Sensitivity Analysis of Creep Effect Parameters Based on 175m-span Extradosed Cable-stayed Bridge

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Abstract. In order to understand the creep effect of Extradosed Bridge, the paper adopted four concrete creep calculation models recommended by Chinese, European, American and Japanese specifications, and conducted single-factor sensitivity analysis of concrete strength, ambient humidity, component theory thickness, maintenance condition and other parameters based on the calculation parameters of each model. The paper concluded the impacts of various factors on creep coefficient of concrete Extradosed Bridge, and proposed parameter impact grades. Pre-camber design of concrete Extradosed Bridge shall fully consider the humidity while performing envelope calculation. The controllable parameters during construction phase should be monitored. Wet curing or steam curing is adopted to reduce the creep effect.

1. Introduction
Extradosed Bridge combines the mechanical features of continuous rigid frame bridge and cable-stayed bridge. If the load proportion of its girder is relatively higher, it is closer to continuous rigid frame bridge. The pre-camber setting is especially important. Therefore, the later-period creep effect should be calculated rationally.

Since there are numerous calculation models of creep effect, the calculation results differ greatly; even for the same model, parameter can be selected in a large scope; there is no specific calculation method for Extradosed Bridge. Based on a 175m-span concrete Extradosed Bridge, the paper adopted four concrete creep calculation models recommended by domestic and foreign specifications, analyzed the main influencing factors of each model, and conducted single-factor sensitivity analysis of these parameters to provide some references for the design and construction of Extradosed Bridge.

The paper adopted four concrete creep calculation models(shown in tab.1) recommended by Chinese JTG D62-2004, European CEB-FIB90, American ACI209 and Japanese specification to conduct the study.

| Specification                  | Calculation Model of Concrete Creep Effect |
|-------------------------------|--------------------------------------------|
| European CEB-FIB90 [10]       | $\phi(t, \tau) = \phi_0 \beta_c (t, \tau) = \varphi_{EH} \beta_{m} \beta_c (t, \tau)$ |
| Japanese specification [12]   | $\phi(t, t_0) = \phi_{d0} \beta_d (t-t_0) + \phi_{f0} [\beta_f (t) - \beta_f (t_0)]$ |

Table 1. The formula of creep effect
2. Factors Affecting Creep Effect

The impact factors considered by the four concrete creep effect calculation models adopted in the paper are different. Generally, they considered more external factors and less internal factors. Detailed summaries are as shown in Tab.2.

The four models adopt the same parameters in the calculation: Strength grade of concrete is C50, ambient humidity is 70%, theoretical thickness of the member is 500mm, cement factor is 5 (Portland cement), void fraction (i.e., air content as stated in Chinese specification) is 1%, collapsibility 150mm, moist curing, content of fine aggregate (i.e., the sand rate as stated in Chinese specification) is 36% and cement content specification (i.e. 500kg/m$^3$). It can be seen from the calculation results graph 2 that the development situations of the creep coefficients of the four models are roughly the same, developing quicker in the first 1000 days and presenting slow increase later. They tend to be straight lines along with the time. In terms of the final value of concrete creep, the calculation value specified in Japanese specification is larger, and the creep coefficient specified in ACI specification is smaller.

| Factor                        | Chinese 04 standard model | CEB-FIP 90 model | American ACI209 model | Japanese specification |
|-------------------------------|---------------------------|------------------|-----------------------|------------------------|
| Internal factors              |                           |                  |                       |                        |
| 28D compressive strength of   | √                         | √                | √                     | √                      |
| concrete                      |                           |                  |                       |                        |
| Air content                   | -                         | -                | √                     | -                      |
| Cement content                | -                         | -                | √                     | -                      |
| Cement type                   | √                         | √                | -                     | √                      |
| Concrete intensity            | -                         | -                | √                     | -                      |
| Proportion of fine aggregate  | -                         | -                | √                     | -                      |
| in aggregate                  |                           |                  |                       |                        |
| Collapsibility                | -                         | -                | √                     | -                      |
| Concrete age of loading       | √                         | √                | √                     | √                      |
| Applied stress                | √                         | √                | √                     | √                      |
| Curing method                 | √                         | √                | √                     | √                      |
| Load duration                 | √                         | √                | √                     | √                      |
| Sectional dimensions of the   | √                         | √                | √                     | √                      |
| member                        |                           |                  |                       |                        |
3. Sensitivity Analysis of the Main Parameters

3.1. A subsection Chinese 04 standard model

The model is recommended by JTG D62-2004 Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts currently in effect. It adopts the defining mode of European CEB-FIP90 model. Factors considered by the calculation formula include: Concrete strength grade, ambient humidity, theoretical thickness of the component and cement type coefficient.

Analysis results of calculating parameters are as shown in Fig. 3. Ambient humidity is the most important factor affecting creep effect. Creep coefficient decreases with the increasing of humidity. The creep coefficient decreases between 6%~8% while the humidity increasing every 10%. Secondly, for the impact of theoretical thickness and strength grade, creep coefficient will decrease with the increasing of theoretical thickness. The impact of theoretical thickness on creep coefficient is mainly within 5 years after building the bridge. The impact is relatively lower 5 years later; after the theoretical thickness increases to over 800mm, it almost has no impact on creep coefficient. The creep coefficient will decrease by about 5% while increasing each grade of concrete intensity; Chinese 04 standard cement type coefficient is from 5 (general cement) to 8 (high-strength cement) which has no impact on the calculation results of creep coefficient.

| Parameter                      | 28D elasticity modulus of concrete | Ambient humidity | Ambient Temperature: |
|--------------------------------|-----------------------------------|-----------------|----------------------|

A) Different concrete strength
B) Different humidity
C) Different Theoretical thickness

Figure 3. Creep coefficient comparison of 04 specification recommended model

3.2. CEB-FIP90 model

Parameters considered by CEB-FIP 90 calculation formula include: Concrete pressure resistance level, ambient humidity, theoretical thickness of the component and cement type.

The grade of CEB concrete doesn’t concrete strength grade as specified in Chinese specification. It is determined by 150 mm / 300 mm cylinder. Therefore, the 28d compressive strength is about 8MPa higher than that specified in Chinese specification (Calculated and reviewed according to reference data). The 28d compressive strength adopted in the study is input according to Chinese specification.

The analysis results of calculated parameters are as shown in Fig.3. It is mostly affected by ambient humidity. Creep coefficient will decrease with the increasing of ambient humidity. Detailed analysis is as shown in Table 3. Secondly, it is affected by the theoretical thickness and strength grade. The creep coefficient decreases with the increasing of theoretical thickness. Provided that the theoretical thickness increases from 300mm to 800mm, the creep coefficient will decrease from 1.94 to 1.72 correspondingly. When the theoretical thickness exceeds 800mm, the impact of theoretical thickness on creep is very small. The creep coefficient will decrease with the increasing of concrete intensity. The creep coefficient will decrease by about 5% while increasing each grade of concrete intensity.
Cement type affects the creep coefficient as well. The creep coefficient of fast hardening and high strength cement is 7% lower than that of quick-setting cement, and the creep coefficient of standard and quick-setting cement is 7% lower than that of slow-setting cement.

A) Different concrete strength

B) Different humidity

C) Different Theoretical thickness

D) The type of cement

Figure 4. Creep coefficient comparison of CEB-FIP90 model

Table 3. Creep coefficient changes by different humidity conditions - CEB-FIP90 model

| Time (d) | 40% Change ratio | 50% Change ratio | 60% Change ratio | 70% Change ratio | 80% Change ratio | 90% Change ratio |
|---------|------------------|------------------|------------------|------------------|------------------|------------------|
| 10      | 0.27             | 0.26             | -6%              | 0.24             | -7%              | 0.22             | -7%              | 0.20             | -8%              | 0.19             | -8%              |
| 1000    | 1.66             | 1.56             | -6%              | 1.45             | -7%              | 1.35             | -7%              | 1.25             | -8%              | 1.14             | -8%              |
| 10000   | 2.10             | 1.97             | -6%              | 1.84             | -7%              | 1.71             | -7%              | 1.57             | -8%              | 1.44             | -8%              |

3.3. American ACI209 model

This model is a creep effect calculation model recommended by the ACI in ACI-209R-82. The creep coefficient is the multiplication product of six coefficients. Factors considered by the model calculation include: Concrete compressive strength level, ambient humidity, theoretical thickness of component, collapsibility, content of fine aggregate, void rate, curing method and content of cement. Detailed analysis is as shown in Fig. 5.

Void rate specified in ACI specification refers to the content of air in fresh concrete. If the content of air is within 1%-7%, it will not affect the result. Chinese specification JGJ55-2000 Specification for mix proportion design of ordinary concrete stipulates that the air content in concrete should not exceed 7%. Therefore, this factor is not analyzed herein. Previous calculations have shown that changes of strength grade from C30 to C65, theoretical thickness from 300mm to 900mm and cement content from 3.5KN/m3 to 6.5KN/m3 have no effect on the super long-term concrete creep.

Ambient humidity is the major impact factor of creep coefficient. The creep coefficient will decrease with the increasing of ambient humidity. The creep coefficient will decrease within 7%–9% while the humidity increasing every 10%; if the humidity increases from 40% to 90%, the final value of creep will decrease from 1.66 to 1.11 correspondingly. Creep coefficient will increase with the
increasing of collapsibility. The creep coefficient will increase within 3%~4% while the humidity increasing every 15mm; if the collapsibility increases from 105mm to 195mm, the final value of creep will increase from 1.15 to 1.4 correspondingly.

According to concrete proportion situation of actual engineering, the fine aggregate content can be selected from 30% to 48%. Creep coefficient will increase with the increasing of fine aggregate content. The creep coefficient will increase 1% while the fine aggregate content increasing every 3%; if the fine aggregate content increases from 30% to 48%, the final value of creep coefficient will increase from 1.27 to 1.33 correspondingly. The creep effect of steam curing concrete is smaller, 4% lower than that of wet curing concrete.

**Figure 5. creep coefficient comparison of ACI209**

### 3.4. Japanese specification model

Japanese specification states that creep coefficient is affected by numerous factors, and should be determined by reference to previous test results at creep coefficient designing. In case of no test result available, the specification presents a calculation formula as shown in Table 1, mainly considering the following factors: concrete pressure resistance level, ambient humidity, theoretical thickness of the component and cement type. Among them, the calculation method of theoretical thickness is different from that in Chinese and European specifications. For the same section, the calculation result calculated following Japanese specification is lower than that calculated following Chinese specification. Specific to the model, the research scope is: 200mm-800mm.

The analysis results of calculated parameters are as shown in Fig.6. Creep coefficient is mostly affected by ambient humidity. Creep coefficient will decrease with the increasing of ambient humidity. Detailed analysis is as shown in Table 4. Creep coefficient decreases with the increasing of theoretical thickness; the impact of theoretical thickness on creep coefficient in year 1-3 years is significant, while the impact on the final value of creep coefficient is small; when the theoretical thickness increases from 200mm to 600mm, creep coefficient will decrease by about 10% in the early stage, and the final value of creep will decrease from 2.42 to 2.14; when the theoretical thickness is greater than 600mm, it has no effect on creep coefficient. The creep effect of high-early-strength cement in the early stage is
higher (about 25%) than that of ordinary cement. The difference on final value, however, is small (2.19 and 2.14 respectively). When the strength variation is between C30 and C65, it will not affect creep coefficient.

Table 4. Creep coefficient changes by different humidity conditions

| Time   | 50%  | 60%  | Change ratio | 70%  | 80%  | Change ratio | 90%  | Change ratio |
|--------|------|------|--------------|------|------|--------------|------|--------------|
| 10     | 0.14 | 0.13 | -6%          | 0.12 | -5%  | 0.12         | -2%  | 0.12         | 0%   |
| 51     | 0.57 | 0.49 | -13%         | 0.43 | -13% | 0.38         | -11% | 0.34         | -9%  |
| 1000   | 1.87 | 1.63 | -13%         | 1.41 | -14% | 1.21         | -14% | 1.04         | -14% |
| 10000  | 2.84 | 2.49 | -12%         | 2.16 | -13% | 1.84         | -15% | 1.53         | -17% |

4. Conclusion
On the basis of single factor sensitivity analysis of creep coefficient, in order to understand the impact of each parameter on creep model more intuitively, the paper selected the most common intervals for each affecting parameter: Humidity 50%-90%, theoretical thickness 500-900mm (100-500 stipulated in Japanese specification), strength C40-C60, collapsibility 150mm-210mm and cement content 420-45kg/m3. And then, the impact of each parameter on creep coefficient has been divided into five levels: Level I-for the most important impact factors: While changing for one grade, generally the impact on creep coefficient will exceed 15%; level II-relatively important impact factors: While changing for one grade, the impact on creep coefficient is between 8%-15%; level III-general impact factors: While changing for one grade, the impact on creep coefficient is between 3%-8%; level IV-less impacting factors: While changing for one grade, generally the impact on creep coefficient is lower than 3%; level V-No impact.

Table 5. Parameter classification grade table

| Parameter range           | Calculation Model | Chinese 04 standard model | CEB-FIP 90 model | American ACI209 model | Japanese specification |
|---------------------------|-------------------|---------------------------|------------------|------------------------|------------------------|
| Concrete strength grade C40-C60 | III               | III                       | V                | V                      |
| theoretical thickness 100-500 | II                | II                        | V                | II                     |
| theoretical thickness 500-900 | III               | III                       | V                | --                     |
| humidity 50%-80%          | III               | III                       | III              | I                      |
| humidity 80%-90%          | III               | II                        | II               | I                      |
| Cement type               | V                 | III                       | --               | I                      |
| Air content               | --                | --                        | V                | --                     |
| Cement content            | --                | --                        | V                | --                     |
| Proportion of fine aggregate | --              | --                        | III              | --                     |
| Collapsibility            | --                | --                        | III              | --                     |
| Curing method             | --                | --                        | III              | I                      |

Based on the calculation of the creep effect of a 175m-span concrete Extradosed Bridge, the paper concluded as follows:

1) For ambient humidity, the design specification generally takes the local annual average humidity. However, this factor is a comparatively sensitive calculating parameter for creep effect. Therefore, the maximum and minimum humidity of local environment can be used for envelope calculation, and the pre-camber setting will be more sensitive.

2) Controllable factors in construction phase, including design of construction mixture ratio, water cement ratio, collapsibility, curing conditions etc., shall be fully considered. We should carry out
construction monitoring properly, deal with problems if any and perform repeating survey on bridges regularly in the operation stage.

3) The impact of concrete curing method on creep Can't be ignored. In the process of construction, wet curing should be adopted. The method of steam curing can be adopted for important projects.

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References
[1] PAN Zuan-feng, MENG Shao-ping. Three-level Experimental Approach for Creep and Shrinkage of High-strength High-performance Concrete. Engineering Structures, 2016,120:23-36.
[2] LIU Mu-yu, LI Qian, Ultra-long Time Performance of Steel-concrete Composite Continuous Beam in Hong Kong-Zhuhai Macao Bridge with Creep and Shrinkage of Concrete Slabs. China Journal of Highway and Transport.2016(12):61-69.
[3] HAN Wei-wei, LÜ Yi-gang. Experimental research on prediction model of concrete shrinkage and creep. Journal of Central South University (Science and Technology) 2016(10):3515-3522.
[4] Shi Jingxian Ran Zhihong. Effect of Concrete shrinkage and creep effect on the Cable Force of Extradosed Cable-stayed Bridge. Highway engineering.2014(01).
[5] XIAO Yu-de, YIN Yong-gao . Numerical simulation of the component mechanical change of the prestressed concrete bridge due to shrink and creep[J]. Journal of Hefei University of Technology.2003(02)
[6] M. Schlaich. Erection of Cable-Stayed Bridges Having Composite Decks with Precast Concrete Slabs. JOURNAL OF BRIDGE ENGINEERING. 2001.
[7] Traffic Standards of the People 's Republic of China. Code for design of highway reinforced concrete and prestressed concrete bridge and culvert[S]. Beijing: China Communications Press. JTGD62-2004.
[8] CEB Europe International Concrete Committee. 1990 CEB-FIP mode specification (concrete structure). China Academy of Building Research.1991
[9] ACI Committee 209. Prediction of Creep. Shrinkage and Temperature Effects in Concrete Structures. Manual of concrete practice. Part1. America Concrete Institute. 209R1992.
[10] Japan Society of Civil Engineers Concrete Committee. Explanation of Design Code of Concrete Structure. Southwest Jiaotong University Press.1990.