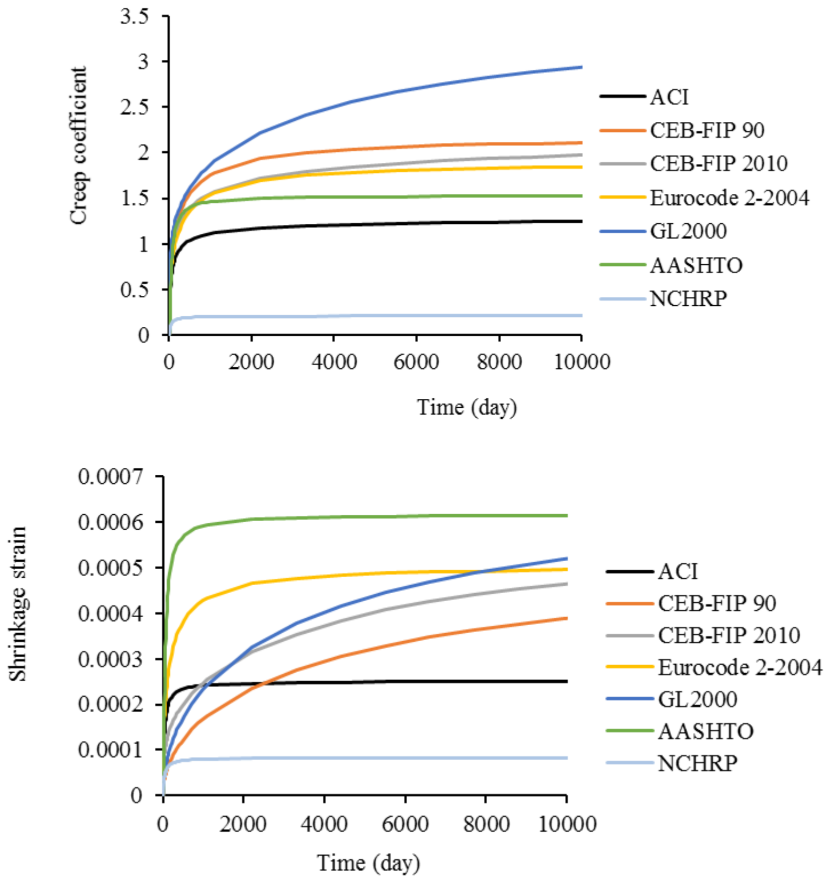

Figure 4. The different values of the concrete creep and shrinkage which applied to the MSB1 bridge sample obtained from different relationships.

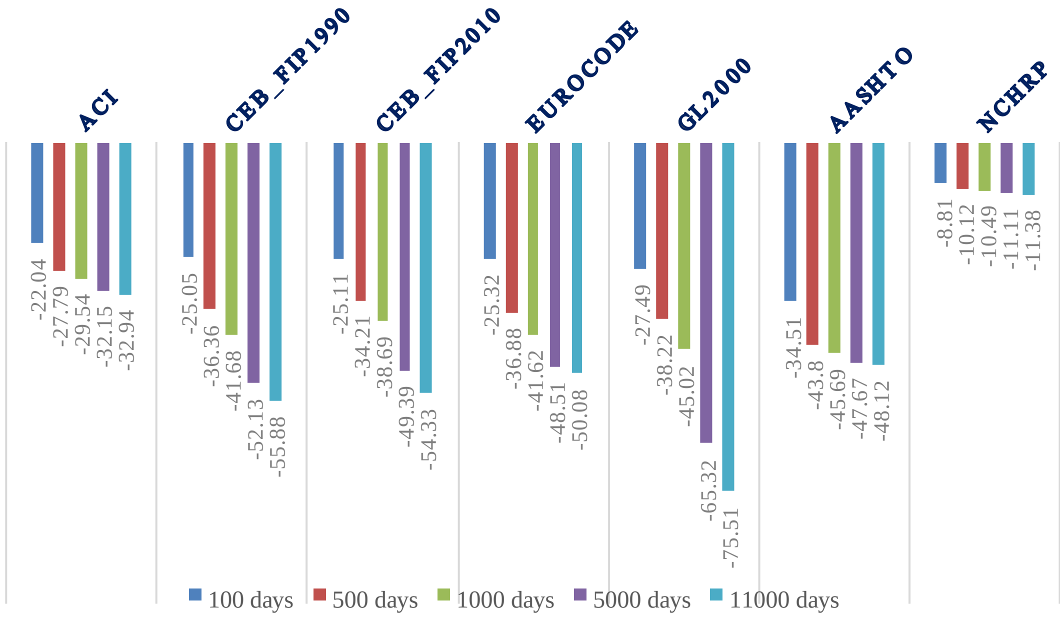

Figure 5. The values of vertical displacements in the middle span of the bridge.

Fig. 5 shows the values of vertical displacements in the middle span of the bridge (point C in Fig. 2), 30 years after the bridge was constructed. In this figure, the Dv variable represents the vertical displacement in the middle span of the bridge

As can be seen in Fig. 5, the analytical results of models simulated with different values of creep and shrinkage can sometimes be very different. Therefore, the results cannot be trusted. In such cases, one way to make sensible decisions is to use statistical methods to interpret the results. For this purpose, fragility curves have been used in this study (Fig. 6), which is one of the most widely used methods in examining the behavior of structures. In this figure, 95% probability values are denoted by the dashed line. It should be noted that this probability percentage is chosen according to the suggestion of previous researchers. According to Bazantz *et al.* [8], large bridges should be designed for a state with a 95% probability of deformation within the permissible range. Thus, in the present research under, long-term deformations are achieved in a situation where the probability of infringement is only 5%.

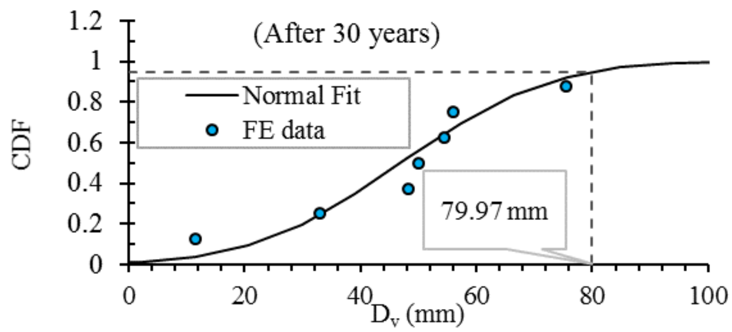

Figure 6. The fragility curve parameter of the mid-span displacement for a state after 30 of the bridge construction.

As can be seen in the figure, the corresponding D_v value with a 95% probability is 79.97 mm. In other words, the probability of long-term mid-span deformations exceeding from 79.97 mm is only 5%. If this deformation value is assumed to be the maximum of long term vertical deformation of the mid-span ($D_{v\text{-max}}$ = 79.79), its value must be less than the permissible value $D_{V\text{-allowable}}$ of the mid-span deformation which can be obtained with relation (12).

$$\varepsilon_{sh}(t,t_s) = 480\times10^{-6} k_{td} k_s k_{hs} k_f K_1 K_2$$
$$k_{hs} = 2 - 0.0143 RH \qquad \text{for} \quad 30\% \le RH \le 80\% \tag{12}$$

According to the results, the value of $D_{v\text{-max}}$ parameter is less than the value of $D_{v\text{-allowable}}$. This indicates that the long-term deformation of the bridge is in the permissible range.

4. PROVIDING A SOLUTION TO REDUCE THE NUMBER OF MODELS NEEDED

An important point to keep in mind is the duration of sample analysis. As mentioned, to obtain the above statistical results, the bridge structure has to be analyzed seven times (seven different inputs according to different code), which requires considerable time. An alternative approach to reduce the number of samples is to perform statistical operations on the software's input data instead of performing statistical operations on the results of seven separate analyzes. In other words, the probability values of the concrete creep diagrams and the probability values of the concrete shrinkage diagrams can be obtained separately (Fig. 7). Then, instead of introducing seven separate states for the values of the creep and shrinkage, only one graph for the shrinkage and one graph for the creep (which corresponds to 95% probability percentiles) are introduced to the software. Thus, instead of analyzing seven samples, only one sample is analyzed, which reduces modeling and analysis time.

Here the question is whether the accuracy of the proposed method is appropriate. This method is implemented on the MSB1 Bridge, and the results are shown in Table (3) to answer this question.

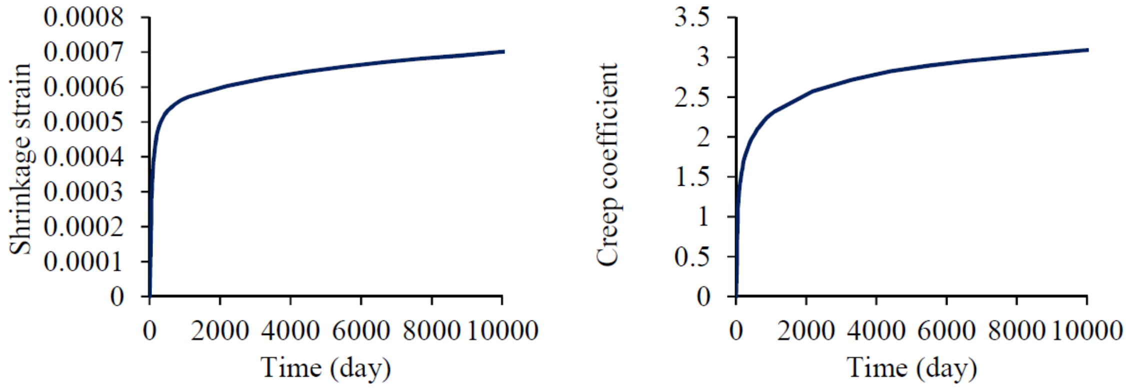

Figure 7. Shrink and Creep values related to the 95% probability.

Table 3: The probabilistic Dv results of the seven separate analysis with the Dv results of the model analysis with probabilistic graphs.

Row	Method	D_v (*mm*) (after 1000 days)	D_v (*mm*) (after 11000 days)
1	ACI	-29.54	-32.94
2	CEB-FIP1990	-41.68	-55.88
3	CEB-FIP2010	-38.69	-54.33
4	Eurocode	-41.62	-50.08
5	GL2000	-45.02	-75.51
6	AASHTO	-45.69	-48.12
7	NCHRP	-10.49	-11.38
8	95%-Analyzing 7 models	-56.78	-79.97
9	95%-Analyzing only 1 model	-58.21	-78.71
10	Absolute Error	2.51%	1.58%

Rows 1 to 7 of Table (3) demonstrate the D_v values for the states using different contents of creep and shrinkage by the various regulations (these numbers are also shown in Fig. 5). By applying the fragility curve to the results of these rows (1-7), row 8 of Table (3) is obtained. Then, a model with probability values of creep and shrinkage is separately defined and analyzed, the results of which are presented in line 9 of Table (3). The tenth line shows the difference between the analysis of 7 separate models and the analysis of the proposed model. As it is evident, this error is less than 3%. Based on these results, it seems that using probabilistic values of creep and shrinkage for modeling and investigating the long-term deformation of segmented concrete bridges can be a good solution. This method not only has good accuracy but also dramatically reducing the analysis time.

5. CONCLUSION

From what has been discussed above, to calculate the long-term vertical displacement of segmented concrete bridges according to the effect of creep and shrinkage, several various relationships, give us different values of displacement. Therefore, designers have to analyze several models with different values of creep and shrinkage, to obtain the maximum deformation value at critical span 30 years after bridge construction (D_v), next use fragility curve to extract the vertical displacement with 95% probability and named it $D_{v\text{-}max}$. It should be noted that previous researchers have suggested the 95% probability. Finally, by comparing $D_{v\text{-}max}$ with the allowable amount of vertical displacement in the middle span, the designer can make a reasonable decision about whether the design is responsive in terms of long-term deformation or not. This procedure is very exhausting and is very low-speed. In the present paper, instead of using fragility curves in interpreting the results of several analyzes, fragility curves are used in the extraction of concrete creep and shrinkage values. Thus, we have only one diagram for creep and shrinkage. These diagrams can be used to find a corresponding percentage of probability, and they can be introduced to the software as long-term concrete properties. The results of the analysis of a bridge sample showed acceptable accuracy of the proposed solution with 95% probability.

ACKNOWLEDGMENT: The authors would like to appreciate the use of the computational clusters of the HPC center (Shahr–e–Kord University, Iran), to complete this work.

REFERENCES

1. Kaveh A, Motesadi Zarandi MM. Optimal design of steel-concrete composite I-girder bridges using three meta-heuristic algorithms, *Period Polytech Civil Eng* 2019; **63**(2): 317-37.
2. Askari Dolatabad Y, Kamgar R, Gouhari Nezad I. Rheological and mechanical properties, acid resistance and water penetrability of lightweight self-compacting concrete containing Nano-SiO2, Nano-TiO2 and Nano-Al2O3, *Iranian J Sci Technol, Tran Civil Eng* 2019; DOI: 10.1007/s40996-019-00328-1
3. Kamgar R, Bagherinejad M H, Heidarzadeh H. A new formulation for prediction of the shear capacity of FRP in strengthened reinforced concrete beams, *Soft Comput* 2019; DOI: 10.1007/s00500-019-04325-4
4. Kaveh A, Maniat M, Arab Naeini M. Cost optimum design of post-tensioned concrete bridges using a modified colliding bodies optimization algorithm, *Adv Eng Softw* 2016; **98**: 12-22.
5. Kaveh A, Bakhshpoori T, Barkhori M. Optimum design of multi-span composite box girder bridges using Cuckoo Search algorithm, *Steel Compos Struct* 2014; **17**(5): 705-19.
6. Hedjazi S, Rahai A, Sennah K. Evaluation of creep effects on the time-dependent deflections and stresses in prestressed concrete bridges, *Bridge Struct* 2007; **3**(2): 119-32.
7. Shayanfar M, Kaveh A, Eghlidos O, Mirzaei B. Damage detection of bridge structures in time domain via enhanced colliding bodies optimization, *Int J Optim Civil Eng* 2016; **6**(2): 211-26.

8. Wendner R, Tong T, Strauss A, Yu Q. A case study on correlations of axial shortening and deflection with concrete creep asymptote in segmentally-erected prestressed box girders, *Struct Infrastruct Eng* 2015; **11**(12): 1672-87.
9. Kaveh A, Hamze-Ziabari S, Bakhshpoori T. Estimating drying shrinkage of concrete using a multivariate adaptive regression splines approach, *Int J Optim Civil Eng* 2018; **8**(2): 181-94.
10. AASHTO L. *AASHTO LRFD Bridge Design Specifications,* American Association of State Highway and Transportation Officials, Washington, DC, 2004.
11. AASHTO L. *AASHTO LRFD Bridge Design Specifications,* American Association of State Highway and Transportation Officials, Washington, DC, 2012.
12. ACI-209R-92. *Prediction of creep, shrinkage, and temperature effects in concrete structures,* American Concrete Institute Farmington Hills, Michigan, 1997.
13. ACI-209R-92. *Prediction of creep, shrinkage, and temperature effects in concrete structures,* American Concrete Institute Farmington Hills, Michigan, 2008.
14. PCI. *Precast/Prestressed Concrete Institute, Manual, PCI Bridge Design,* Chicago, IL, 2003.
15. CEB-FIP M, 90. *Design of concrete structures. CEB-FIP Model Code 1990,* London, British Standard Institution, 1993.
16. NCHRP, *Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders*. 2003, Transportation Research Board: Washington, D.C. USA.
17. Gardner N, Lockman M. Design provisions for drying shrinkage and creep of normal-strength concrete, *Materials journal* 2001; **98**(2): 159-167.
18. Bouassida Y, Bouchon E, Crespo P, Croce P, Davaine L, Denton S, Feldmann M, Frank R, Hanswille G, Hensen W, *Bridge design to Eurocodes-Worked examples*, in *EUR 25193 EN*. 2012, European Commission, Joint Research Centre: Italy. p. 4-6.
19. Normalisation C E D. *Design of concrete structures: Part 1-1: General rules and rules for buildings,* 2004.
20. Lewis M, Karbhari V M, *Experimental verification of the influence of time-dependent material properties on long-term bridge characteristics*. 2006, Department of Transportation: California
21. Ghali A, Elbadry M, Megally S. Two-year deflections of the Confederation Bridge, *Canadian Journal of Civil Engineering* 2000; **27**(6): 1139-49.
22. Bazant Z P, Hubler MH, Yu Q. Pervasiveness of excessive segmental bridge deflections: Wake-up call for creep, *ACI Struct J* 2011; **108**(6): 766-74.
23. Bažant Z k P, Yu Q, Li G-H. Excessive long-time deflections of prestressed box girders. II: Numerical analysis and lessons learned, *J Struct Eng* 2012; **138**(6): 687-96.
24. Bažant Z P, Yu Q, Li G-H. Excessive long-time deflections of prestressed box girders. I: Record-span bridge in Palau and other paradigms, *J Struct Eng* 2012; **138**(6): 676-86.
25. Huang H, Huang S-S, Pilakoutas K. Modeling for assessment of long-term behavior of prestressed concrete box-girder bridges, *J Bridge Eng* 2018; **23**(3): 04018002.
26. Hedjazi S, Rahai A, Sennah K. Long-term behavior of segmentally-erected prestressed concrete box-girder bridges, *Struct Eng Mech* 2005; **20**(6): 673-94.
27. CEB-FIP M, *Design of concrete structures. CEB-FIP Model Code 2010,* London, British Standard Institution, 2010.