SECTION 11 Lightweight aggregate concrete structures

The following clauses of EN 1992-1-1 apply.

11.1 (1)P	*11.3.2 (1)*	*11.3.7 (1)*	*11.6.4.2 (1)*
11.1.1 (1)P	*11.3.2 (2)*	*11.4.1 (1)*	*11.6.4.2 (2)*
11.1.1 (2)P	*11.3.3 (1)*	*11.4.2 (1)P*	*11.6.5 (1)*
11.1.1 (3)	*11.3.3 (2)*	*11.5.1*	*11.6.6 (1)*
11.1.1 (4)P	*11.3.3 (3)*	*11.6.1 (1)*	*11.7 (1)P*
11.1.2 (1)P	*11.3.4 (1)*	*11.6.1 (2)*	*11.8.1 (1)*
11.2 (1)P	*11.3.5 (1)P*	*11.6.2 (1)*	*11.8.2 (1)*
11.3.1 (1)P	*11.3.5 (2)P*	*11.6.3.1 (1)*	*11.10 (1)P*
11.3.1 (2)	*11.3.6 (1)*	*11.6.4.1 (1)*	
11.3.1 (3)	*11.3.6 (2)*	*11.6.4.1 (2)*	

11.9 Detailing of members and particular rules

(101) The diameter of bars embedded in LWAC should not normally exceed 32 mm. For LWAC bundles of bars should not consist of more than two bars and the equivalent diameter should not exceed 45 mm.

NOTE The use of bundled bars may be restricted by the National Annex.

SECTION 12 Plain and lightly reinforced concrete structures

All the clauses of EN 1992-1-1 apply.

SECTION 113 Design for the execution stages

113.1 General

(101) For bridges built in stages, the design should take account of the construction procedure in the following circumstances:

a) Where forces, other than those produced on the completed structure, occur in any structural section during the phases of construction (e.g. deck erection by incremental launching, piers of bridges built by balanced cantilever).

b) Where redistribution of forces due to rheological effects is originated by changes to the structural arrangement during the construction process (e.g. continuous bridges built span by span on falsework or by cantilever).

c) Where redistribution of stresses due to rheological effects is originated by changes to structural sections during the construction process (e.g. decks consisting of precast beams and an insitu slab).

d) Where the erection or casting sequence may have an influence on: the stability of the structure during construction, the forces in the completed structure, or the geometry of the completed structure.

(102) For structures in which any of the circumstances described in paragraphs (101) a) to d) apply, the serviceability limit states and ultimate limit states should be verified at construction stages.

(103) For structures in which the circumstances described in paragraphs (101) b) or c) apply, long term values of forces or stresses should determined from an analysis of redistribution effects. Step by step or approximate methods may be used in these calculations.

(104) For structures in which the circumstances described in paragraph (101) d) apply, erection and casting sequences/procedures should be indicated on drawings or detailed in a construction procedure document.

113.2 Actions during execution

(101) The actions to be taken into account during execution are given in EN 1991-1-6 and annexes.

(102) For the ultimate limit state verification of structural equilibrium for segmental bridges built by balanced cantilever, unbalanced wind pressure should be considered. An uplift or horizontal pressure of at least x N/m^2 acting on one of the cantilevers should be considered.

NOTE The x value to be used in a Country may be found in its National Annex. The recommended value of x is 200 N/m^2.

(103) For verification of ultimate limit states in bridges built by in-situ balanced cantilever, an accidental action arising from a fall of formwork should be considered. The action should include for dynamic effects. The fall may occur in any construction stage. (traveller movement, casting, etc.)

(104) For balanced cantilever construction with precast segments, an accidental fall of one segment should be taken into account.

(105) For incrementally launched decks imposed deformations should be taken into account.

113.3 Verification criteria

113.3.1 Ultimate limit states

(101) See EN 1992-2 section 6.

113.3.2 Serviceability limit states

(101) The verifications for the execution stage should be the same as those for the completed structure, with the following exceptions.

(102) Serviceability criteria for the completed structure need not be applied to intermediate execution stages, provided that durability and final appearance of the completed structure are not affected (e.g. deformations).

(103) Even for bridges or elements of bridges in which the limit-state of decompression is checked under the quasi-permanent or frequent combination of actions on the completed structure, tensile stresses less than $k.f_{ctm}(t)$ under the quasi-permanent combination of actions during execution are permitted.

NOTE The value of k to be used in a Country may be found in its National Annex. The recommended value of k is 1,0.

(104) For bridges or elements of bridges in which the limit-state of cracking is checked under frequent combination on the completed structure, the limit state of cracking should be verified under the quasi-permanent combination of actions during execution.

ANNEX A
(informative)

Modification of partial factors for materials

All the clauses of EN 1992-1-1 apply.

ANNEX B
(informative)

Creep and shrinkage strain

The following clauses of EN 1992-1-1 apply for ordinary concrete, except for particular thick sections (see below).

B.1(1)
B.1(2)
B.1(3)
B.2(1)

Section B.103 specifically applies to high performance concrete, made with Class R cements, of strength greater than C50/60 with or without silica fume. In general, the methods given in Section B.103 are preferred to those given in EN 1992-1-1 for the concretes referred to above and for thick members, in which the kinetics of basic creep and drying creep are quite different. It should be noted that the guidance in this Annex has been verified by site trials and measurements. For background information reference can be made to the following:

Le Roy, R., De Larrard, F., Pons, G. (1996) The AFREM code type model for creep and shrinkage of high performance concrete.

Toutlemonde, F., De Larrard, F., Brazillier, D. (2002) Structural application of HPC: a survey of recent research in France.

Le Roy, R., Cussac, J. M., Martin, O. (1999) Structures sensitive to creep :from laboratory experimentation to structural design - The case of the Avignon high-speed rail viaduct.

B.100 General

(101) This Annex may be used for calculating creep and shrinkage, including development with time. However, typical experimental values can exhibit a scatter of ± 30 % around the values of creep and shrinkage predicted in accordance with this Annex. Where greater accuracy is required due to the structural sensitivity to creep and/or shrinkage, an experimental assessment of these effects and of the development of delayed strains with time should be undertaken. Section B.104 includes guidelines for the experimental determination of creep and shrinkage coefficients.

(102) For High Strength Concrete (f_{ck} > 50MPa) an alternative approach to the evaluation of creep and shrinkage is given in Section B.103. The alternative approach takes account of the effect of adding silica fume and significantly improves the precision of the prediction.

(103) Furthermore, the expressions for creep in Sections B.1 and B.103 are valid when the the mean value of the concrete cylinder strength at the time of loading $f_{cm}(t_0)$ is greater that 0,6f_{cm} ($f_{cm}(t_0)$ > 0,6 f_{cm}).

When concrete is to be loaded at earlier ages, with significant strength development at the beginning of the loading period, specific determination of the creep coefficient should be undertaken. This should be based on an experimental approach and the determination of a mathematical expression for creep should be based on the guidelines included in Section B.104.

(104) Creep and shrinkage formulae and experimental determinations are based on data collected over limited time periods. Extrapolating such results for very long-term evaluations (e.g. one hundred years) results in the introduction of additional errors associated with the mathematical expressions used for the extrapolation. When safety would be increased by overestimation of delayed strains, and when it is relevant in the project, the creep and shrinkage predicted on the basis of the formulae or experimental determinations should be multiplied by a safety factor, as indicated in Section B.105.

B.103 High Strength Concrete

(101) In the case of high strength concrete (HSC), namely for concrete strength classes greater than or equal to C55/67, the model described in this clause should be used to obtain better consistency with experimental data when the information required to utilise the model is available. For HSC without silica fume, creep is generally greater than predicted in the average expressions of Section B.1. Formulae proposed in this section should not be used without verification when the aggregate fraction is lower than 67 %, which may be more frequently the case for self-consolidating concrete.

(102) The model makes a distinction between strains occurring in sealed concrete and additional deformation due to drying. Two expressions for shrinkage and two for creep, are given in this clause. The time-dependant strain components are:

— autogeneous shrinkage,

— drying shrinkage,

— basic creep,

— drying creep.

This distinguishes phenomena which are governed by different physical mechanisms. The autogeneous shrinkage is related to the hydration process whereas the drying shrinkage, due to humidity exchanges, is associated with the structure's environment.

(103) Specific formulae are given for silica-fume concrete (SFC). For the purpose of this clause, SFC is considered as concrete containing an amount of silica fume of at least 5 % of the cementitious content by weight.

B.103.1 Autogeneous shrinkage

(101) The hydration rate governs the kinetics of autogeneous shrinkage. Therefore the hardening rate controls the progress of the phenomenon. The ratio $f_{cm}(t)/f_{ck}$, known as the maturity of young concrete, is taken as the main variable before 28 days. Shrinkage appears to be negligible for maturity less than 0,1. For ages beyond 28 days, the variable governing the evolution of autogeneous shrinkage is time.

The model for evaluation of autogeneous shrinkage is as follows:

— for t < 28 days,

$$\text{if } \frac{f_{cm}(t)}{f_{ck}} < 0{,}1 \quad \varepsilon_{ca}(t) = 0 \tag{B.113}$$

$$\text{if } \frac{f_{cm}(t)}{f_{ck}} \geq 0{,}1 \quad \varepsilon_{ca}(t) = (f_{ck} - 20)\left(2{,}2\frac{f_{cm}(t)}{f_{ck}} - 0{,}2\right)10^{-6} \tag{B.114}$$

where ε_{ca} is the autogeneous shrinkage occurring between setting and time t. In cases where this strength $f_{cm}(t)$ is not known, it can be evaluated in accordance with 3.1.2(6) of EN 1992-1-1.

— for $t \geq 28$ days,

$$\varepsilon_{ca}(t) = (f_{ck} - 20)\,[2{,}8 - 1{,}1 \exp(-t/96)]\,10^{-6} \tag{B.115}$$

Therefore, according to this model, 97 % of total autogeneous shrinkage has occurred after 3 months.

B.103.2 Drying shrinkage

The formulae in 103.2 apply to RH values of up to 80 %.

(101) The expression for drying shrinkage is as follows:

$$\varepsilon_{cd}(t) = \frac{K(f_{ck})\left[72 \exp(-0{,}046 f_{ck}) + 75 - RH\right](t - t_s)10^{-6}}{(t - t_s) + \beta_{cd} h_0^{\,2}} \tag{B.116}$$

with: $K(f_{ck}) = 18$ if $f_{ck} \leq 55$ MPa

$K(f_{ck}) = 30 - 0{,}21 f_{ck}$ if $f_{ck} > 55$ MPa.

$$\beta_{cd} = \begin{pmatrix} 0{,}007 & \text{for silica-fume concrete} \\ 0{,}021 & \text{for non silica-fume concrete} \end{pmatrix}$$

B.103.3 Creep

The formulae in 103.3 apply to RH values of up to 80%.

(101) The delayed stress dependent strain, $\varepsilon_{cc}(t,t_0)$, i.e. the sum of basic and drying creep, can be calculated by the following expression:

$$\varepsilon_{cc}(t,t_0) = \frac{\sigma(t_0)}{E_c}\left[\varphi_b(t,t_0) + \varphi_d(t,t_0)\right] \tag{B.117}$$

B.103.4 Basic creep

(101) The final basic creep coefficient of silica fume concrete has been found to depend on the strength at loading $f_{cm}(t_0)$. Furthermore, the younger the concrete at loading, the faster the deformation. However this tendency has not been observed for non silica-fume concrete. For this material, the creep coefficient is assumed to remain constant at a mean value of 1,4. The kinetics term is therefore a function of the maturity, expressed by the quantity $f_{cm}(t)/f_{ck}$. The equation is:

$$\varphi_b(t,t_0) = \varphi_{b0} \frac{\sqrt{t - t_0}}{\left[\sqrt{t - t_0} + \beta_{bc}\right]} \tag{B.118}$$

with:

$$\varphi_{b0} = \begin{cases} \dfrac{3{,}6}{f_{cm}(t_0)^{0{,}37}} & \text{for silica} - \text{fume concrete} \\ 1{,}4 & \text{for non silica} - \text{fume concrete} \end{cases} \tag{B.119}$$

and

$$\beta_{bc} = \begin{cases} 0{,}37\exp\left(2{,}8\dfrac{f_{cm}(t_0)}{f_{ck}}\right) & \text{for silica} - \text{fume concrete} \\ 0{,}4\exp\left(3{,}1\dfrac{f_{cm}(t_0)}{f_{ck}}\right) & \text{for non silica} - \text{fume concrete} \end{cases} \tag{B.120}$$

B.103.5 Drying creep

The formulae in 103.5 apply to RH values of up to 80%.

(101) The drying creep, which is very low for silica fume concrete, is evaluated with reference to the drying shrinkage occurring during the same period. The drying creep coefficient may be expressed by the following simplified equation:

$$\varphi_d(t, t_0) = \varphi_{d0}\,[\varepsilon_{cd}(t) - \varepsilon_{cd}(t_0)] \tag{B.121}$$

with:

$$\varphi_{d0} = \begin{cases} 1\,000 & \text{for silica - fume concrete} \\ 3\,200 & \text{for non silica - fume concrete} \end{cases}$$

B.104 Experimental identification procedure

(101) In order to evaluate delayed strains with greater precision, it may be necessary to identify the parameters included in the models describing creep and shrinkage from experimental measurements. The following procedure, based on the experimental determination of coefficients altering the formulae of Section B.103, may be used.

(102) Experimental data may be obtained from appropriate shrinkage and creep tests both in autogeneous and drying conditions. The measurements should be obtained under controlled conditions and recorded for at least 6 months.

B.104.1 Autogeneous shrinkage

(101) The autogeneous shrinkage model has to be separated in to two parts.

— for $t < 28$ days,

$$\text{if } \frac{f_{cm}(t)}{f_{ck}} \geq 0{,}1 \quad \varepsilon_{ca}(t) = \beta_{ca1}(f_{ck} - 20)\left(2{,}2\frac{f_{cm}(t)}{f_{ck}} - 0{,}2\right)10^{-6} \tag{B.122}$$

The parameter β_{ca1} has to be chosen in order to minimise the sum of the squares of the differences between the model estimation and the experimental results from the beginning of the measurement to 28 days.

— for $t \geq 28$ days,

$$\varepsilon_{ca}(t) = \beta_{ca1}(f_{ck} - 20)[\beta_{ca2} - \beta_{ca3}\exp(-t/\beta_{ca4})]\ 10^{-6} \tag{B.123}$$

The other parameters β_{ca2}, β_{ca3}, β_{ca4} are then chosen using the same method.

B.104.2 Drying shrinkage

The formulae in 104.2 apply to RH values of up to 80%.

(101) The expression for drying shrinkage is as follows,

$$\varepsilon_{cd}(t) = \beta_{cd1}\frac{K(f_{ck})[72\exp(-0{,}046 f_{ck}) + 75 - RH](t - t_s)10^{-6}}{(t - t_s) + \beta_{cd2}h_0^{\ 2}} \tag{B.124}$$

The parameters β_{cd1}, β_{cd2} have to be chosen in order to minimise the sum of the squares of the differences between the model estimation and the experimental results.

B.104.3 Basic creep

(101) Two parameters have to be identified, a global one β_{cd1} which is applied to the entire expression for basic creep,

$$\varphi_b(t, t_0, f_{ck}, f_{cm}(t_0)) = \beta_{cd1}\varphi_{b0}\frac{\sqrt{t - t_0}}{\left[\sqrt{t - t_0} + \beta_{bc}\right]} \tag{B.125}$$

and β_{bc2} which is included in β_{bc}:

$$\beta_{bc} = \begin{cases} \beta_{bc2}\exp\left(2{,}8\dfrac{f_{cm}(t_0)}{f_{ck}}\right) & \text{for silica-fume concrete} \\ \beta_{bc2}\exp\left(3{,}1\dfrac{f_{cm}(t_0)}{f_{ck}}\right) & \text{for non silica-fume concrete} \end{cases} \tag{B.126}$$

These two parameters have to be determined by minimising the sum of the square of the difference between experimental results and model estimation.

B.104.4 Drying creep

The formulae in 104.4 apply to RH values of up to 80%.

(101) Only the global parameter φ_{d0} has to be identified.

$$\varphi_d(t) = \varphi_{d0}[\varepsilon_{cd}(t) - \varepsilon_{cd}(t_0)] \tag{B.127}$$

This parameter has to be determined by minimising the sum of the squares of the differences between experimental results and model estimation.

B.105 Long term delayed strain estimation

(101) Creep and shrinkage formulae and experimental determinations are based on data collected over limited periods of time. Extrapolating such results for very long-term evaluations (e.g. one hundred years) results in the introduction of additional errors associated with the mathematical expressions used for the extrapolation.

(102) The formulae given in Sections B.1, B.2 and B.103 of this Annex provide a satisfactory average estimation of delayed strains extrapolated to the long-term. However, when safety would be increased by overestimation of delayed strains, and when it is relevant in the project, the creep and shrinkage predicted on the basis of the formulae or experimental determinations should be multiplied by a safety factor.

(103) In order to take into account uncertainty regarding the real long term delayed strains in concrete (ie. uncertainty related to the validity of extrapolating mathematical formulae fitting creep and shrinkage measurements on a relatively short period), the following safety factor γ_{lt} can be included. Values for γ_{lt} are given in Table B.101

Table B.101 — Safety factor for long-term extrapolation of delayed strains, when relevant

t (age of concrete for estimating the delayed strains)	γ_{lt}
t < 1 year	1
t = 5 years	1,07
t = 10 years	1,1
t = 50 years	1,17
t = 100 years	1,20
t = 300 years	1,25

which corresponds to the following mathematical expression:

$$\begin{cases} t \leq 1\,\text{year} & \gamma_{\text{lt}} = 1 \\ t \geq 1\,\text{year} & \gamma_{\text{lt}} = 1 + 0{,}1 \log\left(\dfrac{t}{t_{\text{ref}}}\right) \quad \text{with} \quad t_{\text{ref}} = 1\,\text{year} \end{cases} \tag{B.128}$$

For concrete aged less than one year the B1, B2 and B103 expressions can be used directly, since they correspond to the duration of the experiments used for formulae calibration.

AC1 For concrete aged 1 year or more, and thus especially for long-term evaluations of deformations, the values given in by Expressions (B.1) and (B.11) of EN 1991-1-1 and by Expressions (B.116) and (B.118) of EN 1991-2 (amplitude of delayed strains at time t) have to be multiplied by γ_{lt} . AC1

ANNEX C
(normative)

Properties of reinforcement suitable for use with this Eurocode

All the clauses of EN 1992-1-1 apply.

ANNEX D
(informative)

Detailed calculation method for prestressing steel relaxation losses

All the clauses of EN 1992-1-1 apply.

Annex E
(informative)

Indicative strength classes for durability

All the clauses of EN 1992-1-1 apply.