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Analysis and Selection of Creep Models for Concrete Structures in Tropical Regions

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Abstract. There are a number of models for predicting concrete creep behaviour such as models proposed in RILEM - B3, EN 19921-1-:2004, SABS 0100-1; MC -10… The existence of these different models for concrete creep analysis is resulted from the dependence of creep characteristics on many factors, including internal factors and external factors. Each model is therefore suitable for a specific condition. This study aims to analyse the creep models of concrete given in some concrete standards. Characteristics and scope of application of each model were clarified. These models were then applied to calculate concrete creep based experimental results on long-term deformation of reinforced concrete column sample in Viet Nam. A method of determining concrete creep coefficients was also established in this study. Compare the concrete creep coefficient calculated from the above methods and the results of the experiment to select the expected model. The results show that models ACI 209-2008 and EN 1992-2004 were the most suitable ones for applying in Vietnamese conditions. We recommend using these models for creep analysis of concrete in Viet Nam and in tropical climate.

1. Introduction

Concrete creep is defined as deformation of structure under sustained load. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending. When a load is applied to concrete, it experiences an instantaneous elastic strain which develops into creep strain if the load is sustained.

Concrete creep Coefficient is an important input in many analyses and calculations of reinforced concrete structures. Currently, the concrete creep coefficient has been used by many models in the world to predict the calculation, but each model has its own characteristics, therefore it is only suitable in certain cases and conditions [1,2]. This is a basic knowledge of concrete creep and it was also mentioned by Zdenllk P. Basant in [3].

Due to the characteristics of the concrete creep, it is dependent on many inputs, including internal factors, external factors, and factors showing the nature of aggregate and input materials. , ... [3,4]. Therefore, a lot of models have been proposed to predict variables from variables, concrete creep coefficients have been proposed.

It is important to evaluate the concrete creep coefficients high precision as it is the main input in analysis of reinforced concrete structures. Such as computational analysis in the design of Pre-stressed structure, calculation of long-term deflection of beams, calculation of long-term axial deformation of compressive structures,... [5–8]. Therefore, it is important to select a few predictive models for calculating concrete creep variables to suit the geographical conditions of each region.

Because the characteristics of concrete creeps depend on many factors, including internal and external factors (temperature, humidity), many researchers have proposed many models. And each of these models is only suited to a number of specific conditions. The study [9,10] has concluded that: The shrinkage strains of RPC predicted by the ACI 209-82 model, B3 model, and GL 2000 model are significantly greater than the corresponding experimental results. However, the shrinkage strains of RPC predicted by the CEB FIP 90 model are significantly smaller than the experimental results. Moreover, all four models overestimate the creep strain of RPC. Thus, these models cannot be used for predicting the shrinkage and creep of RPC. Another study [11], “The effect of Cement Class on Creep and Shrinkage of Concrete According to the European Code for Calculation of the Slender Columns”. This this paper gives a short description of the mechanism for the elasticity and shrinkage of concrete according to the European Standard, Eurocode-2. This study has focused on the effect of the cement layer on creep parameters and shrinkage, calculated for slender reinforced concrete columns. Another study concluded that [12]: “Comparing the EN 1992-1 with the DIN 1045-1, it can be concluded from the figures and formulas that the EN 1992-1 does not consider the intensity effects. The German Code still considers the intensity effects, making the creep coefficient values more comparable to the EN 1992-1. Large, partial security; at the time, the EN 1992-1 and the DIN 1045-1 to find different formulas, so that the DIN 1045-1 calculated creep coefficient values are smaller than the EN 1992-1, as shown in the example, is not safe”.

Vietnam, Laos and Cambodia are countries in the tropical northern hemisphere belt and the region is strongly influenced by the Asian seasonal regime. It is a high heat base, the annual average temperature is always above 200C, sunny, total sunshine hours from 1400 to 3000 hours / year. Humidity varies strongly from 30 to over 80%. With this climate feature, it has a great impact on the behavior of concrete materials, which is a direct factor the concrete creep and shrinkage concrete. At the same time, he Geology of this region is characterized by a large variety of aggregate aggregates such as stone, sand, cement, etc., and environmental humidity varies greatly between regions and seasons.

This study provides an analysis of concrete creep coefficients of existing models (ACI 209-2008, GL2000, RILEM - B3, EN 19921-1-: 2004, SABS 0100- 1; MC -10, etc) [13–15] and from the experimental results on long-term deformation of reinforced concrete columns over 2 years. From that, the research team suggested some application models for calculating concrete creep coefficients that are more suitable in tropical conditions.

2. Concrete creep coefficients models of Codes

2.1. *ACI 209 –2008,* [14]

$\varphi(t, \tau_o)$*:* Concrete creep coefficient depends on time, is determined by the following formula:

$$\varphi(t, t_o) = \frac{(t-\tau_o)^{\alpha}}{d+(t-\tau_o)^{\alpha}} \cdot \varphi_u \cdot \gamma_{\tau 0,c} . \gamma_{RH,c} . \gamma_{s,c} \cdot \gamma_{\psi,c} . \gamma_{\alpha a,c} . \gamma_{\frac{v}{s},c} \quad (1)$$

Where:

$\varphi_u = 2.35$ is ultimate (in time) creep coefficient.

$\gamma_{\tau 0,c} . \gamma_{RH,c} \cdot \gamma_{s,c} \cdot \gamma_{\psi,c} \cdot \gamma_{\alpha a,c} . \gamma_{\frac{v}{s},c}$ Respectively are loading age coefficients; environmental humidity; slump; stone content in the mixture; amount of gas in the mixture; element size.

Formula (1) was established and it is based on Branson's formula proposed in 1971. In which d and α are constants take consider to influence of shape and size of components, determined:

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When shapes and dimensions are determined, they are taken: α =1 and $d = 26e^{0.0142(\frac{V}{S})}$. the value V/S is the ratio of the element volume / area of the element to which it is exposed to ambient conditions.

For other cases may be taken: α = 0.6, d = 10. Initial elastic concrete modulus (τ_0):

$$E_{cm\tau o} = 0.043\gamma_c^{1.5}.\sqrt{f_{cmt0}} \quad (2)$$

and

$$f_{cmt} = \frac{t}{a+b.t} f_{cm28} \quad (3)$$

In formulas (2) and (3), γ_c is Specific gravity of concrete (kg/m^3), f_{cmto}: concrete mean compressive cylinder strength, MPa or psi at the time of loading (MPa), f_{cm28}: concrete mean compressive cylinder strength, MPa or psi, at 28 days (MPa), t is the age of concrete at time t.
The constants a and b determined depend on the type of cement and the curing conditions (Table 1).

Table 1. Constant values *a* and *b* used in equation (3)

Type of cement	Moisturizing		Curing with steam	
	a	*b*	*a*	*b*
I	4.0	0.85	1.0	0.95
III	2.3	0.92	0.7	0.98

2.2. EN 19921-1-:2004 [16]

Concrete creep coefficient depends on time is

$$\varphi(t,\tau_o) = \varphi_o\beta_c(t,\tau_o) \quad (4)$$

$\beta_c(t,\tau_o)$: The time-dependent parameter takes consider to the development of creep with time,
With φ_o is nominal creep coefficient, be determined: $\varphi_o = \varphi_{RH}\beta(f_{cm28})\beta(\tau_o)$

$$= \begin{cases} 1 + \left[\frac{1-RH/100}{0.1\sqrt[3]{h}}\right] for\ f_{cm28} \le 35MPa \\ \left[1 + \left[\frac{1-RH/100}{0.1\sqrt[3]{h}}\right] x\alpha_1\right] x\alpha_2\ với\ f_{cm28} > 35MPa \end{cases} \quad (5)$$

$$\alpha_1 = \left[\frac{35}{f_{cm28}}\right]^{0.7} \quad (6)$$

$$\alpha_2 = \left[\frac{35}{f_{cm28}}\right]^{0.2} \quad (7)$$

$$\beta(f_{cm28}) = \frac{16.8}{\sqrt{f_{cm28}}} \quad (8)$$

$$\beta(\tau_o) = \frac{1}{0.1+[\tau_o]^{0.2}} \quad (9)$$

$\beta_c(t,\tau_o)$ is creep developed depend on time defined as follows:

$$\beta_c(t,\tau_o) = \left[\frac{(t-\tau_o)}{\beta_H+(t-\tau_o)}\right]^{0.3} \quad (10)$$

With:

$$\beta_H = \begin{cases} 1.5[1 + (0.012RH)^{18}]h + 250 \leq 1500\ for\ f_{cm} \leq 35MPa \\ 1.5[1 + (0.012RH)^{18}]h + 250\alpha_3 \leq 1500\alpha_3\ for\ f_{cm} \geq 35MPa \end{cases} \quad (11)$$

$$\alpha_3 = \left[\frac{35}{f_{cm28}}\right]^{0.5} \quad (12)$$

2.3. Russian Concrete Institute [17]
Function of Creep:

$$\varepsilon(t, \tau_o) = \frac{1}{E_c(\tau_o)} + C(t, \tau_o) = \frac{1 + \varphi(t, \tau_o)}{E_c(\tau_o)} \quad (13)$$

$C(t, \tau_o)$: Specific creep at time *t* produced by a sustained unit stress first applied at τ_0, It is calculated as follows:

$$C(t, \tau_o) = \frac{1}{E_c(\tau_o)} - \frac{1}{E_c(t)} + C(\infty, 28).\Omega(\tau_o).f(t - \tau_o) \quad (14)$$

And

$$C(\infty, 28) = C^N(\infty, 28).\xi_{2c}.\xi_{3c} \quad (15)$$

$\xi_{2c}.\xi_{3c}$: They are parameters and look up the table in the standard. These parameters are dependent on humidity, element size.
And with

$$C^N(\infty, 28) = k_c\left[\frac{W + v}{B + 4,0}\right] \quad (16)$$

Where:
W, v are respectively the density (by volume) of water and air in the concrete mixture; *B* (MPa) is durable concrete level; k_c is dimensionless factor; $k_c = 15.5\ 10^{-6}$ for fresh concrete and concrete with a small aggregate of quartz stone.
In equation (16): $v = 30.0\ l/m^3$ is when there is no actual data; for concrete with plasticizer admixture, including super plasticizer, it is equal to 10 l/m^3. And when there are additives to create air, it is taken according to real data.
Function: $\Omega(\tau_o)$, $f(t - \tau_o)$:

$$\Omega(\tau_o) = c + d.e^{-\gamma\tau_o} \quad (17)$$

$$f(t - \tau_o) = 1 - k.e^{-\gamma_1.(t - \tau_o)} \quad (18)$$

Where, c=0.50; k=0.80.
Parameters γ and γ_1 according to Table 2; d according to Table 2 & 3:

Table 2. For values of γ and γ_1

Parameters (1/day)	Values of γ and γ_1 with of M_0, m^{-1}			
	≤ 10	20	40	≥ 60
γ	0.008	0.012	0.016	0.020
γ_1	0.004	0.006	0.008	0.010

Table 3. The values of *d*

Parameters	t_0, day	Values of *d* with of M_0, m^{-1} is			
		≤ 10	20	40	≥ 60
d	≤ 7	0.752	0.842	0.942	1.052
	≥ 28	0.625	0.700	0.785	0.875

In addition to the above models, we can also study other models, for example B3; GL2000; MC-10.

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2.4. Reviews
The concrete creep and shrinkage are long-term deformations dependent on time. The graph of these two deformations is curves (function of the curve, nonlinear function). Therefore, in order to represent the correct form of curves, the proposed models have chosen an appropriate form of function. For example, the models ACI 209 - 2008 and EN 1992: 2004 use rational functions, while the model of the Russian Concrete Institute chooses an irrational function. These are the basic functions in math and they are often used to represent curves in computational models.

The model of ACI - 209 has used 13 input parameters, including: Humidity, slump, content of stone in the mixture, gas content in the support, size of components, age of loading, concrete strength, elastic modulus, Cement type, concrete curing form, curing time of concrete, cement ratio - Water and Stone - Cement. All of these parameters reflect the influence of its turn on concrete creep and shrinkage. These are easy to get, easy to define and easy to calculate because they are all in the form of constants. Except for the ratio of the volume ratio of the gas in the mixture is difficult to determine, and the accuracy is less. This model is used for environmental humid teams from 40% to 80% [14].

The EN 1992: 2004 also included many influencing factors such as: humidity; concrete strength; modulus; loading time; curing time; type of cement; component size; ratio of water – cement, etc. The other thing about this model is that the moisture input to the model is not in the form of a constant but in the form of expression (βH, βRH)[15]. The concrete creep coefficients are calculated with two levels according to the average compressive strength, which is less than 35 MPa and greater than 35 MPa. This has shown that the concrete creep coefficient value the difference between high strength concrete and normal concrete. For moisture factor, this model is similar to ACI 209.

In the Russian Concrete Institute posed model concrete creep. This model has also included a calculation model with 13 inputs, namely: humidity; concrete strength; modulus; loading time; curing time; type of cement; component size; water-cement ratio; density of water and air in the mixture; concrete type. Similar to ACI 209, the model provided by the Russian Concrete Institute included air ratio in the mix. Another way is to put the influencing factors of the Russian Concrete Institute in the form of lookup tables, so it is more suitable for many cases. Unlike the two above models, the model proposed by the Russian Concrete Institute has taken into consideration the type of stone (granite macadam, gravel, river basalt). This has very few other suggested models to mention. The humidity in this model has also been introduced from 40% - 100% [17].

Through analysis of the concrete creep coefficient of models we noticed: Predictive models concrete creep (concrete creep coefficients) have included many influencing factors (shape, size, material properties, environmental humidity, quality of stone, cement, curing time, time of loading). The difference in these models is that each model is built in different environmental and local conditions, each model introduces different impact factors, the way to put those factors is also different [8,10,11,13,18].

In the above models, ACI - 209 used a lot of inputs (13 factors), including: Humidity, slump, content of stone in the mixture, gas content in the support, size of components, age of loading, concrete strength, elastic modulus, Cement type, concrete curing form, curing time for concrete, the ratio of cement - Water, Stone - Cement. All the parameters here reflect on its influence from the concrete creep. All the parameters here reflect on its influence from the concrete creep and are easily defined parameters to include in the calculation. For environmental humidity, the model ACI 209 uses from 40% to 100% [14], this is also consistent with the environment humidity of Vietnam.

3. Analysis and determination of concrete creep coefficients through results of long-term deformation tests of RC columns

3.1. Established expression to determine Creep coefficients from the experiment
Experimental model of RC columns with long-term load is shown in Figure 1. Reinforced concrete columns bearing load with time, P (constant), outside diameter D, inner diameter from the long core is

D1, height of column L. An analysis with the same model was also used by Samra [6]. In this experiment, the influence of spiral reinforcement was considered. There have been similar experiments, which means that the impact of the stirrups is also mentioned [19–21].

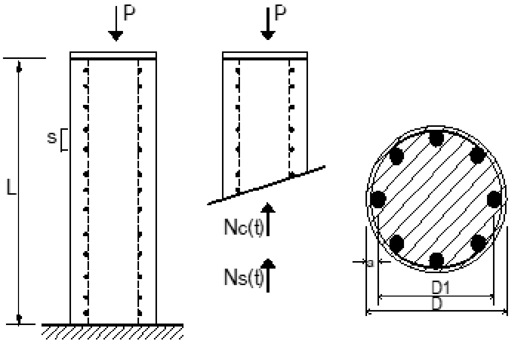

Figure 1. Reinforced concrete columns with long-term axial load

Equation of the equilibrium condition of force:

$$\Phi(t,\tau_o) = \varphi_o \beta_c(t,\tau_o) \tag{19}$$

$$P = N_c(t) + N_s(t) = \sigma_c(t).A_c + \sigma_s(t).A_s + 2.\nu.\frac{f_{sti}.\sigma_{sti}(t)}{s.R}.A_{cen}$$

Where, $A_{cen} = 3.14x\left(\frac{D_1}{2}\right)^2$.

Equation of axial deformation:

$$\varepsilon_c(t) = \varepsilon_s(t) = \varepsilon(t) \tag{20}$$

Where

$$\varepsilon_đ(t) = 2.\nu\varepsilon_c(t) = 2.\nu\varepsilon(t) \tag{21}$$

The law is expressed in the following equation [6].

$$\varepsilon(t) = \frac{\sigma_c(\tau_0)}{E_c(\tau_0)}(1+\varphi_t) - \frac{\Delta\sigma_c(t)}{E_c(\tau_0)}(1+0.8\varphi_t) \tag{22}$$

And

$$\sigma_s(t) = \varepsilon(t).E_s; \quad \sigma_đ(t) = \nu\varepsilon(t).E_s \tag{23}$$

It has been accepted for concrete that the horizontal expansion coefficient in elastic working state and the magnetic state variable are equal and set to 0.2, expressed as:

$$\nu_e(t) = \nu_{cr}(t) = 0.2 \tag{24}$$

For convenience of presenting the problem, in the equation we set as follows:

$$A_{sti} = \frac{2.\nu.f_{sti}.A_{cen}}{s.R} \tag{25}$$

Where f_{sti} is the cross-sectional area of stirrup; *s* is the distance between 2 stirrups. Equation (19) can be rewritten as follows:

$$P = N_c(t) + N_s(t) = \sigma_c(t).A_c + \sigma_s(t).A_s + \sigma_{sti}(t).A_{sti} \tag{26}$$

Combining (24) and (21), it becomes:

$$\sigma_{sti}(t) = \varepsilon_{sti}.E_s = \nu\varepsilon(t).E_s = 0.2.\varepsilon(t).E_s \tag{27}$$

By transforming the expressions (26):

$$\sigma_c(t) = \frac{P - \varepsilon(t).E_s.A_s - 0.2.\varepsilon(t).E_s.A_{sti}}{A_c} \tag{28}$$

Transforming the expression (22) will determine the concrete creep coefficient as follows:

$$\varphi_t = \frac{\varepsilon_{(t)}.E_c(\tau_0) - \sigma_c(\tau_0) + \Delta\sigma_c(t)}{\sigma_c(\tau_0) - 0.8\Delta\sigma_c(t)} \tag{29}$$

$$\Delta\sigma_c(t) = \sigma_c(\tau_0) - \sigma_c(t) \tag{30}$$

Where

$$\sigma_c(\tau_0) = \frac{P}{A_c + n_0.A_s + n_0.A_{sti}};\quad n_0 = \frac{E_s}{E_c(\tau_0)}$$

Replace (28) with (30) identifiable is $\Delta\sigma_c(t)$ and $\Delta\sigma_c(t)$ into (29) will determine the concrete creep coefficient, $\varphi(t)$.

3.2. Application of formula (Eq.29) to experimental results

Experiments on measuring long-term deformation of RC columns subjected to a concentric axial load were conducted, as shown as Figure 2 [5,6,22,23], and give results presented in [24]. Load-bearing samples with test loads, P_{tn} = 17.0 (Ton), loading samples at 7 days of age, curing time of 7 days. Experimental data results were obtained with duration of 600 days [10].

The detailed input values of the experiment are [24]: P = 170 000 (KN), E_0 = 35800 (MPa), s = 50.0 mm, R = 75-15 = 60 mm (Outer coating is 15 mm), $A_{cen} = 3{,}14.60^2 = 11304\ mm^2$. Experimental model is shown in Figure 4.

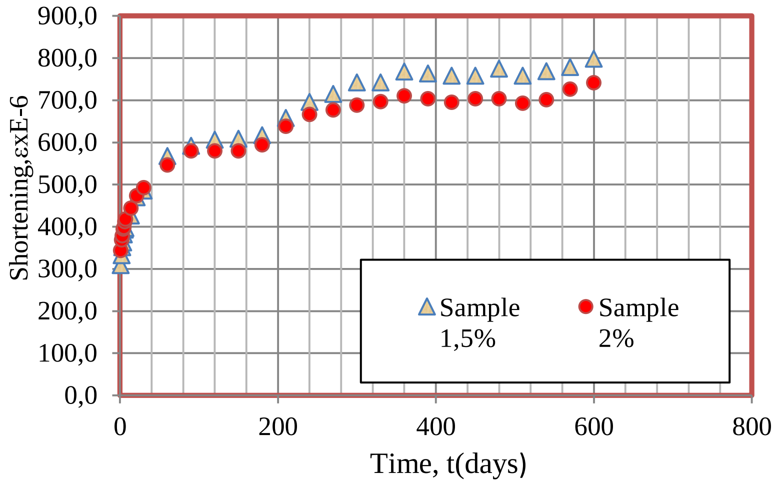

Figure 2. The shortening of column with reinforcement ratio 1.5% and 2.0%, [24]

This experiment has been divided into 2 groups: loading and unloading. The experimental model was built with long-term RC columns with constant load over time (The same as the model in Figure 1). During the experiment, the ambient temperature and humidity were monitored, recorded from time to time recording of deformation [5,22–25].

This experiment has been completed and it has been presented in detail at [24]. The following is a result of the axial strain measurement of the reinforced concrete column shown in Figure 2 and the unload samples are shown in Figure 3 below.

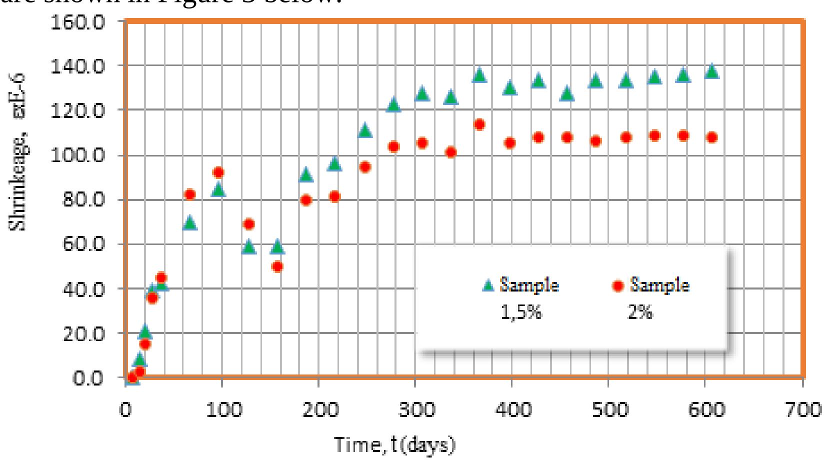

Figure 3. Shrinkage of the column without applied load [24]

Table 4 shows the concrete creep coefficients according to the experimental results and using equation (28).

Table 4. The result of concrete creep coefficient

t(days)	7	14	21	28	35	60	90	120	150	180	210	240
φ(t)	0.00	0.74	0.80	0.90	0.97	1.16	1.27	1.42	1.49	1.38	1.64	1.75
t(days)	270	300	330	360	390	420	450	480	510	540	570	600
φ(t)	1.79	1.86	1.90	1.90	1.92	1.88	1.90	1.92	1.85	1.90	2.02	2.12

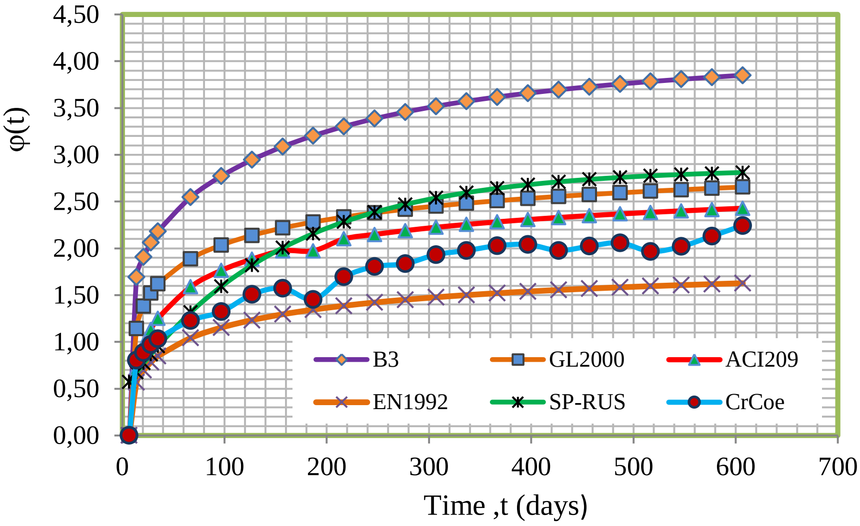

Figure 4. Concrete creep coefficients obtained from experiments [24] and models

From figure 4, the curves are the same, meaning they are similar (the curves of models and experiments). This shows that this result has the accuracy and reliability of the model and the experiment.

The curves of the models are homogeneous and homogeneous with the experimental curves. The curve of the B3 model is the largest and furthest from the experimental curve, followed by the curve of GL2000. The concrete creep coefficient curve from the ACI 209 and the EN1992-2004 model is closer to the concrete creep coefficient from the empirical than the curves of other models.

Groups of curves including B3, GL2000, Russian standard, and EN1992-2004 are most similar to each other and different from ACI 209 and experimental curve. The concrete creep coefficient curve of model ACI 209 is uniform and similar, closest to the curve of the experiment compared to other curves. The longer the time, the closer the two curves are to each other.

4. Conclusion

From the results of theoretical analysis, studying the models for calculating concrete creep coefficients, and from the results, the long-term deformation of reinforced concrete columns, this study has given some conclusions.

1. A formula for determining concrete creep coefficients from experiments was proposed (Eq.29), which have been built on a theoretical basis and undergone transformations.

2. Each model calculated concrete creep is suitable for a specifically defined condition, so the same input data for each model gives a different result. The model ACI - 209 has used a lot of inputs (13 parameters), and these are easy to define parameters to include in the calculation.

3. The model of ACI 209 - 2008, or EN 1992 -2004 should be used to calculate the design of

reinforced concrete structures in tropical climates like in Vietnam. These models can also be applied to other countries with similar climates, such as Lao, Cambodia, Thailand, etc (at the same latitude).

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