Journal of Materials and Engineering Structures

Research Paper

Effect of Creep and Shrinkage model in calculation of long-term deflection of three-span solid slab continuous prestressed concrete bridge

Xuan Tung Nguyen [a,*], *Van Minh Ngo* [a], *Ngoc Long Nguyen* [a], *Tuan Dung Pham* [a]

[a] *University of Transport and Communications, Hanoi, Vietnam*

ARTICLE INFO

Article history:

Received : 15 November 2022

Revised : 25 December 2022

Accepted : 29 December 2022

Keywords:

Shrinkage

Creep

Deflection

Prestressed concrete bridge

ABSTRACT

Shrinkage and creep effect significantly to the long-term deflection of prestressed concrete bridge. The proper shrinkage and creep models should be developed to meet the requirements of deflection effect calculation. There are many models has been researched and developed. Each specification, such as ASSHTO, Eurocode, ACI and CEB-FIB, has their own model of shrinkage and creep by considering different input parameter. The long-term deflection calculation is also different in each specification as a result. In this paper, several shrinkage and creep models were selected and reviewed to see the difference and compare by using popular concrete grade in Vietnamese bridge building (C40 and C45, equivalent to 40 and 45 Mpa, respectively). Those selected shrinkage and creep models are applied in calculation of deflection for a typical three-span continuous solid slab prestressed concrete bridge. The calculation result show the significant different of long-term deflection and the ASSHTO shrinkage and creep model show the biggest deflection.

F. ASMA & H. HAMMOUM (Eds.) special issue, 4th International Conference on Sustainability in Civil Engineering ICSCE 2022, Hanoi, Vietnam, J. Mater. Eng. Struct. 9(4) (2022)

1 Introduction

Continuous prestressed concrete bridge are popular worldwide from the mid of 20th century. Despite many advantages, the long-term deflection of this type of bridge is still under consideration. Many researches indicate the over-estimated deflection in the mid span of the bridge structure. The large and over-estimated deflection at the middle span of bridge is not only affecting the aesthetics, but also may lead to the possibility of collapse, as happened in the Kodor-Babeldaob bridge in Palau. Bob present that one of the main cause for the above collapse is the cracked top slab resulting from the large deflection [1]. Then Kristek et al [2] also indentify that the designer of the Kodor-Babeldaob Bridge selected the oversimplified and unrealistic model for shrinkage and creep prediction. Bažant and his team proposed shrinkage and creep model, B3 that used

* *Corresponding author.*
E-mail address: ngxuantung@utc.edu.vn

e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

for concrete structure designing [3] then he also applied that model to analysis the collapse of the Kodor-Babeldaob bridge and compare with the model of shrinkage and creep of other specification such as ACI, CEB-fib. He did conclude that none of the existing shrinkage and creep model can give a better long-term deflection prediction than the others [4]. Since then, the effected factors, of long-term deflection of prestressed concrete bridge have been studied seriously. Among many factors, shrinkage and creep is considered to be the most important one, since it comprises up to 49% of prestressed loss [2]. Various models of shrinkage and creep of concrete have been suggested. However, the research in Vietnam shows that the deflection calculated from standard models may be two to three times smaller than the experimental results for cantilever prestressed concrete bridge [5, 6]. In this paper, several creep and shrinkage models have been selected for calculation and comparison with typical compressive strength that applied widely in Vietnam, and carry out an example to show the difference in calculation long-term deflection of bridge with different model of shrinkage and creep.

2 Creep and shrinkage model in design standards

There is a number of creep and shrinkage models were introduced in design standards. In this part, some typical models such as AASHTO LRFD - 2012, CEB-FIP Model Code 1990 [7] and 2010 [8]; ACI 209r – 92 and ACI 209 – 2001 are introduced. In those standards, the input parameters for creep coefficient and shrinkage deformation calculation are summarized in Table 1.

Table 1 – Input parameters of creep and shrinkage models

Input parameter	AASHTO LRFD 2012	CEB-FIP90	ACI 209R-92	CEB-FIP2010	ACI 209-2001
Compression (MPa)	16 ÷ 70	12 ÷ 80	-	12 ÷ 80	≤ 85
W/c ratio	-	-	-	-	-
Cement content	-	-	Considered	-	Considered
Humidity (%)	35 ÷ 100	40 ÷ 100	40 ÷ 100	40 ÷ 100	40 ÷ 100
Cement type	I,II,III	I,II,III	I or III	I, II, III	I, II, III
Moisture curing before loading (days)	1 ÷ 3 days	-	1 ÷ 3 days	-	1 ÷ 3 days
Steam curing before loading (days)	≥ 1	≤ 14	≥ 1	≤ 14	≥ 1
Loading age (days)	≥ 1	≥ 1	≥ 1	≥ 1	≥ 1
Fine aggregate	-	-	Considered	-	Considered
Air content	-	Considered	Considered	Considered	Considered
Slump	-	-	Considered	-	Considered
Sample size	Considered	Considered	Considered	Considered	Considered
(-) not considered					

In which, the AASHTO LRFD 2012 model is captured from the experience formula of Collins and Mitchell [3] and correction by ACI Committee 209 proposed the creep coefficient and shrinkages deformation formula based on drying, loading time, compressive strength, humidity and structure/sample dimensions (V/S). In the European model (CEB-FIP), besides the drying, loading time, compressive strength, humidity and structure/sample dimensions, the effects of cement types and temperature during the curing process are taken into account. In ACI model the effects of concrete composition and curing conditions during making process such as slump, cement ratio, fine aggregate ratio, air ratio, curing time and curing method are considered besides the effects of environment and structure/sample dimensions.

The calculation expressions of creep and model due to mentioned standards are introduced at the following:

In AASHTO LRFD 2012, the creep and shrinkage are determined as follow:

Creep coefficient is calculated by:

$$y(t,t_i) = 1.9 k_s k_{hc} k_f k_{td} t^{-0.118} \quad (1)$$

where:

H: Humidity (%).

k_s: Coefficient consider the effect of volume/area ratio

k_f: Coefficient consider the effect of concrete strength

k_{hc}: Moisture coefficient for creep.

k_{hd}: Coefficient depend on time.

t: Concrete age (days),

t_i: Concrete age at loading time (days)

Shrinkage deformation, ε_{sh}, at time t, is calculated as follow:

$$\varepsilon_{sh} = k_s k_{hs} k_f k_{td} 0.48x10^{-3} \quad (2)$$

$$k_{hs} = (2.00 - 0.014H) \quad (3)$$

k_{hs}: Moisture coefficient for shrinkage

According to CEB-FIP-90 (Comité EURO-International du Béton), [7] :

Creep coefficient is calculated by:

$$\varphi(t,t_0) = \varphi_0 \beta_C (t - t_0) \quad (4)$$

where:

φ_o: the National creep coefficient

β_c : the coefficient to describe the development of creep with time after loading

t: Concrete age (days),

t_0: Concrere age at loading time (days)

Total shrinkage deformation is calculated by:

$$\varepsilon_{CS}(t,t_s) = \varepsilon_{CS0} \beta_s (t - t_s) \quad (5)$$

where:

ε_{cso}: the National shrinkage coefficient

β_s: the coefficient to describe the development of shrinkage with time after loading

t: Concrete age (days),

t_s: Concrete age at loading time (days)

$$\varphi(t,t_0) = \varphi_0 \beta_C (t,t_0) \quad (6)$$

where:

φ_o: the notational creep coefficient

$\beta_c(t,t_o)$: the coefficient to describe the development of creep with time after loading

t: the age of concrete (days) at the considered moment

t_o : Concrete age at loading time

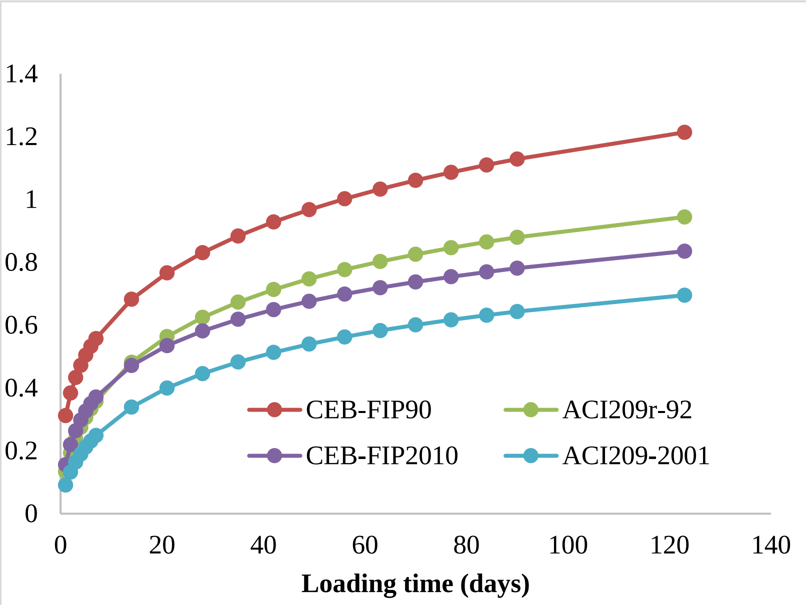


Fig. 1 – Creep coefficient calculation results of concrete grade C45

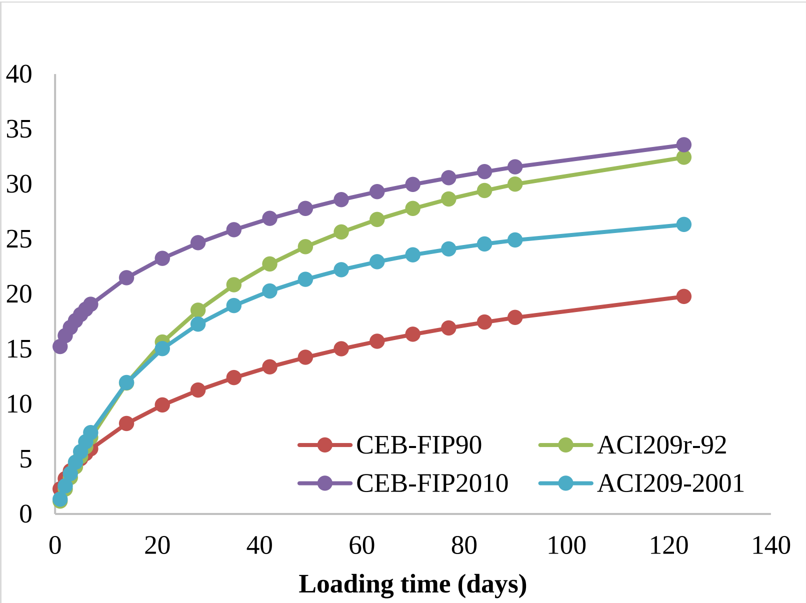


Fig. 2 – Shrinkage deformation calculation results of concrete grade C45 (mm×10-5)

Total shrinkage deformation is calculated by:

$$\varepsilon_{CS}\left(t,t_s\right)=\varepsilon_{cbs}\left(t\right)+\varepsilon_{cds}\left(t,t_s\right) \quad (7)$$

where

t: Concrete age at considered time (days),

t_s: Concrete age at drying time (days)

$(t-t_s)$: drying time (days)

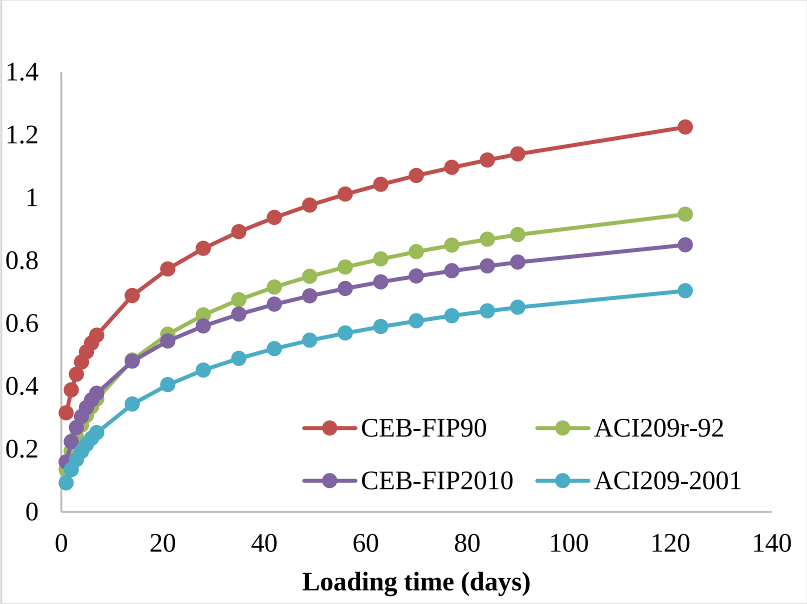


Fig. 3 – Creep coefficient calculation results of concrete grade C40

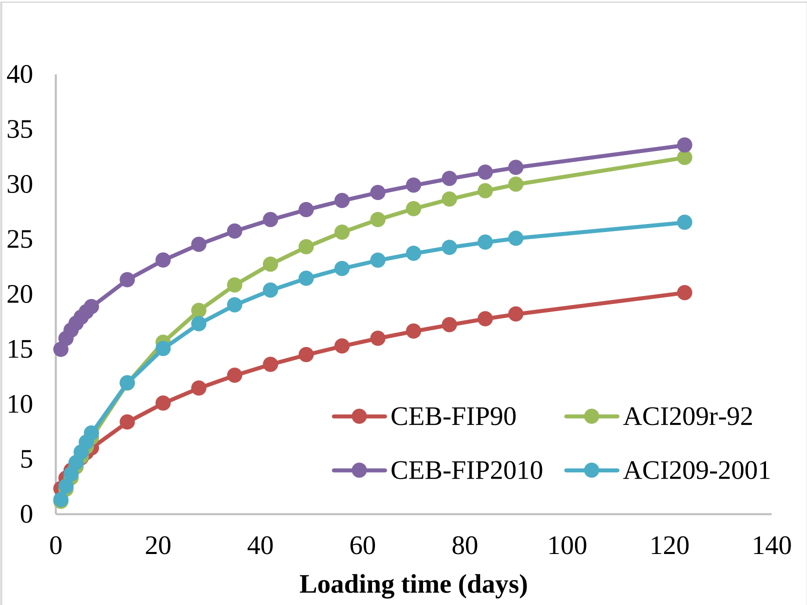


Fig. 4 – Shrinkage deformation calculation results of concrete grade C40 (mm×10^{-5})

In the specification ACI 209r – 92, [9], the creep coefficient is determined by

$$v_t = \frac{t^{0,6}}{10+t^{0,6}} v_u \tag{8}$$

where:

t: time after loading (days)

And shrinkage deformation is determined by

$(\varepsilon_{sh})_t = \frac{t}{35+t}(\varepsilon_{sh})_u$ (Moiture curing)

$(\varepsilon_{sh})_t = \frac{t}{55+t}(\varepsilon_{sh})_u$ (Steam curing)

ν_u : Ultimate creep coefficient

$(\varepsilon_{sh})_u$: Ultimate shrinkage deformation

t : time after shrinkage is considered (days).

The ACI 209 model is then modified by Huo in 2001 in the calculation of creep coefficient:

$$\nu_t = \frac{t^{0,6}}{K_c + t^{0,6}} \nu_u \quad (9)$$

where:

t: time after loading (days) and $K_c = 12 - 0,0073f'_c$

Shrinkage deformation is calculated by:

$$\varepsilon_{sh} = \frac{t}{K_s + t} \quad (10)$$

where :

t : drying time (days) and

K_s : Coefficient consider the quickly development of shrinkage at early age, $K_s = 45 - 0,3626f'_c$

The creep and shrinkage strain curve from different standards are shown for concrete grade C40 and C45 in Fig 1 to Fig 4. It is interesting to note that the entire curve are hyperbolic type, however, they are significantly different in term of value.

For all grades of concrete, at the age of 120 days, the creep coefficient according to ACI209-2001 is about 0.7 and it reaches 1.2 (about 2 times bigger) in CEB-FIP90 specification. The 120 days- shrinkage deformation is about 25×10^{-5} mm in ACI-2009-2001 which is about 2 times smaller than that one in AASHTO LRFD 2012 specification calculation, 40×10^{-5} mm. Each specification considered different effected factors, mentioned in the above paragraphs, resulting to the difference in the calculation result. Due to the significant difference of creep coefficient and shrinkage deformation of different specifications, the selection of creep coefficient and shrinkage deformation model need to be considered carefully in designing.

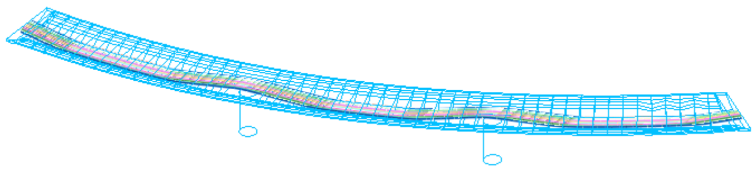
3 Deflection of continuous prestressed concrete bridge with different models of Creep and Shrinkage: a calculation example

The difference in the creep and shrinkage models may lead to significant difference in the calculation deflection of bridge, especially the continuous bridge where the secondary effect of creep and shrinkage is taken in to account. In this part, deflection of a three-span continuous prestressed box slab bridge due to different types of creep and shrinkage model is considered. Bridge parameters are described in Table 2 and Fig 5.

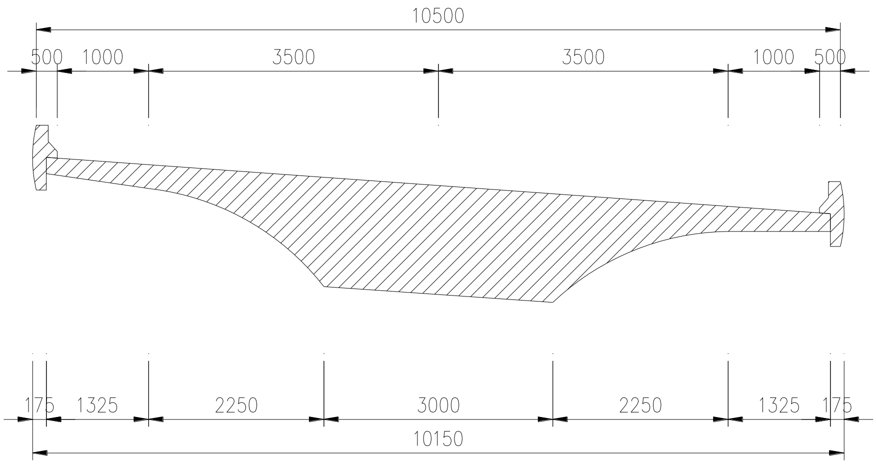
Table 2 – Bridge parameters

Parameter	**Value**
Span	3×35 (m)
Width	10.15 m
Radius of plan curve	145 m
Concrete compressive strength	C40, f'c = 40 MPa
Tendon	12 strand 15,7mm
Jacking stress of tendon	~ 1432 MPa

(a) Overview of bridge



(b) Tendon layout



(c) Typical cross-section of bridge (in mm)

Fig. 5 – General drawing of the bridge (a, b, c)

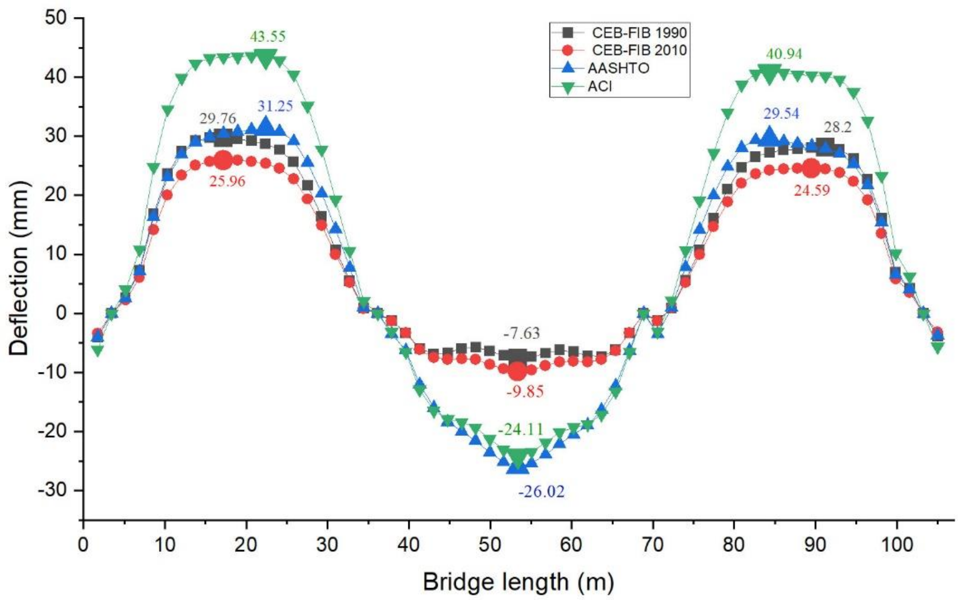


Fig. 6 – Deflection of bridge due to difference types of creep and shrinkage models at 10,000 days after exploitation

The deflection of bridge is calculated due to the accumulation effects of the dead load of the bridge, the dead load of pavement, prestress (including prestress losses), and the preliminary and secondary effect of creep and shrinkage. Whereas, creep and shrinkage effect are estimated based on difference type of model for C40 concrete as described in Fig 3 and Fig 4. Deflections of bridges in 10,000 days after exploitation are shown in Fig 6.

Calculation results show the signification difference in deflection between four models: CEB-FIP 1990, CEB-FIP 2010, AASHTO and ACI, especially in the middle span. In which, the CEB-FIP 1990 model gives the smallest calculation value of deflection (7,63mm), while the AASHTO model gives the maximum estimation which is four-time bigger (26,02mm).

4 Conclusions and Discussion

From the above result of shrinkage and creep calculation by each model and its application in long-term deflection of 3-span continuous prestressed concrete bridge, there are following conclusions have been drawn.

Despite the importance of creep and shrinkage, their expressions in different standards are significantly different.

For long term deflection of three-span solid slab prestressed concrete bridge cast in situ, different models may lead to difference in the estimated result, four-time bigger in comparison of ASSTHO model to CEB-FIP 1990 model. This conclusion is similar to what have been investigated on long term deflection of cantilever bridge [5].

It is necessary to have a better model of creep and shrinkage for practical application in designing of prestressed concrete bridge.

Acknowledgements

This research is funded by University of Transport and Communications (UTC) under grant number T2022-CT-010TĐ.

References

[1]- Bob, C., About the Causes of the Koror Bridge Collapse. Open J. Safety Sci. Technol., 4(2) (2014) 119-126. doi:10.4236/ojsst.2014.42013.

[2]- Bažant, Z.P., Q. Yu, G.-H. Li, G.J. Klein, V. Křístek, and Z.P. Bazant, Excessive deflections of record-span prestressed box girder: Lessons learned from the collapse of the Koror-Babeldaob Bridge in Palau. ACI Conc. Int., 32 (2010) 44-52.

[3]- European standard EN 12620:2013, Aggregates for concrete, in European committee for standardization. (2013).

[4]- Křístek, V., L. Vráblík, and V. Hrdoušek, Causes of long-term deflections of large-span pre-stressed concrete box girders and recommendations on how to avoid these. Trans. Trans. Sci., 1(3) (2017) 97-102. doi:10.5507/tots.2008.014.

[5]- Bob, C., About the Causes of the Koror Bridge Collapse. Open J. Safety Sci. Technol., 4(2) (2014) 8. doi:10.4236/ojsst.2014.42013.

[6]- AASHTO, Bridge design Specifications. 6th Edition ed.: American Association of State Highway and Transportation Officials, 2012.

[7]- CEB-FIP, Model Code 1990, Comite EURO-International du Beton. (1992).

[8]- CEB-FIP, Model Code 2010, Comite EURO-International du Beton. (2012).

[9]- Rhodes, J.A. and D. Carreira, ACI 209R-9, Prediction of creep, shrinkage, and temperature effects in concrete structures, ACI Committee 209. (1982).