Comparison of calculation methods of creep coefficients and shrinkage strains based on four specifications

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Abstract. Formulas for calculating the creep coefficient are compared by using four specifications, in which the main influences on creep are taken into account. Nevertheless there are still a little bit differences among them. For example, the type of cement and curing temperature are not considered in the Chinese Code referred to "Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts (JTG D62_2004)", which in following text is abbreviated as Bridge Specification. Besides for comparison a numerical example was carried out.

1. Introduction.
Creep refers to the deformation of concrete that grows with time while the load remains the same. The creep coefficient refers to the ratio of the concrete creep amplitude value to the instantaneous compressive strain of the concrete. Concrete shrinkage refers to the shrinkage of the volume that occurs during the initial setting or hardening of concrete. The object will undergo a certain deformation under the action of external force, and the degree of deformation is called strain. Concrete shrinkage strain refers to the strain generated when concrete shrinks. The main factors affecting the creep of concrete are as follows [2]:

1) Ambient humidity, temperature
Shrinkage and creep will decrease as the ambient humidity increases, and the relative humidity will have a greater impact on the early creep.
2) Component size
The degree of moisture and temperature of the medium affecting the internal water overflow of the concrete is determined by the size of the member. As the surface ratio of the member increases, the shrinkage and creep of the concrete are small. But when the concrete and the environment reach a moisture balance, the size effect will disappear.
3) Duration of load and age of concrete at loading
When the loading age, stress and other conditions are unchanged, the concrete strength develops faster and the creep becomes smaller.
4) Type of cement
In general, the variety or chemical composition of cement has no effect on the shrinkage of concrete, but the expansion cement can reduce the shrinkage on the concrete to a large extent. Cement also affects creep by affecting concrete strength.
5) Concrete strength
The age of loading has a very significant effect on concrete creep. The smaller loading age gets the greater creep of the concrete. When other conditions remain the same, the creep increases as the loading duration increases.

2. Comparison of Creep Coefficients and Shrinkage Strain Calculation Formulas of Four Norms

This paper deals with the "Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts (JTGD62_2004)"[1], "DIN 1045-1 Concrete, reinforced and prestressed concrete structures - Part 1: Design and construction "[4], "European norms (EN1992_1_1)" [3], and the "US Concrete Structure Design Code (CEB_FIP Model Code 1990)"[2] and analyze and compare the formulas of the creep coefficient in these four specifications.

2.1. Comparison of formulas. [1 3]

The formulas of the four specifications are detailed in Table 4.

2.2. Calculation example.

2.2.1. Respectively calculate the creep coefficient according to the formula of each specification. Set a component, concrete strength class is C30, $h_0=100$, loading time $t_0=30$, concrete age $t=58$, humidity RH = 50%. The calculation results are shown in Table1 and Table 2.

| $\alpha=1$ | JTGD-62 2004[1] | CEB-FIP Model Code 1990[2] | EN 1992-1[3] | DIN 1045-1[4] |
|------------|-----------------|-----------------|-------------|--------------|
| $\beta_{ht}$ | 400.0152 | 400.0152 | 389.9440 | 400.0152 |
| $\beta_{(t-t_0)}$ | 0.4413 | 0.4413 | 0.4444 | 0.4413 |
| $\beta_{(t_0)}$ | 0.5062 | 0.4648 | 0.4648 | 0.4648 |
| $\beta_{(f_{cm})}$ | 2.9628 | 2.7188 | 2.7253 | 2.7253 |
| $\varphi_{nt}$ | 2.0870 | 2.0870 | 1.9841 | 1.9841 |
| $\varphi(t, t_0)$ | 1.3813 | 1.1639 | 1.1169 | 1.1091 |

| $\alpha=1$ | JTGD-62 2004[1] | CEB-FIP Model Code 1990[2] | EN 1992-1[3] | DIN 1045-1[4] |
|------------|-----------------|-----------------|-------------|--------------|
| $\beta_{ht}$ | 400.0152 | 400.0152 | 389.9440 | 400.0152 |
| $\beta_{(t-t_0)}$ | 0.4413 | 0.4413 | 0.4444 | 0.4413 |
| $\beta_{(t_0)}$ | 0.5062 | 0.4696 | 0.4696 | 0.4696 |
| $\beta_{(f_{cm})}$ | 2.9628 | 2.7188 | 2.7253 | 2.7253 |
| $\varphi_{nt}$ | 2.0870 | 2.0870 | 1.9841 | 1.9841 |
| $\varphi(t, t_0)$ | 1.3813 | 1.1760 | 1.1285 | 1.1206 |

2.2.2. Calculate the creep coefficient according to the map method shown in Figure 1. [1 4] Figure 1 is a diagram of the creep coefficient formula based on JTGD-62 2004[1]. The usage of the graphics is shown in Figure 1. This article describes the method in detail through an example. The graphics algorithm simplifies the calculation process a lot.

As shown in Fig. 1,① $t_0 = 30$ is known, the horizontal line and the figure get a point; ② Connect this point to get a straight line with the origin; ③ In the graph on the right, an intersection is obtained by $h_0=100$ and $f_{cm}=32MPa$; ④ Crossing the intersection point to make a horizontal line intersection
to obtain a straight line at one point; ⑤ The value obtained by doing this perpendicular to the vertical line.

Table 3. The conditions remain unchanged and are calculated using the map method shown in Figure 1.

| $\beta_t$ | $\beta_t(t-t_0)$ | $\varphi(t_0, t)$ | $\varphi(t, t_0)$ |
|-----------|------------------|-------------------|------------------|
| 400.0152  | 0.4413           | 3.300             | 1.4245           |

Table 4. The formulas of the creep coefficient in four specifications.

| Specification | Formula                                                                                                                                 |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------|
| JTGD-62 2004[[1]] | $\varphi(t, t_0) = \varphi_0 \beta(t - t_0)$                                                                                           |
| CEB-FIP Model Code 1990[[2]] | $\varphi(t, t_0) = \varphi_0 \beta(t - t_0)$                                                                                           |
| EN 1992-1[[3]] | $\varphi(t, t_0) = \varphi_0 \beta(t - t_0)$                                                                                           |
| DIN 1045-1[[4]] | $\varphi(t, t_0) = \varphi_0 \beta(t - t_0)$                                                                                           |

Note: $\alpha=1$ for cement class S; $\alpha=0$ for cement class N; $\alpha=1$ for cement class R

Where:
- $\varphi_{RH}$ is a factor to allow for the effect of relative humidity on the notional creep coefficient
- $RH$ is the relative humidity of the ambient environment in %
- $f_{cm}$ is the mean compressive strength of concrete in MPa at the age of 28 days
- $\beta(f_{cm})$ is a factor to allow for the effect of concrete strength on the notional creep coefficient
- $\beta(t_0)$ is a factor to allow for the effect of concrete age at loading on the notional creep coefficient
- $h_0$ is the notional size of the member in mm where: $h_0 = 2A_c / u$
- $A_c$ is the cross-sectional area
- $u$ is the perimeter of the member in contact with the atmosphere
- $\beta(t - t_0)$ is a coefficient to describe the development of creep with time after loading, and may be estimated using the following expression
- $t$ is the age of concrete in days at the moment considered
- $t_0$ is the age of concrete in days at the moment considered

$\beta_{\alpha}=\frac{16.8f_{cm}}{1500(1 + (2RH/RH_{0})^{\alpha}h, \leq 250)}$ when $f_{cm} \leq 35MPa$, $\alpha_1 - \alpha_2$
\( \beta_u \) is a coefficient depending on the relative humidity (RH in %) and the notional member size \\
\( \alpha_{1/2/3} \) are coefficients to consider the influence of the concrete strength \\
\( t_{0\text{,eff}} \) is the temperature adjusted age of concrete at loading in days

![Diagram](image)

**Figure 1.** Method for determining the creep coefficient for concrete under normal environmental conditions

**Note:**
- intersection point between lines 4 and 5 can also be above point 1
- for \( t_0 > 100 \) it is sufficiently accurate to assume \( t_0 = 100 \) (and use the tangent line)

### 3. Conclusion

1) It can be seen from the formula that the JTGD-62 2004\(^1\) does not consider the influence of concrete condensing speed, but only reduces the concrete strength. It can be seen from the calculated value of the example. For the all kinds of concrete, the creep coefficient calculated by the JTGD-62 2004\(^1\) is the largest and is safe.

2) Comparing the EN 1992-1\(^3\) with the DIN 1045-1\(^4\), it can be concluded from the figures and formulas that the EN 1992-1\(^3\) 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\(^3\). Large, partial security; at the time, the EN 1992-1\(^3\) and the DIN 1045-1\(^4\) to find different formulas, so that the DIN 1045-1\(^4\) calculated creep coefficient values are smaller than the EN 1992-1\(^3\), as shown in the example, is not safe.

3) Only the influence of concrete setting and hardening time is considered in the CEB-FIP Model Code 1990\(^2\) so it is more unsafe than the other three specifications.

4) Compared with the other four specifications, the JTGD-62 2004\(^1\)is biased towards safety. It should be revised on the basis of data to make it more suitable for our country's built environment and economy.
5) We can know that from Figure 1 when the concrete strength increases the velocity of the creep coefficients grow more slowly. And that shows the influence of the strength of concrete is smaller along with the increasing of concrete strength.

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