

AS 5100.5:2017

(Incorporating Amendments up to and including No. 2)



STANDARDS
Australia



Austroads

Bridge design

Part 5: Concrete



AS 5100.5:2017

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- Australian Steel Institute
- Austroads
- Bureau of Steel Manufacturers of Australia
- Cement and Concrete Association of New Zealand
- Cement Concrete & Aggregates Australia-Cement
- Concrete Institute of Australia
- Consult Australia
- Engineers Australia
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- Steel Construction New Zealand
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Bridge design

Part 5: Concrete

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Preface

This Standard was prepared by Standards Australia Committee BD-090, Bridge Design, to supersede AS 5100.5-2004.

2 This Standard incorporates Amendment No. 1 (November 2018) and Amendment No. 2 (May 2024). The start and end of changes introduced by the Amendment are indicated in the text by tags including the Amendment number. **2**

This Standard is also designated as Austroads publication AP-G51.5-17.

The objectives of the AS(AS/NZS) 5100 series are to provide nationally acceptable requirements for—

- (a) the design of road, rail, pedestrian and cyclist path bridges;
- (b) the specific application of concrete, steel and composite construction, which embody principles that may be applied to other materials in association with relevant Standards; and
- (c) the assessment of the load capacity and rehabilitation of existing bridges.

These requirements are based on the principles of structural mechanics and knowledge of material properties, for both the conceptual and detailed design, to achieve acceptable probabilities that the bridge or associated structure being designed will not become unfit for use during its design life.

The objective of this Part (AS 5100.5) is to specify requirements for the design and construction of concrete bridges and associated structures.

Whereas earlier editions of the *Bridge design* series were essentially administered by the infrastructure owners and applied to their own inventory, an increasing number of bridges are being built under the design-construct-operate principle and being handed over to the relevant statutory authority after several years of operation. This Standard includes clauses intended to facilitate the specification to the designer of the functional requirements of the owner, to ensure the long-term performance and serviceability of the bridge and associated structure.

Significant changes to the 2004 edition of AS 5100.5 are as follows:

- (a) Increase in concrete strength specified in design rules from 65 MPa to 100 MPa. This has resulted in the review of all equations in AS 5100.5 for strength and has meant, in some instances, modification of equations such as the rectangular stress block model and inclusion of requirements for confinement to the core of columns.

The application of the Standard is further influenced by the ductility class of the steel reinforcement, with some new restrictions applying to the use of Ductility Class L reinforcement. Ductility Class N stainless steel reinforcement may now be used.

- (b) [Section 2](#) 'Design procedures actions and loads', has been revised to align with the AS/NZS 1170 series, *Structural design actions*, and additional design check methods for designers to consider has been included.
- (c) [Section 3](#) 'Design properties of materials' has been reviewed to include—
 - (i) new shrinkage equations, to address autogenous and drying shrinkage; and
 - (ii) creep calculations, to modify the creep factor by revising the k_2 and k_3 factors, including the addition of environmental and humidity factors.
- (d) Specification of additional severe exposure classifications and requirements for sulfate soils introduced in [Section 4](#) on durability.
- (e) The fire resistance criteria in [Section 5](#) 'Design for fire resistance' have been updated.
- (f) [Section 6](#) 'Methods of structural analysis' has been completely revised.

- (g) New [Section 7](#) 'Strut-and-tie modelling', which provides rules on strut-and-tie modelling, has been added.
- (h) [Clause 8.2](#) regarding design of flexural members for shear and torsion, incorporating the modified compression field theory.
- (i) [Clause 10.7.3](#) regarding confinement to the core of columns in [Section 10](#) has been significantly changed due the importance of this issue for high strength concrete.
- (j) [Section 11](#) 'Design of walls' has been revised to be more consistent with [Section 10](#) 'Design of columns for strength and serviceability'.
- (k) [Section 13](#) 'Stress development, splicing of reinforcement and coupling of tendons' has been completely revised.
- (l) New [Section 16](#) 'Steel fibre reinforced concrete' has been added.

NOTE Traditionally, the terms 'tie' and 'fitment' were used interchangeably in this Standard. The word 'tie' is now used only in the strut-and-tie analysis section while the term 'fitment' is used for units such as stirrups and ligatures that perform various functions, such as restraining the longitudinal reinforcement and resisting shear.

 [Text deleted.] 

The terms 'normative' and 'informative' have been used in this Standard to define the application of the appendix to which they apply. A 'normative' appendix is an integral part of a Standard, whereas an 'informative' appendix is only for information and guidance.

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NOTES

Australian Standard®

Bridge design

Part 5: Concrete

Section 1 Scope and general

1.1 Scope

This Standard sets out minimum requirements for the design and construction of concrete bridges and associated structures that contain reinforcement or tendons, or both. It also sets out minimum requirements for plain and steel fibre reinforced concrete (SFRC) members.

NOTE 1 It is intended that the properties and requirements for reinforcement or tendons, as set out in this Standard, may also be used for the design and construction of elements not containing concrete, for example, stress laminated timber decks.

NOTE 2 For design life of bridges covered by this Standard, see [Clause 4.1](#).

1.2 Application

This Standard applies to structures and members in which the materials conform to the following:

- (a) Concrete with—
 - (i) characteristic compressive strength at 28 days (f'_c) in the range of 25 MPa to 100 MPa; and
 - (ii) with a saturated surface-dry density in the range 2100 kg/m³ to 2800 kg/m³.
- (b) Reinforcing steel of Ductility Class N in accordance with AS/NZS 4671.

NOTE Reinforcement types with this ductility may be used without restriction, in all applications referred to in this Standard, except where Ductility Class E reinforcing steel is required.

- (c) Reinforcing steel of Ductility Class E in accordance with AS/NZS 4671.

NOTE Reinforcement types of this ductility class will need to be specially sourced to be used in Australia.

- (d) Reinforcing steel of Ductility Class L in accordance with AS/NZS 4671 shall not be used in the design for strength, except in any of the following—

- A2 (i) As lateral restraint to longitudinal reinforcement and reinforcement for confinement of the core in columns.
- (ii) As bursting reinforcement in prestressed concrete anchorages.
- (iii) Where design is validated by testing in accordance with [Appendix A](#) and compliance with any additional acceptance criteria on ductility specified by the authority. A2

Reinforcing steel of Ductility Class L in accordance with AS/NZS 4671 may be used in the design for serviceability including shrinkage, creep and temperature restraint reinforcement, deflections and crack control without restriction.

NOTE The use of Ductility Class L reinforcement is further limited by other clauses within the Standard.

- (e) Prestressing tendons complying with AS/NZS 4672.1 and tested in accordance with AS/NZS 4672.2.

- (f) Stainless steel reinforcing bar of Ductility Class N in accordance with BS 6744 with designations 1.4301, 1.4162, 1.4429, 1.4436, 14362 or 14462 to EN 10088-1.
- (g) Higher reinforcing steel grades from 500 MPa to 750 MPa meeting the requirements of [Table 3.2.1](#). For ultimate limit states the yield strength of the reinforcement shall not be taken as greater than 600 MPa unless noted otherwise.
- (h) Manufactured pozzolans in accordance with AS 3582.4 are alternative materials and subject to the provisions of [Clause 1.9](#). 

1.3 Normative references

The following are the normative documents referenced in this Standard.

NOTE Documents referenced for informative purposes are listed in the [Bibliography](#).

AS 1012.1, *Methods of testing concrete, Method 1: Sampling of fresh concrete*

AS 1012.2, *Methods of testing concrete, Method 2: Preparation of concrete mixes in the laboratory*

AS 1012.3.1, *Methods of testing concrete, Method 3.1: Determination of properties related to the consistency of concrete—Slump test*

AS 1012.3.5, *Methods of testing concrete, Method 3.5: Determination of properties related to the consistency of concrete—Slump flow, T_{500} and J-ring test*

AS 1012.4, *Methods of testing concrete, Method 4: Determination of air content of freshly mixed concrete (all methods)*

AS 1012.9, *Methods of testing concrete, Method 9: Compressive strength tests—Concrete, mortar and grout specimens*

AS 1012.10, *Methods of testing concrete, Method 10: Determination of indirect tensile strength of concrete cylinders ('Brazil' or splitting test)*

AS 1012.11, *Methods of testing concrete, Method 11: Determination of the modulus of rupture*

AS 1012.12.1, *Methods of testing concrete, Method 12.1: Determination of mass per unit volume of hardened concrete—Rapid measuring method*

AS 1012.12.2, *Methods of testing concrete, Method 12.2: Determination of mass per unit volume of hardened concrete—Water displacement method*

AS 1012.13, *Methods of testing concrete, Method 13: Determination of the drying shrinkage of concrete for samples prepared in the field or in the laboratory*

AS 1012.14, *Methods of testing concrete, Method 14: Method for securing and testing cores from hardened concrete for compressive strength*

AS 1012.16, *Methods of testing concrete, Method 16: Determination of creep of concrete cylinders in compression*

AS 1012.17, *Methods of testing concrete, Method 17: Determination of the static chord modulus of elasticity and Poisson's ratio of concrete specimens*

AS 1012.20.1, *Methods of testing concrete, Method 20.1: Determination of chloride and sulfate in hardened concrete and aggregates—Nitric acid extraction method*

AS 1012.20.2, *Methods of testing concrete, Method 20.2: Determination of water-soluble chloride in aggregates and hardened concrete*

AS 1100.501, *Technical drawing, Part 501: Structural engineering drawing*

AS 1199.1, *Sampling procedures and tables for inspection by attributes, Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

AS 1379, *Specification and supply of concrete*

AS 1478.1, *Chemical admixtures for concrete, mortar and grout, Part 1: Admixtures for concrete*

AS 3600, *Concrete structures*

AS 3610.1, *Formwork for concrete, Part 1: Documentation and surface finish*

AS 3799, *Liquid membrane-forming curing compounds for concrete*

AS 3582.4, *Supplementary cementitious materials, Part 4: Pozzolans — Manufactured*

AS/NZS 1170.0, *Structural design actions, Part 0: General principles*

AS/NZS 1554.3, *Structural steel welding, Part 3: Welding of reinforcing steel*

AS/NZS 1554.6, *Structural steel welding, Part 6: Welding stainless steels for structural purposes*

AS/NZS 1597.2, *Precast reinforced concrete box culverts, Part 2: Large culverts (exceeding 1200 mm span or 1200 mm height and up to and including 4200 mm span and 4200 mm height)*

AS/NZS 1768, *Lightning protection*

AS/NZS 2425, *Bar chairs in reinforced concrete—Product requirements and test methods*

AS/NZS 3582.1, *Supplementary cementitious materials and blended cement, Part 1: Fly ash*

AS/NZS 3582.2, *Supplementary cementitious materials and blended cement, Part 2: Ground granulated blast-furnace*

AS/NZS 3582.3, *Supplementary cementitious materials and blended cement, Part 3: Amorphous silica*

AS/NZS 4671, *Steel for the reinforcement of concrete*

AS/NZS 4672.1, *Steel prestressing materials, Part 1: General requirements*

AS/NZS 4672.2, *Steel prestressing materials, Part 2: Testing requirements*

AS/NZS 5100.1, *Bridge design, Part 1: Scope and general principles*

AS/NZS 5100.2, *Bridge design, Part 2: Design loads*

AS/NZS 5100.7, *Bridge design, Part 7: Rating of existing bridges*

ISO 12491, *Statistical methods for quality control of building materials and components*

ASTM C42, *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*

ASTM C295, *Standard Guide for Petrographic Examination of Aggregates for Concrete*

EN 10088-1, *Stainless Steels, Part 1: List Of Stainless Steels*

EN 14721, *Test Method For Metallic Fibre Concrete—Measuring The Fibre Content In Fresh And Hardened Concrete*

EN 14651, *Test Method For Metallic Fibre Concrete—Measuring The Flexural Tensile Strength (limit of proportionality (lop), Residual)*

EN 14889-1, *Fibres for concrete, Part 1: Steel fibres—Definitions, Specifications and Conformity*

BS 6744, *Stainless steel bars—Reinforcement of concrete—Requirements and test methods*

1.4 Definitions

1.4.1

general

for the purposes of this Standard, the definitions below apply

1.4.2

administrative definitions

1.4.2.1

approved

except as may be otherwise stated, approved by authority

1.4.2.2

authority

the body with jurisdiction over the provision of bridges and associated structures, and/or responsible for the design, construction and maintenance of bridges within its jurisdiction

1.4.2.3

drawings

the drawings forming part of the documents setting out the work to be executed

1.4.2.4

specification

the specification forming part of the documents setting out the work to be executed

1.4.3

technical definitions

1.4.3.1

action

set of concentrated or distributed forces acting on a structure (direct action), or deformation imposed on a structure or constrained within it (indirect action)

Note 1 to entry: The term 'load' is often used to describe direct actions.

1.4.3.2

action effects

internal forces and bending moments due to actions (stress resultants)

1.4.3.3

anchorage zone

region between the face of the member where the prestress is applied and the cross-section at which a linear distribution of stress due to prestress is achieved

1.4.3.4

average ambient temperature

average value of the daily maximum and minimum ambient temperatures over the relevant period at a site

1.4.3.5

b-region

portion of a member in which the assumption that plane sections remain plane can be applied

1.4.3.6

basic creep coefficient ($\phi_{cc,b}$)

mean value of the ratio of final creep strain to elastic strain for a specimen loaded at 28 days under a constant stress of $0.4f'_c$

1.4.3.7

bottle-shaped compression field

compression field that is wider at mid-length than at its ends

1.4.3.8**braced column**

column in a structure for which the lateral actions, applied at the ends in the direction under consideration, are resisted by components such as masonry infill panels, shear walls or lateral bracing

1.4.3.9**A2 cement material
cementitious material**

hydraulic binder composed of general purpose or blended cements used alone or combined with one or more supplementary cementitious materials (SCMs)

Note 1 to entry: For requirements on cement material/cementitious material see [Clause 4.4.1](#). A2

1.4.3.10**A2 [Entry deleted.] A2****1.4.3.11****characteristic strength**

value of the material strength, as assessed by standard test, that is exceeded by 95% of the material (lower characteristic strength)

1.4.3.12**composite concrete member**

member consisting of concrete members constructed separately but structurally connected so the member responds as a unit to applied actions

1.4.3.13**concrete**

mixture of cement, aggregates and water, with or without the addition of chemical admixtures

1.4.3.14**construction joint**

joint that is located in a structure or part of a structure for convenience of construction and made so that the load-carrying capacity and serviceability of the structure, or part of the structure, will be unimpaired by the inclusion of the joint

1.4.3.15**cover**

distance between the outside of the reinforcing steel or tendons and the nearest permanent surface of the member, excluding any applied surface finish

1.4.3.16**creep coefficient**

mean value of the ratio of creep strain to elastic strain under conditions of constant stress

1.4.3.17**critical shear perimeter**

perimeter defined by a line geometrically similar to the boundary of the effective area of a support or concentrated load and located at a distance of $d_{om}/2$ therefrom (see [Figure 9.2.3](#))

1.4.3.18**critical opening**

opening through the thickness of a slab where an edge, or part of the edge, of the opening is located at a clear distance of less than $2.5b_o$ from the critical shear perimeter [see [Figure 9.2.3\(b\)](#)]

1.4.3.19**design life**

the period assumed in design for which a structure or a structural element required to perform its intended purpose with minimal maintenance and without replacement or major structural repairs

1.4.3.20**discontinuity**

abrupt change in geometry or loading, including prestress

1.4.3.21**direct loading**

loading on a structure that includes the self-weight of its component members and externally applied loads

1.4.3.22**D-region**

portion of a member within a distance equal to the member depth (D), from a discontinuity

1.4.3.23**duct**

conduit (plain or corrugated) to accommodate prestressing tendon(s) for post-tensioned installation

1.4.3.24**ductility class**

designation relating to the ductility of reinforcement

Note 1 to entry: 'L' designates 'low', 'N' designates 'normal', 'E' designates 'earthquake'.

Note 2 to entry: For further information on designation, refer to AS/NZS 4671.

1.4.3.25**durability**

ability of a structure and its component members to perform the functions for which they have been designed, over a specified period of time, when exposed to their environment

1.4.3.26**effective area of a support or concentrated load for slabs in shear**

area totally enclosing the actual support or load and for which the perimeter is a minimum

Note 1 to entry: For critical shear perimeter, see [Figure 9.2.3](#).

1.4.3.27**effective depth**

distance from the extreme compressive fibre of the concrete to the resultant tensile force in the reinforcing steel and tendons in that zone, which will be tensile at the ultimate strength condition of pure bending

1.4.3.28**embedded items**

items, other than reinforcement and tendons, that are embedded in a concrete member or structure

Note 1 to entry: Embedded items include pipes and conduits with their associated fittings, sleeves, permanent inserts for fixings and other purposes, prestressed anchorages, holding-down bolts and other supports.

1.4.3.29**exposure classification**

designation indicative of the most severe environment to which a concrete member is to be subjected during its design life

Note 1 to entry: For exposure classifications, see [Table 4.3](#).

1.4.3.30**external tendon**

a post-tensioned tendon situated outside the concrete section only connected to the structure by anchorages and deviators

1.4.3.31**fan-shaped compression field**

compression field that has non-parallel straight sides [see [Figure 7.2.1\(b\)](#)]

1.4.3.32**fitment**

unit of reinforcement commonly used to—

- (a) restrain from buckling the longitudinal reinforcing bars in beams, columns and piles;
- (b) carry shear, torsion and diagonal tension;
- (c) act as hangers for longitudinal reinforcement; or
- (d) provide confinement to the core concrete.

Note 1 to entry: Also referred to commonly as a stirrup, ligature or helical reinforcement.

1.4.3.33**fixing**

material cast into concrete for the purpose of maintaining in position reinforcement, tendons, ducts, formwork, inserts or devices for lifting of members

1.4.3.34**footing**

part of a structure in direct contact with and transmitting load to the supporting foundation

1.4.3.35**foundation**

soil, subsoil or rock, whether built-up or natural, by which a structure is supported

1.4.3.36**grout**

mixture of cement and water, with or without the addition of sand, or chemical admixtures, proportioned to produce a pourable liquid without segregation of the constituents

1.4.3.37**headed reinforcement**

steel bar that achieves anchorage by means of a suitably sized head or end plate

1.4.3.38**helical reinforcement**

unit of reinforcement that is wound in a helical fashion around the main longitudinal reinforcing bars in a column or pile, to restrain them from buckling and to carry shear, torsion and diagonal tension, or around tendons at an anchorage to resist bursting action effects

1.4.3.39**initial force**

force, immediately after transfer, at a stated position in a tendon

1.4.3.40**jacking force**

force in a tendon measured at the jack

1.4.3.41**ligature (reinforcement)**

see fitment, [Clause 1.4.3.32](#)

1.4.3.42**limit state**

as defined in AS 5100.1

1.4.3.43**mean strength**

statistical average of a number of test results representative of the strength of a member, prototype or material

1.4.3.44**moist curing**

supplying additional moisture to the concrete surface by means of a complete and continuous application of water to the surface of the concrete

1.4.3.45**movement joint**

joint that is made between parts of a structure for the specific purpose of permitting relative movement between the parts of the structure on either side of the joint

1.4.3.46**node**

point in a joint in a strut-and-tie model where the axes of the struts, ties and concentrated forces acting on the joint intersect

1.4.3.47**nodal zone**

volume of concrete around a node, which is assumed to transfer strut-and-tie forces through the node

1.4.3.48**one-way slab**

slab characterized by flexural action mainly in one direction

1.4.3.49**plain concrete member**

member either unreinforced or containing reinforcement but assumed to be unreinforced

1.4.3.50**post-tensioning**

tensioning of tendons after the concrete has hardened

1.4.3.51**prestressed concrete**

concrete into which internal stresses are induced deliberately by tendons

Note 1 to entry: Prestressed concrete includes concrete commonly referred to as 'partially prestressed'.

1.4.3.52**prestressing steel**

see tendon, [Clause 1.4.3.65](#)

1.4.3.53**pretensioning**

tensioning of tendons before the concrete is placed

1.4.3.54**prismatic compression field**

compression field that is parallel sided [see [Figure 7.2.1\(a\)](#)]

1.4.3.55**professional engineer**

a person who has appropriate experience and competence in the relevant field and—

(a) if legislation is applicable, a registered professional engineer in the relevant discipline; or

- (b) if legislation is not applicable, a corporate member of the Institution of Engineers Australia, or a person eligible to become a chartered professional engineer of the Institution of Engineers, Australia, or the National Engineers Register in the relevant discipline.

**1.4.3.56
reinforcement**

steel bar, wire or mesh but not tendons

Note 1 to entry: Commonly referred to as reinforcing steel.

**1.4.3.57
self-compacting concrete**

concrete that is able to flow and consolidate under its own weight, completely fill the formwork or excavation even in the presence of dense reinforcement, whilst maintaining homogeneity and without the need for additional compaction, and which complies with specified requirements for slump flow, viscosity and passing ability

**1.4.3.58
shear wall**

wall that is intended to resist lateral forces acting in or parallel to the plane of the wall

**1.4.3.59
short column**

column in which the additional bending moments due to slenderness can be taken as zero

**1.4.3.60
slender column**

column that does not satisfy the requirements for a short column

**1.4.3.61
steel fibre reinforced concrete**

concrete manufactured with steel fibres of any type and geometry and where the fibres are mixed together with the other constituent materials before casting

**1.4.3.62
strength grade**

numerical value of the characteristic compressive strength of concrete at 28 days (f'_c), used in design

**1.4.3.63
strut-and-tie model**

truss model made up of struts and ties connected at nodes

**1.4.3.64
supplementary cementitious materials**

1.4.3.64.1

fly ash

the solid material extracted from the flue gases of a boiler fired with pulverized coal

1.4.3.64.2

ground granulated iron blast-furnace slag (slag)

material consisting essentially of silicates and aluminosilicates of calcium, produced simultaneously with iron in a blast furnace

1.4.3.64.3

amorphous silica

very fine pozzolanic material, composed mostly of non-crystalline silica

Note 1 to entry: The high specific surface area of amorphous silica can cause workability problems when used in cement paste, mortar or concrete if suitable measures or precautions are not implemented.

1.4.3.64.4**manufactured pozzolans**

pozzolan which can be a by-product of mineral processing, manufacturing, waste to energy, recovered resources or processed or calcined natural materials

1.4.3.65**tendon**

wire, strand or bar (or any discrete group of such wires, strands or bars) that is intended to be pretensioned or post-tensioned

1.4.3.66**tie**

tension member in a strut-and-tie model

1.4.3.67**transfer**

time of initial transfer of prestressing forces from the tendons to the concrete

1.4.3.68**transmission length**

length, at transfer, over which the stress in a pretensioned tendon builds up from zero at one end to its full value

1.4.3.69**two-way slab**

slab characterized by significant flexural action in two directions at right angles to one another

1.4.3.70**unbonded tendon**

a post-tensioned tendon fabricated from sheathed prestressing strands, bars or rods connected to the structure by anchorage only

1.4.3.71**uniform strain**

strain in the reinforcement at maximum stress, corresponding to the onset of necking

1.4.3.72**upper characteristic strength**

value of the material strength, as assessed by standard test, which is exceeded by 5% of the material

1.4.3.73**water/cement material ratio**

the ratio of the amount of water to the total amount of cementitious materials by mass in a freshly mixed cubic metre of concrete

Note 1 to entry: The water should be the total free water contained in the batch aggregates in excess of their saturated-dry condition.

1.5 Notation

The symbols used in this Standard, including their definitions, are listed below.

Unless a contrary intention appears, the following applies:

- (a) The symbols used in this Standard have the meanings ascribed to them below, with respect to the structure, or member, or condition to which a clause is applied.
- (b) Where non-dimensional ratios are involved, both the numerator and denominator are expressed in identical units.

- (c) The dimensional units for length, force and stress, in all expressions or equations, are to be taken as millimetres (mm), newtons (N) and megapascals (MPa) respectively, unless noted otherwise.
- (d) An asterisk (*) placed after a symbol as a superscript (for example, M_y^*) denotes a design action effect due to the design load.

Symbol	Definition
A_b	cross-sectional area of a reinforcing bar
$A_{b.fit}$	cross-sectional area of the fitment
A_c	smallest cross-sectional area of the concrete strut at any point along its length and measured normal to the line of action of the strut
A_{cp}	total area enclosed by outside perimeter of concrete section
A_{ct}	area of concrete on flexural tension side of member; <i>or</i> area of concrete within the tensile zone (mm ²). NOTE The tensile zone is that part of the cross-section calculated to be in tension just before formation of the first crack
A_g	gross cross-sectional area of a member
A_m	an area enclosed by the median lines of the walls of a single cell
A_o	area enclosed by shear flow path, including any area of holes therein
A_{oh}	area enclosed by centre-line of exterior closed transverse torsion reinforcement, including area of holes (if any)
A_p	cross-sectional area of tendons
A_{pt}	cross-sectional area of the tendons in the zone that will be tensile under ultimate load conditions
A_s	cross-sectional area of reinforcement; <i>or</i>
$A_{s.fit}$	cross sectional area of fitment reinforcement (A_2)
	cross-sectional area of a single anchored bar of diameter d_b
A_{sc}	cross-sectional area of longitudinal compressive reinforcement
A_{sf}	area of fully anchored reinforcement crossing the interface
A_{si}	area of reinforcement in the i th direction crossing a strut
A_{st}	cross-sectional area of longitudinal tensile reinforcement; <i>or</i> cross-sectional area of reinforcement in the zone that would be in tension under the design loads if the effects of prestress and axial loads are ignored
$A_{st.min}$	minimum area of reinforcement required within the tensile zone (mm ²). NOTE If $A_{st.min}$ is zero only steel fibres are necessary to control cracking
A_{sv}	cross-sectional area of shear reinforcement
$A_{sv.min}$	cross-sectional area of minimum shear reinforcement
A_{sw}	cross-sectional area of the bar forming a closed fitment
A_{tr}	cross-sectional area of a transverse bar along the development length
$A_{tr.min}$	cross-sectional area of the minimum transverse reinforcement along the development length
A_1	a bearing area
A_2	largest area of the supporting surface that is geometrically similar to and concentric with A_1
a	a distance; <i>or</i> horizontal projection of the inclined strut; <i>or</i> perpendicular distance from the nearer support to the section under consideration; <i>or</i> dimension of the critical shear perimeter measured parallel to the direction of bending being considered

Symbol	Definition
a_{sup}	length of a support in the direction of the span
a_v	distance from the section at which shear is being considered to the face of the nearest support
b	width of a rectangular cross-section or member
b_c	core dimension measured between the centre-lines of the outermost fitments measured across the width of the section
b_{ef}	effective width of a compression face or flange of a member
b_f	width of the shear plane
b_l	$\langle A_2 \rangle$ dimension of the critical perimeter measured in the direction of the span for which moments are determined $\langle A_2 \rangle$
b_o	dimension of an opening
b_s	width of the flange in a composite member
b_t	$\langle A_2 \rangle$ dimension of the critical perimeter measured perpendicular to b_l $\langle A_2 \rangle$
b_v	effective width of a web for shear
b_w	a width of the web; <i>or</i> minimum thickness of the wall of a hollow section
$c(c_1)$	cover to reinforcing steel or tendons
c_d	the smaller of the concrete covers to the deformed bar and half the clear distance to the next parallel
D	overall depth of a cross-section in the plane of bending; <i>or</i> depth of member
D_b	overall depth of a spandrel beam
D_c	depth of smaller column cross-sectional dimension if rectangular, or the column diameter if circular
D_s	overall depth of a slab or drop panel
d	effective depth of a cross-section in the plane of bending
d_b	nominal diameter of a bar, wire or tendon $\langle A_2 \rangle$ [Text deleted.] $\langle A_2 \rangle$
d_c	width of the idealized strut; <i>or</i> core dimension measured between the centre-lines of the outermost fitments measured through the depth of the section
d_d	diameter of a prestressing duct
d_f	diameter of the bar forming the tie; <i>or</i> equivalent diameter of the steel fibre
d_g	maximum nominal aggregate size
$\langle A_2 \rangle d_i$	nominal internal diameter of reinforcement bend or hook $\langle A_2 \rangle$
d_o	distance from the extreme compressive fibre of the concrete to the centroid of the outermost layer of tensile reinforcement or tendons (not less than $0.8D$ for prestressed concrete members)
d_{om}	mean value of d_o , averaged around the critical shear perimeter
d_p	distance from the extreme compressive fibre of the concrete to the centroid of the tendons in the zone of the concrete in tension under ultimate strength conditions
d_s	overall dimension measured between centre-lines of the outermost fitments; <i>or</i> distance from the extreme compression fibre to the centroid of non-prestressed tensile reinforcement
d_{sc}	distance from the extreme compressive fibre of the concrete to the centroid of compressive reinforcement
d_{sp}	distance of the out-of-plane splitting force that may be considered

Symbol	Definition
d_v	effective shear depth
E_c	mean value of the modulus of elasticity of concrete at 28 days
E_{cj}	mean value of the modulus of elasticity of concrete at age j
E_d	design action effect
E_p	modulus of elasticity of tendons, determined in accordance with Clause 3.3.2
$E_{p\theta}$	modulus of elasticity of tendons at elevated temperatures
E_s	modulus of elasticity of reinforcement, determined in accordance with Clause 3.2.2
$E_{s\theta}$	modulus of elasticity of steel reinforcement at elevated temperatures
e	eccentricity of prestressing force or load; <i>or</i> base of Napierian logarithms
e_o	vertical eccentricity between the centre of gravity of a beam and the longitudinal axis through the lifting points
F	force
F_L	peak load obtained from a 3-point notch bending test undertaken in accordance with EN 14651
F_{td}	required tensile force in longitudinal reinforcement on the flexural tension side of a member
f_{cm}	mean value of concrete compressive strength at the relevant age; <i>or</i> mean concrete compressive strength at the time cracking is expected to occur
f_{cmi}	mean value of the in situ compressive strength of concrete at the relevant age
f_{cp}	mean compressive strength of concrete at transfer
f_{ct}	uniaxial tensile strength of concrete
$f_{ct.f}$	measured flexural tensile strength of concrete
$f_{ct.ef}$	tensile strength of the concrete effective at the time when the cracks may first be expected to occur
$f_{ct.sp}$	measured splitting tensile strength of concrete
f_{cv}	concrete shear strength
f_{pb}	characteristic minimum breaking strength
f_{py}	yield strength of tendons
f_{po}	stress in prestressed reinforcement when stress in the surrounding concrete is zero
$f_{p\theta}$	minimum tensile strength of tendons at elevated temperatures
f_r	average confining pressure on the core cross-section taken at the level of the fitments
$f_{R,j}$	residual flexural tensile strength
$f_{r.ef}$	effective confining pressure applied to the core of a column
$f_{s.max}$	maximum stress permitted in the reinforcement immediately after formation of the crack
f_{scr}	maximum steel stress for crack control
f_{si}	serviceability limit stress in the reinforcement
f_{sy}	characteristic yield strength of reinforcement (referred to as R_e in AS/NZS 4671), determined in accordance with Clause 3.2.1
$f_{sy.f}$	yield strength of reinforcement used as fitments
$f_{sy\theta}$	characteristic yield strength of reinforcement at elevated temperatures
f_{ul}	characteristic ultimate strength of the longitudinal reinforcement
f'_c	characteristic compressive (cylinder) strength of concrete at 28 days

Symbol	Definition
f'_{cp}	characteristic concrete strength at transfer
f'_{ct}	characteristic uniaxial tensile strength of concrete
$f'_{ct.f}$	characteristic flexural tensile strength of concrete at 28 days
$f'_{c\theta}$	design characteristic compressive strength of concrete at elevated temperature
$f'_{R,2}$	mean residual flexural strength determined at a crack mouth opening displacement (CMOD) of 1.5 mm as determined from a 3-point notch bending test undertaken in accordance with EN 14651
$f'_{R,4}$	mean residual flexural strength determined at a crack mouth opening displacement (CMOD) of 3.5 mm as determined from a 3-point notch bending test undertaken in accordance with EN 14651
$f'_{1.5}$	characteristic residual tensile strength of steel fibre reinforced concrete (SFRC)
G	permanent action (dead load)
g_p	permanent distributed load normal to the shear interface per unit length, in newtons per millimetre
H_w	floor-to-floor unsupported height of a wall
H_{we}	effective height of a wall
h	overall depth of a joint
I	second moment of area of the uncracked concrete cross-section about the centroidal axis
I_c	second moment of area of a concrete section
I_{cr}	second moment of area of a cracked section with the reinforcement transformed to an equivalent area of concrete
I_{ef}	an effective second moment of area
$I_{ef,max}$	maximum effective second moment of area
I_f	second moment of area of a flexural member
J_t	a torsional modulus
J_{tb}	torsional modulus of the standard precast prestressed concrete I-girder section
J_{tn}	torsional modulus of the I-girder sections with a composite slab connected above
j	time after prestressing, in days; or appropriate age of concrete, in days
K	a factor that accounts for the position of the bars being anchored with respect to the transverse reinforcement
k	a coefficient, ratio or factor used with and without numerical subscripts
k_c	a coefficient that takes account of the nature of the stress distribution within the section immediately prior to cracking
k_{co}	cohesion coefficient
k_{cs}	factor used in serviceability design to take account of the long-term effects of creep and shrinkage
$\sqrt[3]{A_2} k_{dg}$	maximum nominal aggregate size $\sqrt[3]{A_2}$
k_e	effectiveness factor accounting for the arrangement of the fitments
k_m	coefficient
k_p	coefficient that takes account of the level of prestress
$k_{R,4}$	ratio of the mean residual tensile strength taken at a crack opening displacement (COD) of 1.5 mm

Symbol	Definition
k_r	ratio of the dimension of an anchorage bearing plate to the corresponding depth, or breadth, of the symmetrical prism
k_u	neutral axis parameter being the ratio, at ultimate strength under any combination of bending and compression, of the depth to the neutral axis from the extreme compressive fibre to d
k_{u0}	ratio, at ultimate strength, without axial force of the depth to the neutral axis from the extreme compressive fibre to d_0
$\overline{A_2} k_v$	coefficient for concrete contribution to shear capacity $\overline{A_2}$
$\overline{A_2} k_{vs}$	constant related to the size effect on the shear strength of a slab without shear reinforcement $\overline{A_2}$
$\overline{A_2} k_{vu}$	constant related to the shear strength upper limit of a slab from concrete cracking near shear fitments $\overline{A_2}$
$\overline{A_2} k_{vuc}$	constant related to the shear strength reduction in a slab with shear reinforcement from concrete cracking $\overline{A_2}$
$\overline{A_2} k_{vuCs}$	constant related to the influence of aggregate size and slab depth on the shear strength of a slab without shear reinforcement $\overline{A_2}$
k_1	a coefficient which allows for the effect of non-uniform self-equilibrating stresses due to non-linear shrinkage or temperature profiles through the member depth
$k_{\theta 1}$	compressive strength factor for concrete at elevated temperatures
$k_{\theta 2}$	tension reinforcement factor with strain $\geq 2\%$
$k_{\theta 3}$	modulus of elasticity factor of steel reinforcement at elevated temperatures
$k_{\theta 4}$	minimum tensile strength factor of tendons at elevated temperatures
$k_{\theta 5}$	modulus of elasticity of tendons factor at elevated temperatures
L	centre-to-centre distance between the supports of a flexural member
L_e	effective length of a column
L_{ef}	effective span of a member, taken as the lesser of $(L_n + D)$ and L for a beam or slab; or $L_n + D/2$ for a cantilever
L_l	distance between centres of lateral restraints or from a lateral restraint to the free edge
L_n	length of clear span in the direction in which moments are being determined, measured face-to-face of supporting beams, columns or walls, or for a cantilever, the clear projection
L_p	total development length of tendons
L_{pa}	length of the tendon from the jacking end to a point at a distance 'a' from that end
$\overline{A_2} L_{pe}$	effective length of tendon for determining stress in tendon at ultimate moment capacity $\overline{A_2}$
L_{pt}	transmission length for pretensioned tendons
L_{sc}	development length of a bar for a compressive stress less than the yield stress
L_{st}	development length of a bar for a tensile stress less than the yield stress
$L_{sy.c}$	development length in compression, being the length of embedment required to develop the yield strength of a deformed bar in compression
$L_{sy.cb}$	basic development length of a deformed bar in compression
$L_{sy.t}$	development length in tension, to develop the characteristic yield strength of a deformed bar in tension
$L_{sy.t.lap}$	tensile lap length for either contact or non-contact splices
$L_{sy.tb}$	basic development length of a deformed bar in tension

Symbol	Definition
L_u	unsupported length of a column, taken as the clear distance between the faces of members capable of providing lateral support to the column. Where column capitals or haunches are present, L_u is measured to the lowest extremity of the capital or haunch
L_w	overall length of a wall
l_b	length of the bursting zone
l_f	length of the steel fibre
M^*	design bending moment at a cross-section
$\boxed{A_2} M_f^*$	portion of M_v^* resisted by flexure in the slab $\boxed{A_2}$
M_h^*	design lateral bending moment
M_s^*	maximum bending moment at the section, based on the short-term serviceability load or construction load
M_v^*	design bending moment to be transferred from a slab or beam to a support
$\boxed{A_2} M_{vv}^*$	portion of M_v^* resisted by eccentric shear on the critical perimeter $\boxed{A_2}$
M_x^*, M_y^*	design bending moment in a column about the major and minor axes respectively under the design axial force N^*
M_1^*, M_2^*	smaller and larger design bending moment respectively at the ends of a column
M_c	moment used in the calculation of the buckling load (N_c)
M_{cr}	bending moment causing cracking of the section with due consideration to prestress, restrained shrinkage and temperature stresses
M_g	bending moment due to self-weight plus dynamic allowance at serviceability limit state (SLS)
M_u	ultimate strength in bending at a cross-section of an eccentrically loaded compressive member
M_{ub}	particular ultimate strength in bending when $k_{uo} = 0.003 / (0.003 + f_{sy} / E_s)$
M_{uo}	ultimate strength in bending, without axial force, at a cross-section
$(M_{uo})_{min}$	minimum required ultimate strength in bending at a critical cross-section
M_{ux}, M_{uy}	ultimate strength in bending about the major and minor axes respectively of a column under the design axial force N^*
m	number of fitments legs crossing the confinement plane
N^*	design axial compressive or tensile force on a cross-section
N_G^*	design axial force due to permanent effects at the ultimate limit state (ULS)
N_c	buckling load used in column design
N_u	ultimate strength in compression, or tension, at a cross-section of an eccentrically loaded compression or tension member respectively; <i>or</i> ultimate strength per unit length of wall
N_{ub}	particular ultimate strength in compression of a cross-section when $k_{uo} = 0.003 / (0.003 + f_{sy} / E_s)$
N_{uo}	ultimate strength in compression, without bending, of an axially loaded cross-section
N_{uot}	ultimate strength in tension, without bending, of an axially loaded cross-section
n	number of bars uniformly spaced inside helical reinforcement; <i>or</i> number of laterally restrained longitudinal bars; <i>or</i> number of stress cycles

Symbol	Definition
P	force in the tendons; <i>or</i> maximum force occurring at the anchorage during jacking; <i>or</i> applied load
P_e	total effective prestress force allowing for all losses
P_i	prestressing force after initial losses
P_v	vertical component of the prestressing force
p	a reinforcement ratio
$\langle A_2 \rangle$	[Text deleted.] $\langle A_2 \rangle$
p_{cw}	web reinforcement ratio for compressive reinforcement
p_w	a reinforcement ratio in a wall; <i>or</i> web reinforcement ratio for tensile reinforcement
R	design relaxation of a tendon
R_b	basic relaxation of a tendon
R_d	design capacity of a member or structure (equal to ϕR_u or $\phi_{sys} R_{u,sys}$)
R_u	ultimate strength of a member
$R_{u,sys}$	mean capacity of the structure
r	radius of gyration of a cross-section; <i>or</i> radius of curvature of the duct; <i>or</i> radius of curvature of the prestressing tendon
S_p	structural performance factor
s	centre-to-centre spacing of fitments including shear, torsional or confining reinforcement, measured parallel to the longitudinal axis of a member; <i>or</i> standard deviation; <i>or</i> maximum spacing of transverse reinforcement within $L_{sy,c}$, or spacing of fitments, or spacing of successive turns of helical reinforcement, all measured centre to centre, in millimetres; <i>or</i> spacing of anchored shear reinforcement crossing interface
s_b	clear distance between bars of the non-contact lapped splice
s_d	centre-to-centre distance between lines of ducts in the plane of the curvature
s_L	clear distance between bars of the non-contact lapped splice
s_m	spacing of bars being developed, in millimetres
T	a temperature; <i>or</i> force resultant of transverse tensile stresses
T^*	torsional moment at a cross-section; <i>or</i> applied torsion
T_b^*	design bursting force calculated at the ultimate limit state (ULS)
$T_{b,s}^*$	design bursting force calculated at the serviceability limit state (SLS)
$T_{b,cr}$	bursting (or splitting) force across a strut caused at the time of cracking of the strut
T_{cr}	torsional cracking moment
T_u	ultimate torsional strength
T_{uc}	ultimate torsional strength of a beam without torsional reinforcement and in the presence of shear
T_{us}	ultimate torsional strength of a beam with torsional reinforcement
$T_{u,max}$	ultimate torsional strength of a beam limited by web crushing failure
T_w	vertical component of the force carried by the secondary struts
t	time
t_f	thickness of topping or flange anchored by shear reinforcement

Symbol	Definition
t_h	hypothetical thickness of a member used in determining creep and shrinkage, taken as $2A_g/u_e$
t_w	thickness of a wall
u	effective length of the critical shear perimeter
$\langle A_2 \rangle u_c$	length of the outside perimeter of concrete cross-section $\langle A_2 \rangle$
u_e	exposed perimeter of a member cross-section plus half the perimeter of any closed voids contained therein, used to calculate t_h
u_h	perimeter of the centre-line of the closed transverse torsion reinforcement
V^*	design shear force at a cross-section
$\langle A_2 \rangle V_v^*$	shear force that crosses a critical perimeter $\langle A_2 \rangle$
V_o	shear force which would occur at a section when the bending moment at that section was equal to the decompression moment M_o
V_t	shear force, which, in combination with the prestressing force and other action effects at the section, would produce a principal tensile stress of f'_{ct} at either the centroidal axis or the intersection of flange and web, whichever is the more critical
$\langle A_2 \rangle$	[Text deleted.] $\langle A_2 \rangle$
V_{min}^*	minimum design shear force for all load combinations
V_u	ultimate shear strength
$V_{u,max}$	ultimate shear strength limited by web crushing failure
$V_{u,min}$	minimum ultimate shear strength of a $\langle A_2 \rangle$ member $\langle A_2 \rangle$ provided with minimum shear reinforcement ($A_{sv,min}$)
V_{uc}	ultimate shear strength excluding shear reinforcement
V_{uf}	ultimate shear strength of an SFRC beam
$\langle A_2 \rangle$	[Text deleted.] $\langle A_2 \rangle$
V_{us}	contribution by shear reinforcement to the ultimate shear strength of a $\langle A_2 \rangle$ member $\langle A_2 \rangle$
w	average clear spacing between adjacent tied longitudinal bars; <i>or</i> width of loaded area or node
X	a dimension
x	shorter overall dimension of a rectangular part of a cross-section
Y	a dimension
y	larger overall dimension of a rectangular part of a cross-section
y_t	depth from the centroidal axis to the extreme fibre at the top of the section
y_1	larger overall dimension of a closed fitment
Z	section modulus of the uncracked cross-section, referred to the extreme fibre at which flexural cracking occurs
z	projection of the inclined compressive strut normal to the shear span; <i>or</i> internal moment lever arm of the section
α	coefficient; <i>or</i> divergence angle between bottled shape compression fields and idealized parallel sided strut
α_b	coefficient for beams
α_c	coefficient; <i>or</i> modular ratio of the cast-in-place concrete to the precast beam concrete in the composite member
α_f	stress range factor

Symbol	Definition
α_n	coefficient
α_s	correlation factor
α_{tot}	sum in radians of the absolute values of successive angular deviations of the prestressing tendon over a length of the tendon from the jacking end to a point at distance (a) from that end (L_{pa})
α_v	angle between the inclined shear reinforcement and the longitudinal tensile reinforcement
β	an effective compression strength factor; <i>or</i> fixity factor; <i>or</i> a ratio; <i>or</i> a factor with or without alphanumeric subscripts
β_d	a factor
β_h	a ratio
β_n	factor to account for the effect of the anchorage of ties on the effective compressive strength of a nodal zone
β_p	an estimate of the angular deviation due to wobble effects, in radians per metre (rad/m)
β_s	strut efficiency factor
β_v	angle of tilt assumed for the calculation of stability of a slender beam during erection
γ	ratio, under design bending or design combined bending and compression, of the depth of the assumed rectangular compressive stress block to $k_u d$
γ_1, γ_2	column end restraint coefficients, determined in accordance with Clause 10.5.3
γ_i	angle between the axis of a strut and the bars in the i th direction of reinforcement crossing that strut
Δ	a deflection
Δ_h	lateral deviation of a slender beam at mid-span from the specified datum line immediately after transfer
Δ_v	lateral deflection caused by the self weight of the beam due to bending about the y - y axis
ΔF_{cd}	required additional force in longitudinal reinforcement on the flexural compression side of a member
$\Delta \sigma_p$	change in the stress due to the change in length of the prestressed tie
$\delta, \delta_b, \delta_s$	moment magnifiers for slenderness effects
ε	a strain
ε_{cc}	strain due to concrete creep
ε_{cs}	design shrinkage strain of concrete
ε_{cs}^*	final design shrinkage strain of concrete
ε_{csd}	drying shrinkage strain
ε_{cse}	autogenous shrinkage strain
ε_{cse}^*	final autogenous shrinkage strain
$\varepsilon_{csd.b}$	basic drying shrinkage strain
$\varepsilon_{csd.b}^*$	final drying basic shrinkage strain
ε_{pu}	strain at maximum stress of a prestressing tendon
ε_{su}	uniform strain at maximum stress, corresponding to the onset of necking
ε_x	longitudinal strain in concrete at mid-depth of member for determining concrete shear capacity

Symbol	Definition
θ	angle measured between the axis of the strut and the axis of a tie passing through a common node; <i>or</i> angle between tie leg and confinement plane
θ_v	angle between the axis of the concrete compression strut and the longitudinal axis of the member
λ	a factor
λ_{uc}	a ratio of loads
μ	friction curvature coefficient; <i>or</i> coefficient of friction; <i>or</i> structural ductility factor; <i>or</i> displacement ductility
ν	Poisson's ratio for concrete, determined in accordance with Clause 3.1.5
ρ	density of plain concrete, in kilograms per cubic metre (kg/m ³), determined in accordance with Clause 3.1.3
ρ_{ccj}	residual creep coefficient; <i>or</i> residual shrinkage coefficient
ρ_p	transverse compressive pressure at the ultimate limit state (ULS) along the development length perpendicular to the plane of splitting in megapascals
ρ_s	volumetric ratio of the fitments relative to the volume of the core
σ_{ci}	sustained stress in the concrete at the level of the centroid of the tendons, calculated using the initial prestressing force prior to any time-dependent losses and the sustained portions of all the service loads
σ_{cp}	average intensity of effective prestress in concrete
$\sigma_{cp.f}$	compressive stress due to prestress, at the extreme fibre where cracking occurs
σ_{cs}	maximum shrinkage-induced tensile stress on the uncracked section at the extreme fibre at which cracking occurs
σ_{min}	minimum compressive stress at the extreme fibres under consideration, taken as zero if tensile.
σ_{max}	maximum compressive stress at the extreme fibres under consideration.
$\sigma_{max} - \sigma_{min}$	maximum permissible stress range under fatigue loading for the calculated σ_{min} and equal to $0.45 f'_c$ when σ_{min} is zero.
σ_o	a constant sustained stress
σ_p	effective stress in the prestressing tendon at the time under consideration
σ_{pa}	stress in the tendon at a distance 'a', measured from the jacking end
$\sigma_{p.ef}$	effective stress in the tendon after allowing for all losses
σ_{pi}	stress in the tendon immediately after transfer
σ_{pj}	maximum stress in the tendon at the jacking end
σ_{pu}	maximum stress that would be reached in a tendon at ultimate strength of a flexural member
σ_{sc}	a compressive stress being developed in a bar in compression
σ_{scr}	tensile steel stress at the serviceability limit state (SLS) for a beam in flexure or in tension or for a slab in flexure
σ_{st}	tensile stress in reinforcement
τ^*	design shear stress acting on the interface
τ_u	shear stress capacity
ϕ	capacity reduction factor for design using linear elastic analysis
ϕ_s	stress reduction factor for design using linear stress analysis
ϕ_{st}	strength reduction factor for design using strut-and-tie analysis

Symbol	Definition
ϕ_{sys}	system strength reduction factor for design using non-linear methods of analysis
φ_{cc}	design creep coefficient at any time t
$\varphi_{\text{cc},j}$	creep coefficient at any time j
φ_{cc}^*	final design creep coefficient
$\varphi_{\text{cc},b}$	basic creep coefficient of concrete, determined in accordance with Clause 3.1.8.2
ψ_r	factor of safety against lateral buckling
Ω	dimension of node

1.6 Construction

All concrete structures, designed in accordance with this Standard, shall be constructed so that all the requirements of the design, as contained in the drawings and specifications, are achieved.

1.7 Existing bridges

The general principles of this Standard shall be applied when evaluating the strength or serviceability of an existing bridge.

Where the strength or serviceability of a member or prototype is to be tested, the actual geometry, section sizes and condition of the member, as well as the material properties of the member shall be used (see [Section 17](#)).

Where the strength or serviceability of an existing bridge is to be evaluated, the provisions of AS 5100.7 shall apply.

NOTE Existing bridges may contain materials that do not comply with the material specifications herein and may have been designed to different requirements, but the general principles of this Standard would apply. (Refer to AS 5100.8 with respect to strengthening and rehabilitation of an existing bridge.)

1.8 Design

1.8.1 Design data

In addition to the data specified in AS 5100.1, the drawings shall include the following design data:

- (a) Exposure classification for durability and associated cover to reinforcing steel and tendons.
- (b) Class and grade of concrete.
- (c) Grade, ductility class and type of reinforcement and grade and type of tendons.
- (d) Reference number and date of issue of applicable design Standards.
- (e) Design life (if not 100 years).

1.8.2 Design details

The drawings or specifications for concrete members and structures shall include, as appropriate, the following:

- (a) The shape and size of each member.
- (b) The finish and method of control for unformed surfaces.

- (c) Class of formwork for the surface finish specified.
- (d) The number of bars, size, bar shape, spacing and location of all reinforcement to AS 1100.501 and the required concrete cover.
- (e) The size, quantity and location of tendons and structural fixings and the required concrete cover.
- (f) Any required properties of the concrete.
- (g) The curing procedure.
- (h) The force required in each tendon, the maximum jacking force to be applied in each tendon and the order in which the tendons are to be stressed.
- (i) The minimum strength concrete required before the application of prestressing forces.
- (j) The location and details of planned construction and movement joints, and of connections and splices.
- (k) The minimum period of time before stripping of forms and removal of shores.
- (l) Any constraint on construction assumed in the design including, where relevant, the casting procedure.
- (m) Any other requirements.

1.9 Use of alternative materials or methods

A₂ Where alternative materials, methods of design or construction are used, they shall conform to AS 5100.1:2017 Section 7.**A₂**

Section 2 Design procedures, actions and loads

2.1 Design procedures

2.1.1 Design for strength and serviceability

Concrete structures shall be designed for ultimate strength and serviceability limit states (SLSs) in accordance with the general principles and procedures for design as set out in AS 5100.1 and the specific requirements of [Clauses 2.3](#) and [2.4](#).

Notwithstanding the requirements of [Clauses 2.3](#) and [2.4](#), it shall be permissible to carry out design checks for strength and serviceability by testing a structure or a component member in accordance with [Appendix A](#).

2.1.2 Design for fatigue

Where relevant, concrete structures shall be designed for fatigue effects in accordance with [Clause 2.2](#).

2.1.3 Design for earthquake actions

[A2](#) Where structures are required to be designed for earthquake actions, they shall conform to AS 5100.2 and this Section (2). [A2](#)

2.1.4 Design for robustness

Concrete structures shall be designed to be robust in accordance with the procedures and criteria given in AS 5100.1 and AS/NZS 1170.0, as appropriate.

2.1.5 Design for durability

Concrete structures shall be designed to be durable in accordance with the requirements of [Section 4](#).

2.1.6 Design for fire resistance

Where it is considered necessary for the structure or part thereof to be fire resistant, it shall be designed in accordance with the requirements of [Section 5](#).

2.1.7 Material properties

The properties of materials used in the design shall be in accordance with [Section 3](#).

When evaluating the behaviour of a concrete structure, member or cross-section, the values of concrete properties used in the calculation shall be appropriate to the age of the concrete, rate of loading and expected variations of material properties.

2.2 Design for fatigue

2.2.1 General

Fatigue shall be considered where relevant and shall be taken into account in the design of the structure. Fatigue shall always be considered in the design of concrete railway bridges, but need not be considered in the design of concrete road bridges where the effective number of stress cycles is less than 500 000.

The fatigue loadings to be used and the number of stress cycles shall be determined in accordance with AS 5100.2.

A2 Concrete structures shall be designed for fatigue effects in accordance with —

- (a) the simplified approach to fatigue design in this Clause (2.2); or
- (b) the more detailed method provided in AS 3600.

Alternative fatigue design methods to those in this Clause (2.2) and AS 3600 may be used if approved by the relevant authority. **A2**

Design actions for use in fatigue analysis shall be determined in accordance with the methods specified in [Items \(a\) to \(d\) of Clauses 6.1.3](#). Moment redistribution is not permitted.

2.2.2 Maximum range in concrete compressive stresses

A2 The fatigue design stress range in concrete compressive stress under the combination of—

- (a) long-term permanent effects; and
- (b) the fatigue design traffic loading specified in AS 5100.2,

shall be determined from the following equations.

For sections with a triangular distribution of stress:

$$(\sigma_{\max} - \sigma_{\min}) \leq 0.45 (\phi_{\text{c.fat}} f'_c - \sigma_{\min}) \quad 2.2.2.1$$

For sections with a rectangular distribution of stress:

$$(\sigma_{\max} - \sigma_{\min}) \leq 0.30 (\phi_{\text{c.fat}} f'_c - 1.7\sigma_{\min}) \quad 2.2.2.2$$

where

$\sigma_{\min}$ = minimum compressive stress at the extreme fibre at the section under consideration, taken as zero if tensile

$\sigma_{\max}$ = maximum compressive stress at the extreme fibre at the section under consideration

$\phi_{\text{c.fat}}$ = capacity reduction factor for fatigue in concrete, taken as 0.65

Equations 2.2.2.1 and 2.2.2.2 are valid for the number of effective stress cycles n , where $10^4 \leq n \leq 10^8$.

The concrete compressive stress due to long-term permanent effects shall not exceed $0.7\phi_{\text{c.fat}} f'_c$.

$\sigma_{\max}$ and $\sigma_{\min}$ shall be calculated using the same PE load combination such that the fatigue design stress range ($\sigma_{\max} - \sigma_{\min}$) is the stress from the fatigue design traffic loading. **A2**

2.2.3 Shear limited by web compressive stresses

In no case shall the maximum shear force in flexural members under the combination of permanent effects and the fatigue design loading exceed 0.60 times the value of $\phi V_{\text{u,max}}$, where $V_{\text{u,max}}$ is calculated in accordance with [Clause 8.2.3.3](#).

2.2.4 Shear in slabs

The maximum shear force in concrete slabs, as determined in accordance with [Clause 9.2](#) under the combination of permanent effects and the fatigue design loading, shall be limited to the values specified in this Clause.

Where the slab can act as a wide beam and a shear failure could occur across a substantial width, the maximum calculated shear shall be limited to 0.60 times the value of ϕV_{u} in accordance with [Clause 9.2](#).

For slabs where the effective number of stress cycles is greater than 2 000 000, the maximum calculated shear shall be limited to 0.54 times the value of ϕV_u . If the longitudinal tensile reinforcement ratio $(A_{st} + A_{pt})/(bd_o)$ is less than 0.01, the permissible shear shall be reduced by multiplying the permissible value of ϕV_u by the factor $[100(A_{st} + A_{pt})/(bd_o)]^{1/3}$.

Where the potential failure surface could form a truncated cone or pyramid around a support or loaded area, the maximum calculated shear shall be limited to 0.50 times the value of ϕV_u specified in [Clause 9.2.3](#).

2.2.5 Tensile stress range in steel

The maximum tensile stress range in tendons and reinforcement, including stainless steel reinforcement, under the fatigue loading specified in AS 5100.2 shall be limited to the appropriate values given in [Table 2.2.5](#). These stress ranges are applicable for 2 000 000 stress cycles.

To account for the design number of stress cycles (n), determined from AS 5100.2, the values given in [Table 2.2.5](#) shall be multiplied by the stress range factor α_f —

where

$$\alpha_f = \left(2 \times 10^6 / n\right)^{1/3} \geq 0.74 \quad 2.2.5$$

In areas of high fluctuating stresses, such as in deck slabs, welded lap splices shall not be used. All other welding, including tack-welding of reinforcing bar shall be in accordance with AS/NZS 1554.3, or welded mesh in accordance with AS/NZS 4671, as appropriate.

The verification of fatigue capacity of welded reinforcement, welded mesh and mechanical splices shall be in accordance with AS 3600.

Other verification methods for fatigue capacity may be applied, if approved by the relevant authority.

Table 2.2.5 — Permissible tensile fatigue stress ranges in steel

Type of steel embedded in concreted	Fatigue design stress range limit, MPa
Reinforcement for straight bar	150
Reinforcement at bar bend	$150 (0.35 + 0.026 d_i/d_b) \leq 150$
Prestressing wires and strands in grouted plastic ducts	150
Prestressing wires, strands and bars in grouted steel ducts	100
Straight pretensioned strands	150
Deflected pretensioned strands	70
LEGEND: d_b = nominal diameter of a reinforcing bar d_i = nominal internal diameter of reinforcement bend or hook	

2

2.2.6 Calculation of stresses in the reinforcement and tendons of flexural members for members with at least minimum transverse shear reinforcement

2.2.6.1 General

When assessing steel stresses for fatigue in flexural members with minimum transverse shear reinforcement in accordance with [Clause 8.2.5](#), the stress variations in both the longitudinal reinforcement and tendons and shear reinforcement shall be calculated in accordance with either [Clause 2.2.6.2](#) or [Clause 2.2.6.3](#).

The calculated maximum stress range in tensile reinforcements due to the fatigue loading shall be not greater than the stress range limits given in [Clause 2.2.5](#).

2.2.6.2 Determination by strut and tie modelling

The stress variations in —

- (a) longitudinal reinforcement and tendons; and
- (b) shear reinforcement,

shall be calculated using a strut and tie model in accordance with [Section 7](#).

The angle between the compression struts and the longitudinal axis of the member shall be —

- (i) between 40° and 55° for non-prestressed slabs; and
- (ii) between 35° and 55° for all other applications.

2.2.6.3 Determination by simplified calculation

The stress variations in longitudinal reinforcement and tendons shall be calculated by elastic cracked section analysis.

The stress variations in the shear reinforcement shall be calculated in accordance with [Clause 8.2](#), with the shear force carried by concrete taken as $0.5V_{uc}$, where V_{uc} is determined from [Clause 8.2.4](#) for the combination of unfactored permanent effects and fatigue vehicle loading.

In the calculation of shear and longitudinal forces, the angle of the compression strut with the longitudinal axis in [Clause 8.2.5.2](#) shall be replaced with θ_{fat} where:

$$\theta_{fat} = \arctan\left(\sqrt{\tan \theta_v}\right) \quad 2.2.6.3$$

When $\theta_v < 45$ degrees; $\theta_{fat} = \theta_v$,

In Equation 2.2.6.3, θ_v is calculated in accordance with [Clause 8.2.4.2](#). ^(A2)

2.3 Design for strength

2.3.1 General

Strength checks for concrete structures and their component members shall be carried out using the procedures specified in [Clauses 2.3.2](#) to [2.3.6](#), and methods of structural analysis specified in [Section 6](#), as appropriate to the strength check procedures being used.

It shall be permissible to use different strength check procedures for different members in a structure, and for the structure as a whole, provided it can be shown that all external actions and forces and calculated internal stress resultants are consistent with the requirements of equilibrium and compatibility for the entire structure.

2.3.2 Strength check procedure for use with linear elastic methods of analysis

The strength check procedure for use in conjunction with—

- (a) linear elastic methods of analysis of indeterminate structures and members;
- (b) simplified methods of analysis of indeterminate structures and members; and
- (c) static analysis of determinate structures,

shall be carried out as follows:

- (i) It shall be confirmed that the design capacity is equal to or greater than the design action effect, for all critical cross-sections and regions—

$$R_d \geq E_d \quad 2.3.2$$

where

R_d = design capacity (equal to ϕR_u)

E_d = design action effect

- (ii) The design capacity ($R_d = \phi R_u$) shall be obtained using the appropriate capacity reduction factor (ϕ), given in [Table 2.3.2](#), and the ultimate strength (R_u), determined in accordance with the relevant sections of this Standard, using characteristic values for the material strengths.
- (iii) The design action effect (E_d) shall be determined for the critical combination of factored actions specified in AS 5100.2 and [Clause 2.5](#) by one of the following methods of analysis:
 - (A) Linear elastic analysis in accordance with [Clause 6.2](#).
 - (B) Linear elastic analysis incorporating secondary bending moments due to lateral joint displacement in accordance with [Clause 6.3](#).
 - (C) Analysis in accordance with [A2 Clause 6.4 A2](#).
 - (D) Equilibrium analysis of a statically determinate structure.

[A2](#) The capacity reduction factor (ϕ) in Item (ii) and load combinations in Item (iii) above shall not apply when using displacement-based earthquake design for assessing the flexural strength of plastic hinge zones of bridge columns in seismic design categories BEDC-2 to BEDC-4. [A2](#)

For displacement-based earthquake design, the capacity reduction factor $\phi = 1.0$.

Table 2.3.2 — Capacity reduction factors (ϕ)

Type of action effect	Capacity reduction factor (ϕ)
(a) Axial force without bending:	
(i) Tension:	0.8
(ii) Compression	0.6
(b) Bending without axial tension or compression:	$0.6 \leq (1.19 - 13k_{uo}/12) \leq 0.8$
(c) Bending with axial tension:	$\phi + [(0.8 - \phi) (N_u / \text{A2} N_{ub} \text{A2})]$ and ϕ is obtained from Item (b)
(d) Bending with axial compression, where—	
(i) $N_u \geq N_{ub}$	0.6
(ii) $N_u < N_{ub}$	$0.6 + [(\phi - 0.6) (1 - N_u / \text{A2} N_{ub} \text{A2})]$ and ϕ is obtained from Item (b)
(e) Shear	0.7
(f) Torsion	0.7

Table 2.3.2 (continued)

Type of action effect	Capacity reduction factor (ϕ)
(g) Bearing	0.6
(h) Bending, shear and compression in plain concrete	0.6
(i) Bending, shear and tension fixings	0.6
[A2] [Note deleted.] [A2]	

2.3.3 Strength check procedure for use with linear elastic stress analysis

The strength check procedure for use with a linear elastic stress analysis of a structure or member shall be made as follows:

- (a) The structure or member shall be analysed for the critical combination of factored actions, as specified in AS 5100.2 and [Clause 2.5](#), by linear stress analysis, in accordance with [Clause 6.4](#), assuming the concrete to be uncracked, and using accepted principles of mechanics.
- (b) The calculated principal compressive stresses shall not exceed the following value:

$$\phi_s \beta 0.9 f'_c \quad 2.3.3$$

where

ϕ_s = stress reduction factor with values taken from [Table 2.3.3](#)

β = an effective compressive strength factor, to be evaluated as follows:

- (i) In regions not containing effective confining reinforcement, β shall equal 1.0 when the principal tensile stress does not exceed f'_{ct} , otherwise β shall equal 0.6.
- (ii) In regions where effective confining reinforcement is provided, β shall be evaluated by rational calculation taking account of the amount of confining steel and the details used, but shall not exceed 2.
- (c) Reinforcement and/or tendons shall be provided to carry all of the internal tensile forces, with stresses not exceeding $\phi_s f_{sy}$ and $\phi_s f_{py}$ respectively, where values for the stress reduction factor using linear analysis (ϕ_s) are in accordance with [Table 2.3.3](#).
- (d) In determining the areas of steel reinforcement, it shall be permissible to reduce the peak stresses by averaging the stresses over an area appropriate to the size of the member.
- (e) The stress development of the reinforcement and tendons shall be determined in accordance with [Clauses 13.1](#) and [13.3](#) respectively.

Table 2.3.3 — Stress reduction factors for design using linear stress analysis (ϕ_s)

Material	Stress reduction factor (ϕ_s)
Concrete	0.6
Reinforcement and tendons	0.8
[A2] [Note deleted.] [A2]	

2.3.4 Strength check procedure for use with strut-and-tie analysis

The strength check procedure for use with strut-and-tie analysis shall be carried out as follows:

- (a) The strut-and-tie model shall satisfy the requirements of [Section 7](#).

- (b) The forces acting on all struts and ties and nodes shall be determined for the critical combination of factored actions as specified in AS 5100.2 and [Clause 2.5](#) by an analysis of the strut-and-tie model in accordance with [Section 7](#).
- (c) The compressive force in any concrete strut shall not exceed the design strength of that strut determined in accordance with [Clause 7.2.3](#). The strength reduction factor (ϕ_{st}) to be used in determining the design strength shall be in accordance with [Table 2.3.4](#).
- (d) The tensile force in any tie shall not exceed the design strength of the tie determined in accordance with [Clause 7.3.2](#) where the strength reduction factor (ϕ_{st}) is given in [Table 2.3.4](#).
- (e) The reinforcement and/or tendons in the ties shall be anchored in accordance with [Clause 7.3.3](#).
- (f) The design strength of nodes shall be calculated in accordance with [Clause 7.4.2](#) and shall not be exceeded. The strength reduction factor (ϕ_s) shall be in accordance with [Table 2.3.4](#).

Table 2.3.4 — Strength reduction factors for design using strut-and-tie analysis (ϕ_{st})

Material	Strength reduction factor (ϕ_{st})
Concrete in compression	0.6
Steel in tension	0.8

2.3.5 Strength check procedure for use with non-linear analysis of framed structures

The strength check procedure for use with non-linear analysis of framed structures at collapse shall be carried out as follows:

- (a) It shall be confirmed that the design capacity of the structure (R_d) is equal to or greater than the design action effect (E_d)—

$$R_d \geq E_d \quad 2.3.5$$
- (b) The design action effect (E_d) is the critical combination of factored actions as specified in AS 5100.2 and [Clause 2.5](#).
- (c) The design capacity of the structure ($R_d = \phi_{sys} R_{u,sys}$) shall be obtained using the appropriate system strength reduction factor (ϕ_{sys}) given in [Table 2.3.5](#), and the mean capacity of the structure ($R_{u,sys}$) determined for the same combination of actions adopted in Item (b) to evaluate E_d , by using non-linear frame analysis as specified in [Clause 6.5](#), with mean values of material properties.

Table 2.3.5 — System strength reduction factors for design using non-linear methods of analysis (ϕ_{sys})

Type of failure	System strength reduction factor (ϕ_{sys})
For structural systems in which the deflections and local deformations at high overload are an order of magnitude greater than those for service conditions; and yielding of the reinforcement and/or the tendon occurs well before the peak load is reached	0.7
In all other cases	0.5 (see Note)
NOTE Larger values than 0.5 may be used if it can be shown that, at high overload, adequate warning is given of impending collapse.	

2.3.6 Strength check procedure for use with non-linear stress analysis

The strength check procedure for use with non-linear stress analysis at collapse shall be carried out as follows:

- (a) It shall be confirmed that the design capacity of the structure or the component member is equal to or greater than the design action effect—

$$R_d \geq E_d \quad 2.3.6$$

where

R_d = design capacity of the structure or component

E_d = design action effect on the structure or the design action effects for a component

- (b) The design action effect (E_d) shall be the critical combination of factored actions (or action effects) as specified in AS 5100.2 and [Clause 2.5](#).
- (c) The design capacity of the structure (or component) ($R_d = \phi_{sys} R_{u,sys}$) shall be obtained using the appropriate system strength reduction factor (ϕ_{sys}) given in [Table 2.3.5](#), and the mean capacity of the structure (or component) ($R_{u,sys}$), which shall be determined for the same combination of actions adopted for E_d , by non-linear stress analysis as specified in [Clause 6.6](#), with mean values of material properties.

2.4 Design for serviceability

2.4.1 General

Design checks shall be carried out for all appropriate service conditions to ensure the structure will perform in a manner appropriate for its intended function and purpose.

NOTE Design limits given or implied in [Clauses 2.4.2](#) and [2.4.3](#) are based on previous design experience, and reflect requirements for normal structures. In special situations other limits may be appropriate.

2.4.2 Deflection

A limit for the calculated deflection of the member shall be chosen and shall be appropriate to the structure and its intended use. The chosen value shall be not greater than the deflection limits as specified in AS 5100.2. Deflections shall be calculated in accordance with [Clause 8.5](#) or [Clause 9.3](#), as appropriate.

2.4.3 Cracking

2.4.3.1 General

Cracking in concrete structures shall be controlled by appropriate design, specification and construction measures so that structural performance, durability and appearance of the structure are appropriate to its intended use, which shall include cracking in both the pre-hardened and hardened concrete states.

2.4.3.2 Control of cracking

The design requirements for the control of cracking in the hardened concrete state, as set out in [Clause 2.4.3.1](#), shall be deemed to be satisfied by designing the structure and members to conform to the following requirements:

- (a) Flexural cracking in concrete beams and slabs under service conditions shall be controlled in accordance with [Clause 8.6](#), [9.4.1](#), [9.4.2](#), [9.4.4](#) or [9.4.5](#), as appropriate.

- (b) Cracking caused by shrinkage and temperature in concrete slabs shall be controlled in accordance with [Clause 9.4.3](#).
- (c) Cracking in concrete walls under service conditions shall be controlled in accordance with [Clause 11.7.2](#).
- (d) Cracking in D-regions under service conditions shall be controlled in accordance with [\[A2\] Clause 12.7 \[A2\]](#).
- (e) Early age thermal cracking of large and/or restrained members shall be controlled in accordance with [Clause 4.12](#).

Notwithstanding the above requirements, all concrete members shall be provided with a minimum of reinforcement as follows:

- (i) For members with a thickness of 150 mm or less, a single layer of reinforcement of not less than 500 mm²/m shall be provided for each of two directions, at right angles to each other.

NOTE Reinforcement provided for structural reasons may be considered as contributing towards this requirement.

- (ii) For members with a thickness greater than 150 mm, each face of the member shall be reinforced with not less than 500 mm²/m for each of two directions at right angles to each other. The layers shall be placed, as close to each surface as cover and detailing permit.

NOTE Reinforcement provided for structural reasons and located within 80 mm of the face may be considered as contributing towards this requirement (see Tables 4.13.3.2 and 4.13.3.3).

Reinforcement shall be provided in two directions at right angles to each other and with a spacing that is less than or equal to 300 mm.

Where considered necessary for durability requirements (for example, for exposure classifications B2 or more severe) or where crack width is considered detrimental to the appearance of the structure, consideration shall be given to limiting the steel stresses near the tension face to values less than those given in this Standard. In addition, in such conditions consideration shall be given to the detailing of the structure to minimize cracking due to restraint and shrinkage.

2.4.4 Vibration

Vibration in concrete structures and members shall comply with the dynamic behaviour requirements as specified in AS 5100.2 so that the serviceability and structural performance are not adversely affected.

2.5 Actions and combinations of actions

2.5.1 Actions and loads

The minimum actions and loads used in the design shall be those set out in AS 5100.2.

2.5.2 Combinations of actions and loads

The combinations of actions, loads and forces (including prestressing forces) used in the design shall be in accordance with AS 5100.2.

[\[A2\]](#) [Note deleted.] [\[A2\]](#)

2.6 Design for strength and serviceability by prototype testing

Notwithstanding the requirements of [Clause 2.2](#), a structure or a component may be designed for strength provided the prototype is tested in accordance with [Appendix A](#).

If this alternative procedure is adopted, the requirements of [Clause 2.7](#) shall apply, as appropriate.

2.7 Other design requirements

Requirements, such as progressive collapse and any special performance requirements, shall be considered where relevant and, if significant, shall be taken into account in the design of the structure in accordance with the principles of this Standard and appropriate engineering principles.

The use of reinforcing steels complying with AS/NZS 4671 having a yield strength (f_{sy}) of 500 MPa and Ductility Class E shall be considered for members and structures requiring increased ductility to satisfy seismic design requirements. Grade 500E reinforcement shall not be subjected to welding or heating.

Beam stability during lifting and erection shall be in accordance with [Appendix B](#).

Section 3 Design properties of materials

3.1 Properties of concrete

3.1.1 Strength

3.1.1.1 Characteristic compressive strength

The characteristic compressive strength of concrete at 28 days (f'_c) shall be either—

- (a) taken as equal to the specified strength grade, provided the appropriate curing is ensured and that the concrete complies with [Section 17](#); or
- (b) determined statistically from compressive strength tests carried out in accordance with AS 1012.9.

NOTE The characteristic compressive strengths of the standard strength grades are 25 MPa, 32 MPa, 40 MPa, 50 MPa, 65 MPa, 80 MPa and 100 MPa.

3.1.1.2 Mean in situ compressive strength

In the absence of more accurate data, the mean value of the in situ compressive strength (f_{cmi}) shall be taken as 90% of the mean value of the cylinder strength (f_{cm}) at the relevant age or shall be taken as those given in [Table 3.1.2](#).

3.1.1.3 Tensile strength

The uniaxial tensile strength (f_{ct}) is the maximum stress that concrete can withstand when subjected to uniaxial tension.

The uniaxial tensile strength shall be determined from either the measured flexural tensile strength ($f_{ct,f}$) or from the measured splitting tensile strength ($f_{ct,sp}$) using either—

$$f_{ct} = 0.6 f_{ct,f}$$

or

$$f_{ct} = 0.9 f_{ct,sp}$$

where $f_{ct,f}$ and $f_{ct,sp}$ are determined statistically from—

- (a) flexural strength tests carried out in accordance with AS 1012.11; or
- (b) indirect tensile strength tests carried out in accordance with AS 1012.10, respectively.

In the absence of more accurate data, the characteristic flexural tensile strength of concrete ($f'_{ct,f}$) and the characteristic uniaxial tensile strength of concrete (f'_{ct}) shall be taken as—

$$f'_{ct,f} = 0.6 \sqrt{f'_c} \text{ and } f'_{ct} = 0.36 \sqrt{f'_c} \text{ at 28 days and standard curing,}$$

where the mean and upper characteristic values are obtained by multiplying these values by 1.4 and 1.8, respectively.

3.1.1.4 Supplementary cementitious materials

3.1.1.4.1 General

[A2] [Text deleted.] [A2]

3.1.1.4.2 Fly ash

Fly ash, which is the solid material extracted from the flue gases of a boiler fired with pulverized coal, shall comply with AS/NZS 3582.1.

3.1.1.4.3 Ground granulated iron blast-furnace slag (slag)

Ground granulated iron blast-furnace slag, which is a material consisting essentially of silicates and aluminosilicates of calcium produced simultaneously with iron in a blast furnace, shall comply with AS 3582.2.

3.1.1.4.4 Amorphous silica

Amorphous silica, which is a very fine pozzolanic material composed mostly of non-crystalline silica, shall comply with AS/NZS 3582.3.

NOTE The high specific surface area of amorphous silica can cause workability problems when used in cement paste, mortar or concrete if suitable measures or precautions are not implemented.

[A2] 3.1.1.4.5 Manufactured pozzolans

Pozzolan, which can be a by-product of mineral processing, manufacturing, waste to energy, recovered resources or processed or calcined natural materials, shall conform to AS 3582.4. **[A2]**

3.1.2 Modulus of elasticity

The mean value of modulus of elasticity of concrete (E_{cj}) at the appropriate age j , in days, shall be either one of the following:

(a) Taken as equal to—

$$(i) \quad \left(\rho^{1.5}\right) \times \left(0.043 \sqrt{f_{cmi}}\right) \quad (\text{in megapascals}) \quad \text{when } f_{cmi} \leq 40 \text{ MPa; or}$$

$$(ii) \quad \left(\rho^{1.5}\right) \times \left(0.12 + 0.024 \sqrt{f_{cmi}}\right) \quad (\text{in megapascals}) \quad \text{when } f_{cmi} > 40 \text{ MPa.}$$

(b) For Standard strength grades at 28 days determined from [Table 3.1.2](#) and determined by test in accordance with AS 1012.17.

NOTE 1 Where E_{cj} is determined from Item (a) or (b) above, consideration should be given to the fact that this value has a range of $\pm 20\%$.

NOTE 2 Where a load is sustained and where the concrete deformation is unrestrained such that time-dependent deflections or strains are produced, or where a deformation is sustained so that the time-dependent stress reductions occur, the final value of the time-dependent effects may be calculated by using an effective modulus of elasticity equal to E_c divided by $(1 + \phi_{cc}^*)$ where ϕ_{cc}^* is taken at its final value.

Table 3.1.2 — Concrete properties at 28 days

f'_c , MPa	20	25	32	40	50	65	80	100
f_{cmi} , MPa	22	28	35	43	53	68	82	99

Table 3.1.2 (continued)

E_c , MPa	24 000	26 700	30 100	32 800	34 800	37 400	39 600	42 200
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3.1.3 Density

The density of concrete (ρ) shall be either—

- (a) taken as not less than 2400 kg/m³ for normal weight concrete; or
- (b) determined by test in accordance with AS 1012.12.1 or AS 1012.12.2.

3.1.4 Stress-strain curves

The stress-strain curve for concrete shall be either—

- (a) assumed to be of curvilinear form defined by recognized simplified equations; or
- (b) determined from suitable test data.

For design purposes, the shape of the in situ uniaxial compressive stress-strain curve shall be modified so that the maximum stress is $0.9f'_c$.

The maximum stress specified above shall not apply when assessing the flexural strength of plastic hinge zones of bridge columns in accordance with [Clause 10.2.4.2](#).

3.1.5 Poisson's ratio

Poisson's ratio for concrete (ν) shall be either—

- (a) taken as equal to 0.2; or
- (b) determined by test in accordance with AS 1012.17.

3.1.6 Coefficient of thermal expansion

The coefficient of thermal expansion of concrete shall be either—

- (a) taken as equal to $10 \times 10^{-6}/^{\circ}\text{C}$, consideration being given to the fact that this value has a range of $\pm 20\%$; or
- (b) determined from suitable test data.

3.1.7 Shrinkage**3.1.7.1 Calculation of design shrinkage strain**

The design shrinkage strain of concrete (ϵ_{cs}) shall be determined—

- (a) from measurements on similar local concrete;
- A2 (b) by calculation in accordance with [Clause 3.1.7.2](#);
- (c) by calculation in accordance with [Clause 3.1.7.2](#) where the value for $\epsilon_{csd,b}^*$ is evaluated from testing.

NOTE Refer to Clause 3.1.7.2 of AS 3600:2018 Sup 1:2022 for guidance on the evaluation from testing method. A2

3.1.7.2 Design shrinkage strain

2 The design shrinkage strain of concrete (ϵ_{cs}) shall be calculated as the sum of the chemical (autogenous) shrinkage strain (ϵ_{cse}) and the drying shrinkage strain (ϵ_{csd}), as follows:

$$\epsilon_{cs} = \epsilon_{cse} + \epsilon_{csd} \quad 3.1.7.2(1)$$

The autogenous shrinkage strain shall be taken as—

$$\epsilon_{cse} = \epsilon_{cse}^* \times (1.0 - e^{-0.07t}) \quad 3.1.7.2(2)$$

where t is the time (in days) after setting and ϵ_{cse}^* is the final autogenous shrinkage strain given by—

$$\begin{aligned} \text{For } f'_c \leq 50 \text{ MPa, } \epsilon_{cse}^* &= (0.07f'_c - 0.5) \times 50 \times 10^{-6} \\ \text{For } f'_c > 50 \text{ MPa, } \epsilon_{cse}^* &= (0.08f'_c - 1) \times 50 \times 10^{-6} \end{aligned} \quad 3.1.7.2(3)$$

NOTE 1 The effect of temperature on autogenous shrinkage may be taken into account by adjusting time t in Equation 3.1.7.2(2).

At any time (t), in days, after the commencement of drying, the drying shrinkage strain shall be taken as—

$$\epsilon_{csd} = k_1 k_4 \epsilon_{csd.b} \quad 3.1.7.2(4)$$

and k_1 is obtained from [Figure 3.1.7.2](#) and k_4 is equal to 0.7 for an arid environment, 0.65 for an interior environment, 0.6 for a temperate inland environment and 0.5 for a tropical or near-coastal environment.

The basic drying shrinkage strain ($\epsilon_{csd.b}$) shall be taken as—

$$\epsilon_{csd.b} = (0.9 - 0.005f'_c) \times \epsilon_{csd.b}^* \quad 3.1.7.2(5)$$

where $\epsilon_{csd.b}^* = 800 \times 10^{-6}$.

NOTE 2 Typical final design shrinkage strains after 30 years are found in [Table 3.1.7.2](#).

NOTE 3 Consideration should be given to the fact that ϵ_{cs} has a range of $\pm 30\%$.

NOTE 4 Concrete exposed to early drying undergoes shrinkage due to capillary suction. This can result in cracking and poor service performance, particularly of exposed slabs. The amount of shrinkage from suction depends on the ambient conditions and the concrete mix, and can exceed the combined shrinkage from other causes. Excessive drying of concrete between the commencement of casting and the application of curing at the completion of finishing should therefore be avoided. [42](#)