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Excerpt
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Part |

Reinforced concrete

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Introduction

1.1 Historical notes

Australian Standard (AS) 3600-1988 *Concrete Structures*, the first of the AS 3600 series, was published in March 1988. In line with European practices, it was a unified code covering reinforced and prestressed concrete structures. In effect, AS 3600-1988 *Concrete Structures* was the revised and amalgamated version of AS 1480-1982 *Concrete Structures Code* and AS 1481-1978 *Prestressed Concrete Code*, which it then superseded. Limit state design philosophy was adopted in AS 3600-1988. In practice, especially in strength design, engineers familiar with AS 1480-1982 could make the changeover without too much difficulty. Many of the design equations for shear, torsion, slabs and columns changed, but the strength design procedure was basically the same, that is, to ensure

$$\phi R_u \geq S^*$$
Equation 1.1(1)

where for a given section of any structural member to be designed, S^* was the ‘action effect’ or axial force, moment, shear or torsion due to the most critical combination of the external service loads, each multiplied by a corresponding load factor; R_u was the computed ultimate resistance (or strength) of the member at that section against the said type of action effect; and ϕ was the capacity reduction factor specified for the type of ultimate strength in question.

Since 1988, AS 3600 has been revised and updated three times and published consecutively at approximately six-year intervals as AS 3600-1994, AS 3600-2001 and now AS 3600-2009 (the Standard). However, the limit state design philosophy remains unchanged in the latest version of the Standard in which Clause 2.2.2 states that

$$R_d \geq E_d$$
Equation 1.1(2)

where $R_d = \phi R_u$ is the ‘design capacity’, and $E_d = S^*$, the design action effect.

Although the strength design procedure is unchanged, the recommended load factors are generally lower than previously specified. However, accompanying these lower load factors are reduced values of ϕ . These changes to ϕ , if seen in isolation, are no doubt retrograde because the implications are that we are less confident now in our design formulas than we were before. A probabilistic-based analytical model was adopted to re-evaluate the reliability of the design procedure. Unfortunately, actual failure statistics were inadequate for the probabilistic analysis to produce a new and more reliable procedure (in terms of load factors and ϕ). Instead, the new procedure was calibrated simply using designs based on the old AS 1480-1982 code. In simplistic terms, the old and the new codes applied in parallel should lead to the same design.

Note also that in AS 3600-2001, which appeared in 2002, N-grade or 500 MPa steel was specified, leading to modifications in serviceability specifications and other consequential changes. In AS 3600-2001, an additional strength grade for concrete was introduced – the characteristic compressive strength $f'_c = 65$ MPa. Two more grades are now provided in AS 3600-2009 ($f'_c = 80$ MPa and 100 MPa). This has resulted in modification to many of the design equations.

Henceforth, unless otherwise specified, all procedures, clauses, terms, formulas, factors and so forth refer to those given in AS 3600-2009.

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1.2 Design requirements

In addition to strength and serviceability, durability and fire resistance are specific design requirements – see Sections 4 and 5 of the Standard, respectively, for details. Since most of the recommended procedures for durability and fire resistance are empirical, they will not be dealt with in as much depth in this book.

Durability requirements mainly affect the choice of concrete strength and the provision of adequate concrete cover for reinforcement (see also Section 1.4). The four exposure conditions originally specified in AS 1480-1982 had been revised. Since AS 3600-1988, there have been six ‘classifications’: A1, A2, B1, B2, C and U, in order of severity. Minimum concrete strength grades and concrete covers for all except Classification U are detailed in Tables 4.10.3.2 and 4.10.3.3 of AS 3600-2009 for different types of construction method and/or environment. Note that Classification C has been expanded into C1 and C2 in these tables. For Classification U, the designer is responsible for providing their own concrete strength and cover specifications appropriate to the desired design. Additional durability requirements for abrasion, freezing and thawing, and other environmental and chemical actions may be found in Clauses 4.6 to 4.9 of the Standard.

Design for fire resistance is achieved by providing adequate concrete cover. Recommendations are given in the form of tables and charts in Section 5 of the Standard.

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1.3 Loads and load combinations

For the first time, the provisions for loads and load combinations are no longer available in AS 3600-2009. The recommendations adopted herein follow those given in the loading Standard AS/NZS 1170.0-2002.

1.3.1 Strength design

For every member section in question, the design effective resistance (ϕR_u) must be able to sustain the action effects ($\pm S^*$) due to the following load combinations:

(a) Dead load only

$$1.35G$$

Equation 1.3(1)

(b) Dead load and live load

$$1.2G + 1.5Q$$

Equation 1.3(2)

(c) Dead load and long-term imposed action

$$1.2G + 1.5\psi_l Q$$

Equation 1.3(3)

(d) Dead load, wind and live load

$$1.2G + W_u + \psi_c Q$$

Equation 1.3(4)

(e) Dead load and wind action reversal

$$0.9G + W_u$$

Equation 1.3(5)

(f) Dead, earthquake and live load

$$G + E_u + \psi_c Q$$

Equation 1.3(6)

(g) Dead load, liquid pressures and live load

$$1.2G + S_u + \psi_c Q$$

Equation 1.3(7)

where G is the effect due to permanent action (dead load); Q is due to imposed action (live load); W_u is due to ultimate wind action (wind load); E_u is due to ultimate earthquake action (earthquake load); and S_u is due to snow load or liquid pressure or earth and/or ground water pressure; the combination and long-term load factors, ψ_c and ψ_l , vary from 0.0 to 1.2 and 1.0, respectively, depending on the function of the

structure to be designed. For convenience, the values for ψ_c and ψ_l are reproduced from the AS/NZS Standard in Table 1.3(1).

Table 1.3(1) Live load factors for strength design

	Type of live load	Short-term factor (ψ_s)	Long-term factor (ψ_l)	Combination factor (ψ_c)
Distributed imposed actions, Q	Floors			
	Domestic	0.7	0.4	0.4
	Offices	0.7	0.4	0.4
	Parking area	0.7	0.4	0.4
	Storage area	0.7	0.4	0.6
	Other	1.0	0.6	0.6
	Roofs			
	Roofs used for floor-type activities	0.7	0.4	0.4
	All other roofs	0.7	0.0	0.0
Concentrated imposed actions, Q	Floors	1.0	0.6	0.4
	Floors of domestic housing	1.0	0.4	0.4
	Roofs used for floor type activities	1.0	0.6	0.4
	All other roofs	1.0	0.0	0.0
	Balustrades	1.0	0.0	0.0
	Long-term installed machinery, tare weight	1.0	1.0	1.2
Source: Standards Australia (2002). <i>AS/NZS 1170.0:2002 Structural design actions – General principles</i> , Standards Australia, Sydney, NSW. Reproduced with permission from SAI Global under Licence 1004–C029. The Standard is available online at < http://www.saiglobal.com >.				

1.3.2 Serviceability design

The following load combinations must be considered when designing for serviceability.

(a) Short-term effects

(i) G

(ii) $G + W_u$

(iii) $G + \psi_s Q$

Equation 1.3(8)

(b) Long-term effects

(i) G

(ii) $G + \psi_l Q$

Equation 1.3(9)

Note that as per Clause 4.2.4 in AS/NZS 1170.0-2002, the following combination is required for fire resistance design,

$$G + \psi_c Q$$

Equation 1.3(10)

For Equation 1.3(8), the values for the short-term load factor (ψ_s) may also be found in Table 1.3(1).

1.3.3 Application

The purpose of load combinations is to obtain the most critical condition for which the structure must be designed. For the same structure, there may be more than one live load (see, for example, Clause 2.4.4 of the Standard) or wind load pattern, each of which, in combination with other loads, may be critical to different members or different sections of the same member. This makes the computation of S^* very tedious indeed. This is particularly true in column design and the design for shear and torsion where the critical condition is not governed by individual actions, but the interaction of two different effects. For example, in column design, the interaction of axial force and bending moment must be considered.

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1.4 Concrete cover and reinforcement spacing

1.4.1 Cover

For durability design of a concrete structure under various environmental conditions, concrete of suitable strength must be specified by the designer, and adequate cover for the steel reinforcement must be provided. Note that cover means clear cover, or to the ‘outside of the reinforcing steel’. To guide the designer of reinforced and prestressed concrete structures, Table 4.3 of the Standard defines seven classifications of exposure, namely A1, A2, B1, B2, C1, C2 and U, in order of increasing severity. These definitions are re-presented in Table 1.4(1).

For the first six exposure classifications, combinations of concrete strength and minimum cover are specified for various types of construction process and/or environment. These are contained in two tables in the Standard; for convenience they are reproduced herein as Tables 1.4(2) and (3). Note that for crack control, Clause 8.6.1(b) of the Standard states that the maximum cover shall not be greater than $(100\text{ mm} - d_b/2)$ where d_b is the bar diameter.

Adequate concrete cover must also be provided for fire resistance. In-depth and wide-ranging recommendations are provided in Section 5 of the Standard. It is appropriate here to remind the reader that following durability design for environmental factors, checks must be made against the requirements for fire resistance. Increase the cover if necessary.

Table 1.4(1) Exposure classifications

Surface and exposure environment	Exposure classification
1. Surfaces of members in contact with the ground	
(a) Members protected by a damp-proof membrane	A1
(b) Residential footings in non-aggressive soils	A1
(c) Other members in non-aggressive soils	A2
(d) Members in aggressive soils	U
(e) Salt rich soils and soils in salinity-affected areas	U
2. Surfaces of members in interior environments	
(a) Fully enclosed within a building except for a brief period of weather exposure during construction	A1
(b) In industrial buildings, the member being subject to repeated wetting and drying	B1
3. Surfaces of members in above-ground exterior environments	
(a) Inland areas (>50 km from coastline)	
(i) Non-industrial and arid climatic zone	A1
(ii) Non-industrial and temperate climatic zone	A2
(iii) Non-industrial and tropical climatic zone	B1
(iv) Industrial and any climatic zone	B1
(b) Near-coastal areas (1 km to 50 km from coastline), any climatic zone	B1
(c) Coastal areas and any climatic zone ^a	B2
4. Surface of members in water	
(a) In fresh water	B1
(b) In soft or running water	U
5. Surface of maritime structures in sea water	
(a) permanently submerged	B2
(b) in spray zone ^b	C1
(c) in tidal/splash zone	C2
6. Surfaces of members in other environments	
Any exposure environment not otherwise described in Items 1 to 5 above ^c	U
a The coastal zone includes locations within 1 km of the shoreline of large expanses of salt water. Where there are strong prevailing winds or vigorous surf, the distance should be increased beyond 1 km and higher levels of protection should be considered.	
b The spray zone is the zone from 1 m above the wave crest level.	
c Further guidance on measures appropriate in exposure Classification U may be obtained from AS 3735-2001.	
Source: Standards Australia (2009). <i>AS 3600-2009 Concrete Structures</i> . Standards Australia, Sydney, NSW. Reproduced with permission from SAI Global under Licence 1004-C029. The Standard is available online at < http://www.saiglobal.com >.	

Table 1.4(2) Required cover (mm), where standard formwork and compaction are used

Exposure classification	Characteristic concrete strength (f'_c)				
	20 MPa	25 MPa	32 MPa	40 MPa	≥50 MPa
A1	20	20	20	20	20
A2	(50)	30	25	20	20
B1	–	(60)	40	30	25
B2	–	–	(65)	45	35
C1	–	–	–	(70)	50
C2	–	–	–	–	65

– = not applicable

Notes:

(1) Figures in parentheses are the appropriate covers when the concession given in Clause 4.3.2 of the Standard, relating to the strength grade permitted for a particular exposure classification is applied.

(2) Cover should not be less than the greater of the maximum nominal aggregate size and bar diameter.

Source: Standards Australia (2009). *AS 3600-2009 Concrete Structures*. Standards Australia, Sydney, NSW. Reproduced with permission from SAI Global under Licence 1004-C029. The Standard is available online at <<http://www.saiglobal.com>>.

Table 1.4(3) Required cover (mm) where repetitive procedures and intense compaction or self-compacting concrete are used in rigid formwork

Exposure classification	Characteristic concrete strength (f'_c)				
	20 MPa	25 MPa	32 MPa	40 MPa	≥50 MPa
A1	20	20	20	20	20
A2	(45)	30	20	20	20
B1	–	(45)	30	25	20
B2	–	–	(50)	35	25
C1	–	–	–	(60)	45
C2	–	–	–	–	60

– = not applicable

Notes:

(1) Bracketed figures are the appropriate covers when the concession given in Clause 4.3.2, relating to the strength grade permitted for a particular exposure classification, is applied.

(2) Cover should not be less than the greater of the maximum nominal aggregate size and bar diameter.

Source: Standards Australia (2009). *AS 3600-2009 Concrete Structures*. Standards Australia, Sydney, NSW. Reproduced with permission from SAI Global under Licence 1004-C029. The Standard is available online at <<http://www.saiglobal.com>>.

Table 1.4(4) Minimum clear spacing of parallel bars

Bars between which clear spacing is measured	Direction in which spacing is measured	Minimum clear spacing (or pitch) shall be the greatest value of ...		
(a) Horizontal bars in beams	Horizontally Vertically	25 mm 25 mm	$1d_b$ $1d_b$	1.5a –
(b) Horizontal bars in slabs, walls and footings	Horizontally Vertically	50 mm 25 mm	$3d_b$ $1d_b$	1.5 a –
(c) Vertical bars	Horizontally	40 mm	$1.5d_b$	1.5a
(d) Bars in ribs of hollow-block or concrete-joist slab construction	Horizontally	15 mm	$1d_b$	1.5a
(e) Helical reinforcement	Pitch or helix	40 mm	$3d_b$ (pitch)	1.5a (pitch)

where

a = the maximum nominal size of the aggregate

d_b = the diameter of the larger bar, or

 = twice the diameter of the larger bar in the bundle, or

 = the diameter of a pipe or a conduit, in which case the spacing applied between adjacent parallel pipes or conduits, whichever is the greater or the greatest, as applicable, or

 = the diameter of the bar forming the helix.

Source: Standards Association of Australia (1982). *SAA 1480-1982 SAA Concrete Structures Code*, Standards Association of Australia, North Sydney, NSW. Reproduced with permission from SAI Global under Licence 1004-C029. The Standard is available online at <<http://www.saiglobal.com>>.

Table 1.4(5) Maximum centre-to-centre spacing of parallel bars and closed ties

Bars ¹	Beams	300 mm (Clause 8.6.1(b))
	Slabs	Lesser of D_s and 300 mm (Clause 9.4.1(b))
Ties	Shear	Lesser of $0.5D$ and 300 mm or Lesser ² of $0.75D$ and 500 mm (Clause 8.2.12.2)
	Torsion	Lesser of $0.12u_t$ and 300 mm (Clause 8.3.8(b))
	Columns	Lesser ³ of D_c and $1.5d_b$ for single bars or $0.5 D_c$ and $7.5d_b$ for bundled bars (Clause 10.7.4.3(b))
	Torsion strips and spandrel beams	Not exceeding the greater of 300 mm and D_b or D_s (Clause 9.2.6(b))

Notes:

1 For crack control purposes.

2 In case of $V^* \leq \phi V_{u,min}$ (see Section 5.2.2 and Equation 5.2(13)).

3 D_c is the diameter of a circular column or the smaller dimension of a rectangular column.

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1.4.2 Spacing

No minimum spacing for bars in beams or other structural elements is specified in the Standard; it only qualifies that ‘the minimum clear distance between parallel bars (including bundled bars), ducts and tendons shall be such that the concrete can be properly placed and compacted . . .’ (see Clauses 8.1.9, 9.1.5 and 11.7.3 of the Standard).

For crack control, Clause 8.6.1(b) of the Standard recommends that the center-to-center spacing of bars shall not exceed 300 mm near the tension face of the beam. The Standard specifies the maximum spacing of transverse reinforcement or closed ties for shear (Clause 8.2.12.2), torsion (Clause 8.3.8(b)), columns (Clause 10.7.4.3(b)), and for torsion strips and spandrel beams of flat plates (Clause 9.2.6(b)). For crack control of slabs, Clause 9.4.1(b) specifies that the maximum center-to-center spacing ‘shall not exceed the lesser of 300 mm and $2.0D_s$ ’ where D_s is the overall depth of the slab. For walls, on the other hand, the minimum clear spacing as per Clause 11.7.3 ‘shall not be less than $3d_b$ ’. For general guidance on minimum reinforcement spacing, the designer may refer to AS 1480-1982. Relevant recommendations are reproduced in Table 1.4(4).

For ease of reference, the various maximum spacing specifications are collated in Table 1.4(5).