3.1.8 Creep

3.1.8.1 *General*

The creep strain at any time (t) caused by a constant sustained stress (σ_o) shall be calculated from—

$$\varepsilon_{cc} = \varphi_{cc}\sigma_o / E_c \qquad \ldots 3.1.8.1$$

where

E_c = mean modulus of elasticity of the concrete at 28 days

φ_{cc} = design creep coefficient at time (t) determined in accordance with Clause 3.1.8.3

3.1.8.2 *Basic creep coefficient*

The basic creep coefficient of concrete ($\varphi_{cc.b}$) is the mean value of the ratio of final creep strain to elastic strain for a specimen loaded at 28 days under a constant stress of $0.4 f'_c$ and shall be—

(a) determined from measurements on similar local concrete; or

(b) determined by tests in accordance with AS 1012.16; or

(c) taken as the value given in Table 3.1.8.2.

TABLE 3.1.8.2

BASIC CREEP COEFFICENT

Characteristic strength (f'_c), MPa	**20**	**25**	**32**	**40**	**50**	**65**	**80**	**100**
Basic creep coefficient ($\varphi_{cc.b}$)	5.2	4.2	3.4	2.8	2.4	2.0	1.7	1.5

3.1.8.3 *Design creep coefficient*

The design creep coefficient for concrete at any time, t, (φ_{cc}) shall be determined from the basic creep coefficient ($\varphi_{cc.b}$) by any accepted mathematical model for creep behaviour, calibrated such that $\varphi_{cc.b}$ is also predicted by the chosen model.

In the absence of more accurate methods, φ_{cc} at any time shall be taken as—

$$\varphi_{cc} = k_2\, k_3\, k_4\, k_5\, k_6\, \varphi_{cc.b} \qquad \ldots 3.1.8.3$$

where k_2 is obtained from Figure 3.1.8.3 and k_3 depends on the age of the concrete (τ) at the time of loading (in days) and is given by the following:

k_3 = $2.7/[1 + \log(\tau)]$ for $\tau \geq 1$ day

k_4 = 0.70 for an arid environment, 0.65 for an interior environment, 0.60 for a temperate inland environment and 0.50 for a tropical or near-coastal or coastal environment

k_5 = a modification factor for high strength concrete, which shall be taken as—

k_5 = 1.0 when $f'_c \leq 50$ MPa; or

k_5 = $(2.0 - \alpha_3) - 0.02(1.0 - \alpha_3) f'_c$ when 50 MPa $< f'_c \leq 100$ MPa

the factor $\alpha_3 = 0.7/(k_4\alpha_2)$; and α_2 is defined in Figure 3.1.8.3

k_6 accounts for the non-linear creep that develops at sustained stress levels in excess of $0.45 f_{cmi}$:

$k_6 = 1.0$ when $\sigma_o \leq 0.45 f_{cmi}$

$k_6 = e^{1.5\left(\frac{\sigma_o}{f_{cmi}} - 0.45\right)}$ when $\sigma_o > 0.45 f_{cmi}$

Consideration shall be given to the fact that φ_{cc} has a range of approximately ±30%. This range is likely to be exceeded if the concrete member is subjected to prolonged periods of temperature in excess of 25°C.

The final design creep coefficients (φ^*_{cc}) (after 30 years) predicted by this method for concrete first loaded at 28 days with a sustained stress level not exceeding $0.45 f_{cmi}$ are given in Table 3.1.8.3.

NOTE: The compressive stress in concrete caused by the permanent effects (including prestress) should not exceed $0.45 f_{cmi}$.

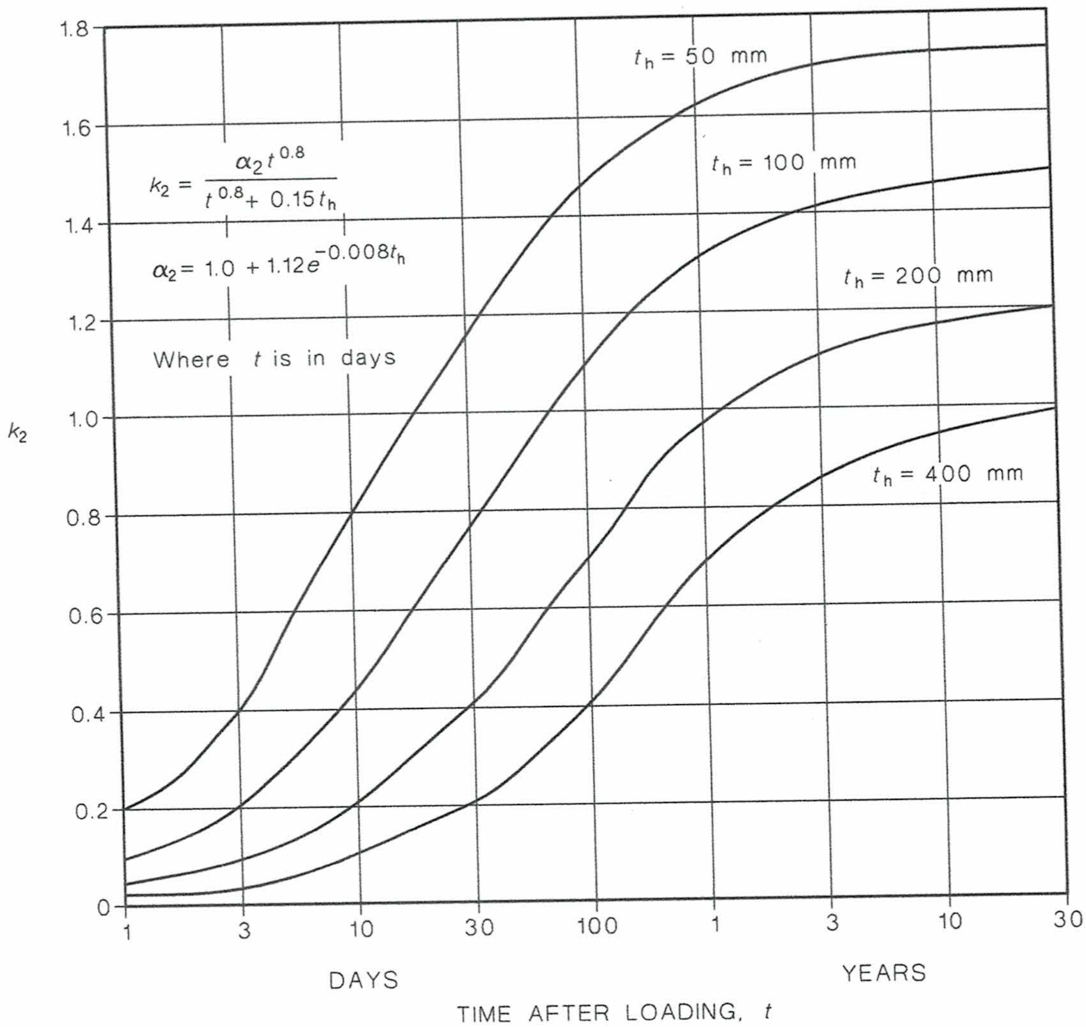

FIGURE 3.1.8.3 COEFFICIENT (k_2)

TABLE 3.1.8.3

FINAL CREEP COEFFICIENTS (AFTER 30 YEARS) FOR CONCRETE FIRST LOADED AT 28 DAYS

f'_c (MPa)	Final creep coefficient (ϕ^*_{cc})											
	Arid environment			Interior environment			Temperate inland environment			Tropical, near-coastal and coastal environment		
	t_h (mm)			t_h (mm)			t_h (mm)			t_h (mm)		
	100	200	400	100	200	400	100	200	400	100	200	400
25	4.82	3.90	3.27	4.48	3.62	3.03	4.13	3.34	2.80	3.44	2.78	2.33
32	3.90	3.15	2.64	3.62	2.93	2.46	3.34	2.70	2.27	2.79	2.25	1.90
40	3.21	2.60	2.18	2.98	2.41	2.02	2.75	2.23	1.87	2.30	1.86	1.56
50	2.75	2.23	1.89	2.56	2.07	1.73	2.36	1.91	1.60	1.97	1.59	1.33
65	2.07	1.75	1.53	1.95	1.66	1.46	1.84	1.59	1.38	1.61	1.38	1.23
80	1.56	1.40	1.29	1.50	1.36	1.25	1.45	1.32	1.22	1.33	1.23	1.14
100	1.15	1.14	1.11	1.15	1.14	1.11	1.15	1.14	1.11	1.15	1.14	1.11

3.2 PROPERTIES OF REINFORCEMENT

3.2.1 Strength and ductility

For the purposes of design, the characteristic yield strength of reinforcement (f_{sy}) shall be taken as not greater than the value specified in Table 3.2.1 for the type of reinforcement (see also Clause 17.2.1.1).

The ductility of the reinforcement shall be characterized by its uniform strain (ε_{su}) and tensile-to-yield stress ratio and designated as low (L) or normal (N) Ductility Class as given in Table 3.2.1. For the purposes of design, values of these parameters for each Ductility Class shall conform with AS/NZS 4671.

NOTE: In AS/NZS 4671, ε_{su} is referred to as A_{gt}, expressed as a percentage, and f_{sy} is referred to as R_e.

ANNEX B (Informative)

Creep and shrinkage strain

B.1 Basic equations for determining the creep coefficient

(1) The creep coefficient $\varphi(t,t_0)$ may be calculated from:

$$\varphi(t,t_0) = \varphi_0 \cdot \beta_c(t,t_0) \qquad \text{(B.1)}$$

where:

φ_0 is the notional creep coefficient and may be estimated from:

$$\varphi_0 = \varphi_{RH} \cdot \beta(f_{cm}) \cdot \beta(t_0) \qquad \text{(B.2)}$$

φ_{RH} is a factor to allow for the effect of relative humidity on the notional creep coefficient:

$$\varphi_{RH} = 1 + \frac{1 - RH/100}{0{,}1 \cdot \sqrt[3]{h_0}} \quad \text{for } f_{cm} \leq 35 \text{ MPa} \qquad \text{(B.3a)}$$

$$\varphi_{RH} = \left[1 + \frac{1 - RH/100}{0{,}1 \cdot \sqrt[3]{h_0}} \cdot \alpha_1\right] \cdot \alpha_2 \quad \text{for } f_{cm} > 35 \text{ MPa} \qquad \text{(B.3b)}$$

RH is the relative humidity of the ambient environment in %

$\beta(f_{cm})$ is a factor to allow for the effect of concrete strength on the notional creep coefficient:

$$\beta(f_{cm}) = \frac{16{,}8}{\sqrt{f_{cm}}} \qquad \text{(B.4)}$$

f_{cm} is the mean compressive strength of concrete in MPa at the age of 28 days

$\beta(t_0)$ is a factor to allow for the effect of concrete age at loading on the notional creep coefficient:

$$\beta(t_0) = \frac{1}{(0{,}1 + t_0^{0{,}20})} \qquad \text{(B.5)}$$

h_0 is the notional size of the member in mm where:

$$h_0 = \frac{2A_c}{u} \qquad \text{(B.6)}$$

A_c is the cross-sectional area

u is the perimeter of the member in contact with the atmosphere

$\beta_c(t,t_0)$ is a coefficient to describe the development of creep with time after loading, and may be estimated using the following Expression:

$$\beta_c(t,t_0) = \left[\frac{(t-t_0)}{(\beta_H + t - t_0)}\right]^{0,3} \tag{B.7}$$

t is the age of concrete in days at the moment considered

t_0 is the age of concrete at loading in days

$t - t_0$ is the non-adjusted duration of loading in days

β_H is a coefficient depending on the relative humidity (RH in %) and the notional member size (h_0 in mm). It may be estimated from:

$$\beta_H = 1,5\,[1 + (0,012\,RH)^{18}]\,h_0 + 250 \le 1500 \quad \text{for } f_{cm} \le 35 \tag{B.8a}$$

$$\beta_H = 1,5\,[1 + (0,012\,RH)^{18}]\,h_0 + 250\,\alpha_3 \le 1500\,\alpha_3 \quad \text{for } f_{cm} \ge 35 \tag{B.8b}$$

$\alpha_{1/2/3}$ are coefficients to consider the influence of the concrete strength:

$$\alpha_1 = \left[\frac{35}{f_{cm}}\right]^{0,7} \quad \alpha_2 = \left[\frac{35}{f_{cm}}\right]^{0,2} \quad \alpha_3 = \left[\frac{35}{f_{cm}}\right]^{0,5} \tag{B.8c}$$

(2) The effect of type of cement (see 3.1.2 (6)) on the creep coefficient of concrete may be taken into account by modifying the age of loading t_0 in Expression (B.5) according to the following Expression:

$$t_0 = t_{0,T} \cdot \left(\frac{9}{2 + t_{0,T}^{\,1,2}} + 1\right)^{\alpha} \ge 0,5 \tag{B.9}$$

where:

$t_{0,T}$ is the temperature adjusted age of concrete at loading in days adjusted according to Expression (B.10)

α is a power which depends on type of cement
= -1 for cement Class S
= 0 for cement Class N
= 1 for cement Class R

(3) The effect of elevated or reduced temperatures within the range 0 – 80°C on the maturity of concrete may be taken into account by adjusting the concrete age according to the following Expression:

$$t_T = \sum_{i=1}^{n} e^{-(4000/[273+T(\Delta t_i)]-13,65)} \cdot \Delta t_i \tag{B.10}$$

where:

t_T is the temperature adjusted concrete age which replaces t in the corresponding equations

$T(\Delta t_i)$ is the temperature in °C during the time period Δt_i

Δt_i is the number of days where a temperature T prevails.

The mean coefficient of variation of the above predicted creep data, deduced from a computerised data bank of laboratory test results, is of the order of 20%.

The values of $\varphi(t,t_0)$ given above should be associated with the tangent modulus E_c.
When a less accurate estimate is considered satisfactory, the values given in Figure 3.1 of 3.1.4 may be adopted for creep of concrete at 70 years.

B.2 Basic equations for determining the drying shrinkage strain

(1) The basic drying shrinkage strain $\varepsilon_{cd,0}$ is calculated from

$$\varepsilon_{cd,0} = 0,85\left[(220 + 110\cdot\alpha_{ds1})\cdot\exp\left(-\alpha_{ds2}\cdot\frac{f_{cm}}{f_{cmo}}\right)\right]\cdot 10^{-6}\cdot\beta_{RH} \qquad \text{(B.11)}$$

$$\beta_{RH} = 1,55\left[1-\left(\frac{RH}{RH_0}\right)^3\right] \qquad \text{(B.12)}$$

where:

f_{cm} is the mean compressive strength (MPa)
f_{cmo} = 10 Mpa
α_{ds1} is a coefficient which depends on the type of cement (see 3.1.2 (6))
= 3 for cement Class *S*
= 4 for cement Class *N*
= 6 for cement Class *R*
α_{ds2} is a coefficient which depends on the type of cement
= 0,13 for cement Class *S*
= 0,12 for cement Class *N*
= 0,11 for cement Class *R*
RH is the ambient relative humidity (%)
RH_0 = 100%.

Note: exp{ } has the same meaning as $e^{(\;)}$