How to Specify Durable and Sustainable Concrete

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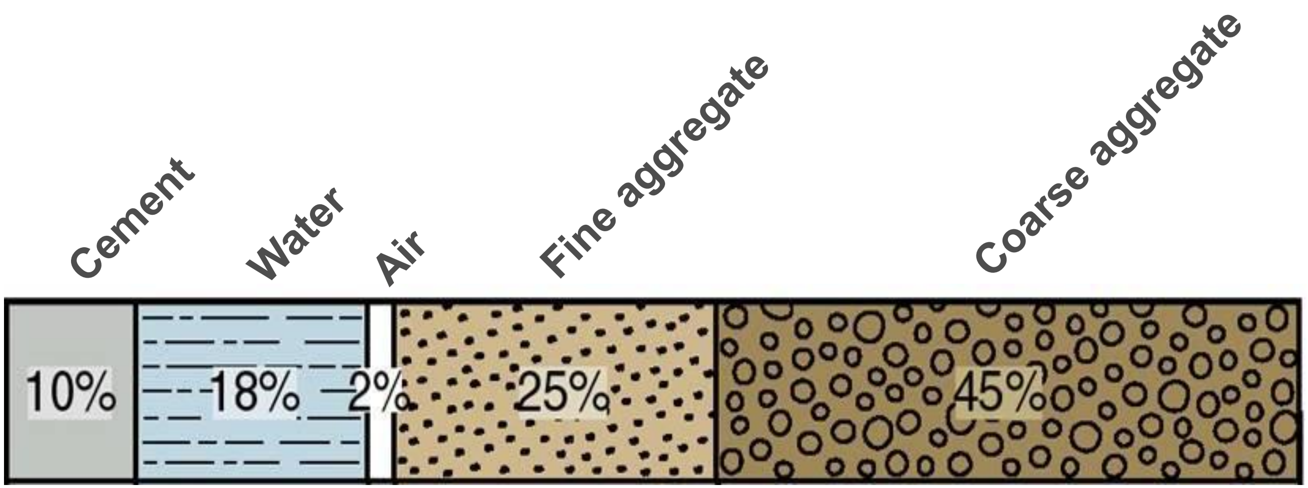
Concrete



Cement
Water
Air
Fine aggregate
Coarse aggregate
10%
18%
2%
25%
45%

Outline

- Specifying the correct exposure class
- Specification methods
- Aggregates
- Cements and combinations
- Use of admixtures
- Responsible sourcing
- Further information

Intended Working Life

BS EN 1990: 2002 *'Eurocode – Basis of structural design'*

• Temporary structures	10 years
• Replaceable structural parts	10-25 years
• Agricultural and similar structures	15-30 years
• Building structures and other common structures	50 years
• Monumental buildings; Bridges; Civil engineering structures	100 years

Intended Working Life

Table A.4 **Durability A) recommendations for reinforced or prestressed elements with an intended working life of at least 50 years**

Nominal cover B) mm	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete C) with 20 mm maximum aggregate size D)								Cement/combination types
	15 + Δc	**20 + Δc**	**25 + Δc**	**30 + Δc**	**35 + Δc**	**40 + Δc**	**45 + Δc**	**50 + Δc**	
Corrosion induced by carbonation (XC exposure classes)									
XC1	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	All in Table A.6
XC2	—	—	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6
XC3/4	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6 except IVB-V
	—	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	IVB-V
Corrosion induced by chlorides (XS from sea water, XD other than sea water) *Also adequate for any associated carbonation induced corrosion (XC)*									
XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XS1	—	—	—	C45/55 E) 0.35 F) 380	C35/45 E) 0.45 360	C32/40 E) 0.50 340	C32/40 E) 0.50 340	C32/40 E) 0.50 340	CEM I, IIA, IIB-S, SRPC
	—	—	—	C40/50 E) 0.35 F) 380	C32/40 E) 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40 E) 0.40 380	C25/30 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIIB
	—	—	—	C32/40 E) 0.40 380	C28/35 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IVB-V
XD2 or XS2	—	—	—	C40/50 E) 0.40 380	C32/40 E) 0.50 340	C28/35 0.55 320	C28/35 0.55 320	C28/35 0.55 320	CEM I, IIA, IIB-S, SRPC
	—	—	—	C35/45 E) 0.40 380	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40 E) 0.40 380	C25/30 0.50 340	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V

Intended Working Life

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Table A.5 **Durability[A] recommendations for reinforced or prestressed elements with an intended working life of at least 100 years**

Nominal cover [B] mm	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete [C] with 20 mm maximum aggregate size [D]										Cement/combination types
	15 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	55 + Δc	60 + Δc	65 + Δc	
Corrosion induced by carbonation (XC exposure classes)											
XC1	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	All in Table A.6
XC2	—	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6
XC3/4	—	—	C40/50 0.45 340	C35/45 0.50 320	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6 except IVB-V
	—	—	—	C40/50 0.45 340	C35/45 0.50 320	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	IVB-V
Corrosion induced by chlorides (XS from sea water, XD other than sea water) *Also adequate for any associated carbonation induced corrosion (XC)*											
XD1	—	—	C45/55 0.40 380	C40/50 0.45 360	C35/45 0.50 340	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XS1	—	—	—	—	—	C45/55[E] 0.35[F] 380	C40/50[E] 0.40 380	C35/45[E] 0.45 360	C35/45[E] 0.45 360	C35/45[E] 0.45 360	CEM I, IIA, IIB-S, SRPC
	—	—	—	C35/45 0.40 380	C32/40[E] 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C35/45 0.45 360	C30/37[E] 0.50 340	C28/35 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIIB
	—	—	—	C40/50 0.45 360	C35/45 0.50 340	C30/37 0.55 320	C28/35 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IVB-V
XD2 or XS2	—	—	—	—	C35/45[E] 0.45 360	C32/40[E] 0.50 340	C28/35 0.55 320	C28/35 0.55 320	C28/35 0.55 320	C28/35 0.55 320	CEM I, IIA, IIB-S, SRPC
	—	—	—	—	C32/40[E] 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	—	C28/35 0.45 360	C25/30 0.50 340	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V

Exposure classification

XC: Corrosion induced by carbonation

XD: Corrosion induced by chlorides

XS: Corrosion induced by chlorides from sea

XF: Freeze-thaw attack

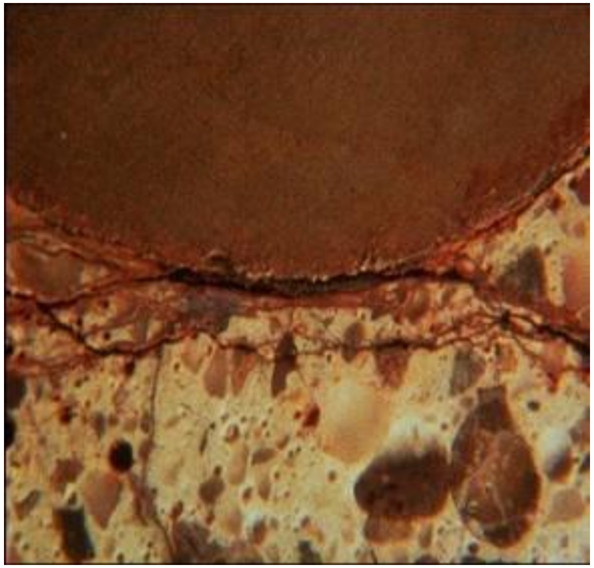
AC: Chemical attack

Exposure classification

XC: Corrosion induced by carbonation

XD: Corrosion induced by chlorides

XS: Corrosion induced by chlorides from sea



XF: Freeze-thaw attack

AC: Chemical attack

Exposure classification

XC: Corrosion induced by carbonation

- **XC1:** Dry or permanently wet
- **XC2:** Wet, rarely dry
- **XC3:** Moderate humidity
- **XC4:** Cyclic wet and dry

XD: Corrosion induced by chlorides

XS: Corrosion induced by chlorides from sea

XF: Freeze-thaw attack

AC: Chemical attack

Exposure classification

XC: Corrosion induced by carbonation

XD: Corrosion induced by chlorides

- **XD1:** Moderate humidity
- **XD2:** Wet, rarely dry
- **XD3:** Cyclic wet and dry

XS: Corrosion induced by chlorides from sea

XF: Freeze-thaw attack

AC: Chemical attack

Exposure classification

XC: Corrosion induced by carbonation

XD: Corrosion induced by chlorides

XS: Corrosion induced by chlorides from sea

- **XS1:** Exposed to airborne salt
- **XS2:** Permanently submerged
- **XS3:** Tidal, splash and spray zones

XF: Freeze-thaw attack

AC: Chemical attack

Exposure classification

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XC: Corrosion induced by carbonation

XD: Corrosion induced by chlorides

XS: Corrosion induced by chlorides from sea

XF: Freeze-thaw attack

AC: Chemical attack

- **XF1:** Moderate water saturation *(no de-icing agent)*
- **XF2:** Moderate water saturation *(de-icing agent)*
- **XF3:** High water saturation, *(no de-icing agent)*
- **XF4:** High water saturation *(de-icing agent)*

Exposure classification

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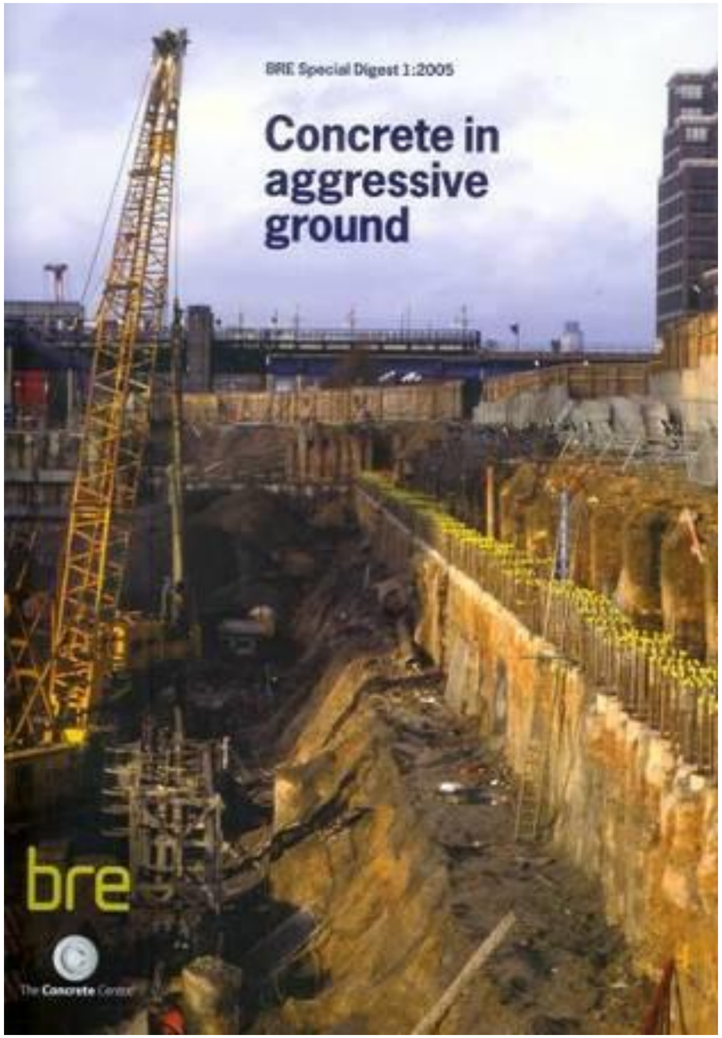
XC: Corrosion induced by carbonation

XD: Corrosion induced by chlorides

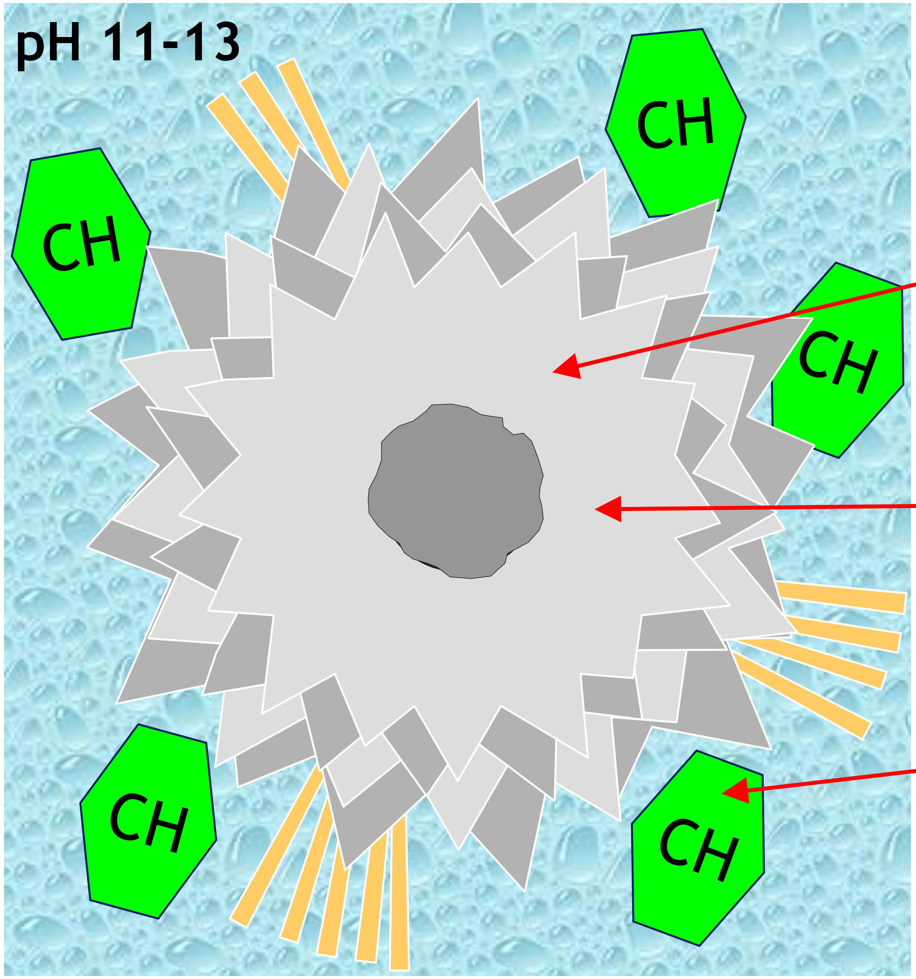
XS: Corrosion induced by chlorides from sea

XF: Freeze-thaw attack

AC: Chemical attack



Cement Hydration



Calcium silicate hydrate **(C-S-H)**

Calcium aluminate hydrate **(C-A-H)**

Calcium hydroxide **($Ca(OH)_2$)**

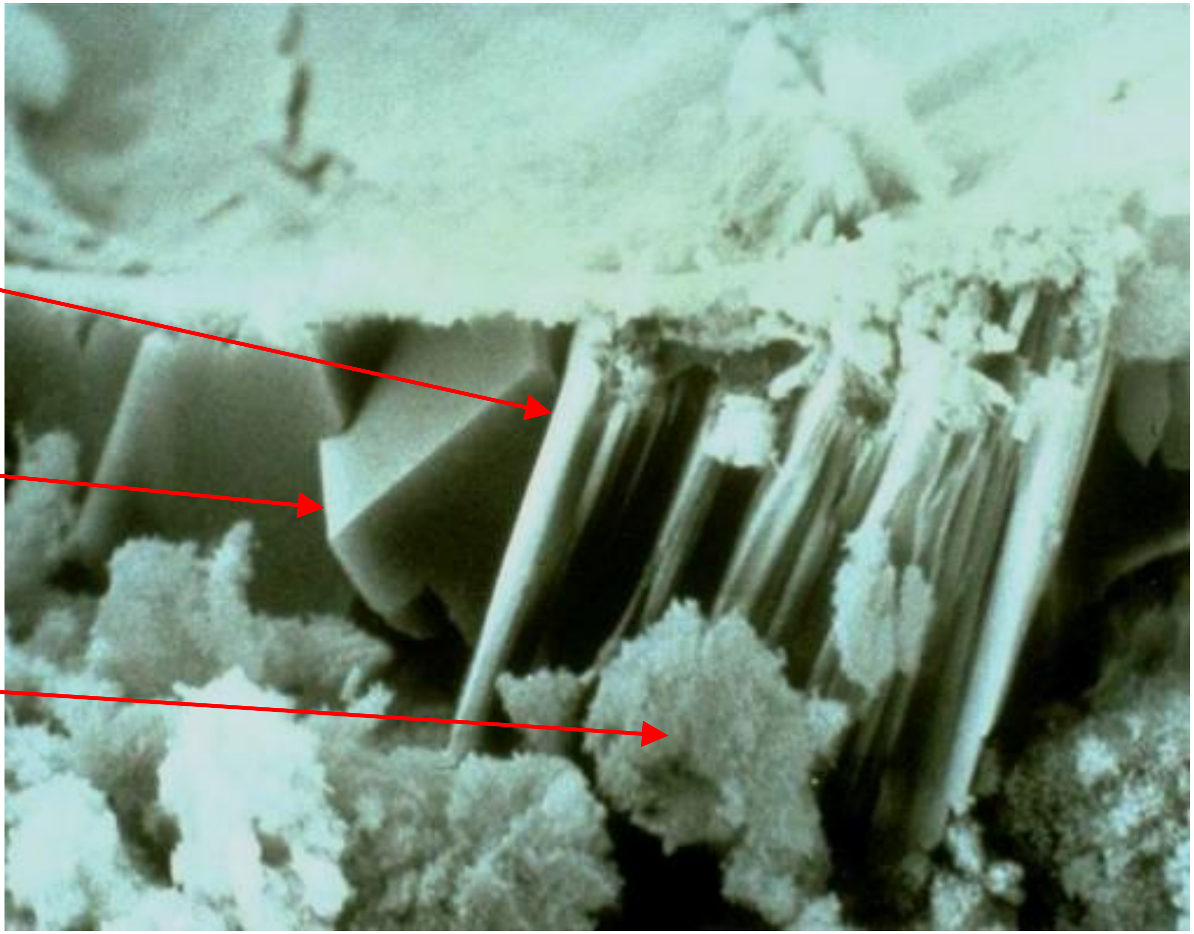
Cement Hydration

Ettringite

$Ca(OH)_2$

C-A-H

C-S-H



Conventional Sulfate Attack

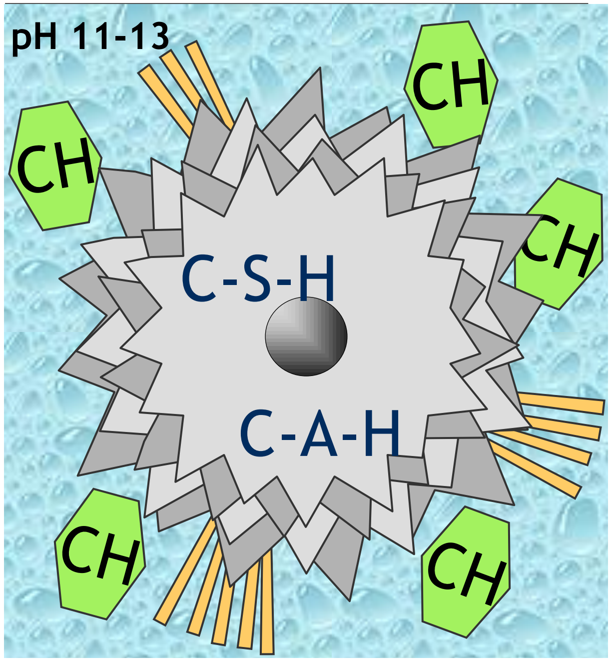
Sulfate + C-A-H =

$3CaO.Al_2O_3.3CaSO_4.31H_2O$

(ettringite)

Sulfate + $Ca(OH)_2$ = $CaSO_4.2H_2O$

(gypsum)



Result is **expanison**

Conventional Sulfate Attack

Sulfate + **C-A-H** =

$3CaO.Al_2O_3.3CaSO_4.31H_2O$

(ettringite)

Sulfate + $\mathbf{Ca(OH)_2}$ = $CaSO_4.2H_2O$

(gypsum)

Result is **expansion**

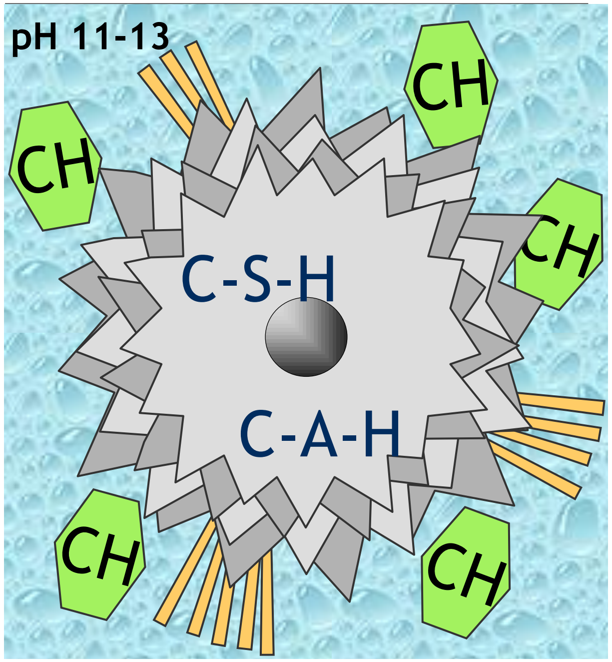
Thaumasite form of Sulfate Attack

CO_3 / low temperature (<15º) /

high pH (≥10.5)

Sulfates + **C-S-H** = $CaSiO_3.CaCO_3.CaSO_4.15H_2O$

(thaumasite)



Result is **weakening** and some **expansion**

Thaumasite form of Sulfate Attack

CO_3 / low temperature (<15°) /

high pH (≥10.5)

Sulfates + **C-S-H** = $CaSiO_3.CaCO_3.CaSO_4.15H_2O$

(thaumasite)

Result is **weakening** and some **expansion**

DS and ACEC Classes - Natural Ground

Table C1 Aggressive Chemical Environment for Concrete (ACEC) classification for natural ground locations [a]

Sulfate				Groundwater		ACEC
Design Sulfate Class for location	2:1 water/soil extract [b]	Groundwater	Total potential sulfate [c]	Static water	Mobile water	Class for location
1	2 (SO_4 mg/l)	3 (SO_4 mg/l)	4 (SO_4 %)	5 (pH)	6 (pH)	7
DS-1	< 500	< 400	< 0.24	≥ 2.5		AC-1s
					> 5.5 [d]	AC-1 [d]
					2.5–5.5	AC-2z
DS-2	500–1500	400–1400	0.24–0.6	> 3.5		AC-1s
					> 5.5	AC-2
				2.5–3.5		AC-2s
					2.5–5.5	AC-3z
DS-3	1600–3000	1500–3000	0.7–1.2	> 3.5		AC-2s
					> 5.5	AC-3
				2.5–3.5		AC-3s
					2.5–5.5	AC-4
DS-4	3100–6000	3100–6000	1.3–2.4	> 3.5		AC-3s
					> 5.5	AC-4
				2.5–3.5		AC-4s
					2.5–5.5	AC-5
DS-5	> 6000	> 6000	> 2.4	> 3.5		AC-4s
				2.5–3.5	≥ 2.5	AC-5

DS and ACEC Classes - Natural Ground

Table C1 Aggressive Chemical Environment for Concrete (ACEC) classification for natural ground locations [a]

Sulfate				Groundwater		ACEC Class for location
Design Sulfate Class for location	2:1 water/soil extract [b]	Groundwater	Total potential sulfate [c]	Static water	Mobile water	
1	2 (SO_4 mg/l)	3 (SO_4 mg/l)	4 (SO_4 %)	5 (pH)	6 (pH)	7
DS-1	< 500	< 400	< 0.24	≥ 2.5		AC-1s
					> 5.5 [d]	AC-1 [d]
					2.5–5.5	AC-2z
DS-2	500–1500	400–1400	0.24–0.6	> 3.5		AC-1s
					> 5.5	AC-2
				2.5–3.5		AC-2s
					2.5–5.5	AC-3z
DS-3	1600–3000	1500–3000	0.7–1.2	> 3.5		AC-2s
					> 5.5	AC-3
				2.5–3.5		AC-3s
					2.5–5.5	AC-4
DS-4	3100–6000	3100–6000	1.3–2.4	> 3.5		AC-3s
					> 5.5	AC-4
				2.5–3.5		AC-4s
					2.5–5.5	AC-5
DS-5	> 6000	> 6000	> 2.4	> 3.5		AC-4s
				2.5–3.5	≥ 2.5	AC-5

DC Class and APMs

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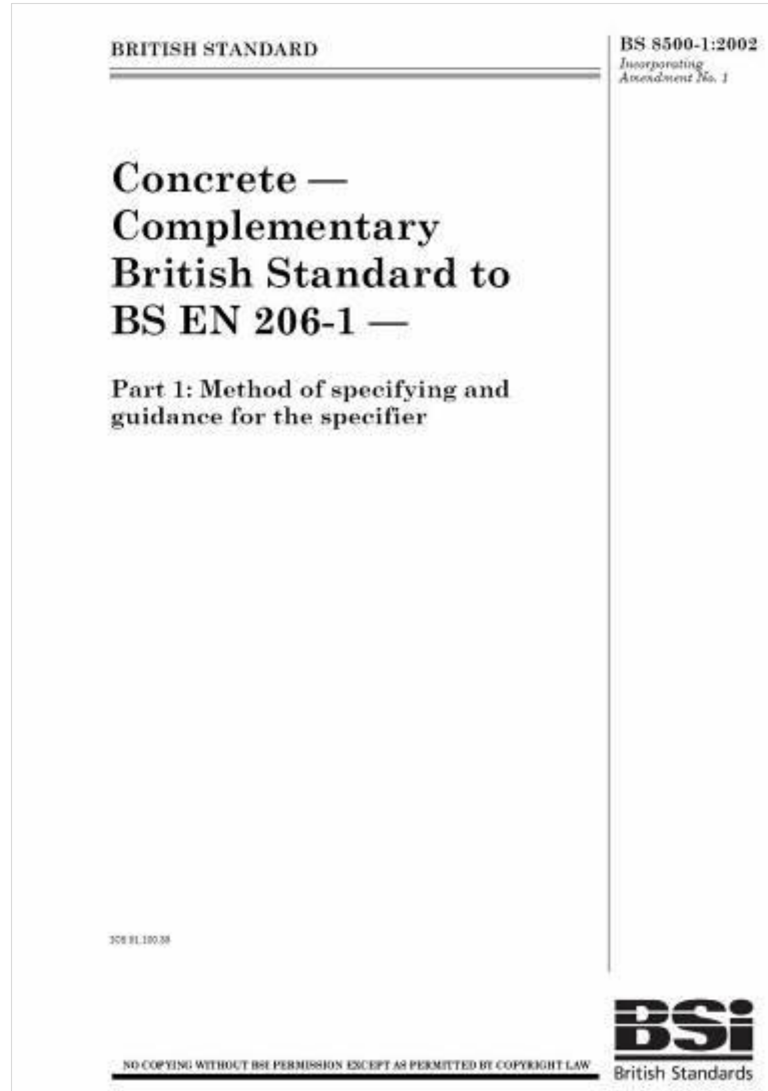
Table D1 Selection of the DC Class and the number of APMs for concrete elements where the hydraulic gradient due to groundwater is 5 or less: for general in-situ use of concrete [a,b,c]

ACEC Class (from Tables C1 and C2)	Intended working life	
	At least 50 years[d,e]	At least 100 years
AC-1s, AC-1	DC-1	DC-1
AC-2s, AC-2	DC-2	DC-2
AC-2z	DC-2z	DC-2z
AC-3s	DC-3	DC-3
AC-3z	DC-3z	DC-3z
AC-3	DC-3	DC-3 + one APM of choice
AC-4s	DC-4	DC-4
AC-4z	DC-4z	DC-4z
AC-4	DC-4	DC-4 + one APM of choice
AC-4ms	DC-4m	DC-4m
AC-4m	DC-4m	DC-4m + one APM of choice
AC-5z	DC-4z + APM3[f]	DC-4z + APM3[f]
AC-5	DC-4 + APM3[f]	DC-4 + APM3[f]
AC-5m	DC-4m + APM3[f]	DC-4m + APM3[f]

Specification Method

- **Designated** concrete
- **Designed** concrete
- **Prescribed** concrete
- **Standardised prescribed** concrete
- **Proprietary** concrete


BRITISH STANDARD

BS 8500-1:2002
Incorporating Amendment No. 1

Concrete — Complementary British Standard to BS EN 206-1 —

Part 1: Method of specifying and guidance for the specifier

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BSi British Standards

Designated Concretes

- Simple and reliable form of specification, widely used
- Strength, durability performance requirements specified
- Maximum aggregate size and consistency specified
- Producer can vary cement and combination types, aggregates etc.
- Cannot be used in presence of chlorides

Designated Concrete

Basic specification requirements

- Concrete designation
- Max. aggregate size
- Consistence class

Other?

Designated Concrete

Basic specification requirements

- Concrete designation
- Max. aggregate size
- Consistence class

Other?

- Restriction / relaxation of cement type
- Special aggregate requirements
- Accelerated / retarded set
- Colour
- Fibres / air content

Designated Concrete

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BS 8500-1: 2006 (Table A.3)

Use	**Exposure class**	**Nominal cover** A) mm	**Minimum designated concrete** B)
Reinforced and prestressed concrete inside enclosed buildings except poorly ventilated rooms with high humidity	XC1	(15 + Δc)	RC20/25
External reinforced and prestressed vertical elements of buildings sheltered from, or exposed to, rain C)	XC3/XC4 + XF1	(20 + Δc) (25 + Δc) (30 + Δc)	RC40/50 RC32/40 RC28/35
Horizontal elements with high saturation without de-icing agent and subject to freezing while wet C)	XC4+XF3	(20 + Δc) (30 + Δc) (35 + Δc)	RC40/50XF PAV2 PAV1
Reinforced or prestressed buried foundation in AC-1 where the hydraulic gradient is not greater than 5	XC2/AC-1	50 D) 75 E)	RC25/30
C25/30 reinforced or prestressed buried foundation in AC-2 or more aggressive ground conditions	AC-2 to AC-5m	50 D) 75 E)	See F)

Designated Concrete

BS 8500-2: 2006 (Table 5)

Concrete designation	Min. strength class	Slump class A)	Max. w/c ratio	Min. cement or combination content (kg/m³) for max. aggregate size (mm)				Cement and combination types
				⩾40	20	14	10	
GEN0	C6/8	S3	—	120	120	120	120	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN1	C8/10	S3	—	180	180	180	180	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN2	C12/15	S3	—	200	200	200	200	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN3	C16/20	S3	—	220	220	220	220	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
RC20/25	C20/25	S3	0.70	240	240	260	280	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
RC25/30	C25/30	S3	0.65	240	260	280	300	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC28/35	C28/35	S3	0.60	260	280	300	320	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC30/37	C30/37	S3	0.55	280	300	320	340	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC32/40	C32/40	S3	0.55	280	300	320	340	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC35/45	C35/45	S3	0.50	300	320	340	360	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC40/50	C40/50	S3	0.45	320	340	360	360	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)

Designated Concrete

BS 8500-1: 2006 (Table A.3)

Use	Exposure class	Nominal cover [A)] mm	Minimum designated concrete [B)]
Reinforced and prestressed concrete inside enclosed buildings except poorly ventilated rooms with high humidity	XC1	(15 + Δc)	RC20/25
External reinforced and prestressed vertical elements of buildings sheltered from, or exposed to, rain [C)]	XC3/XC4 + XF1	(20 + Δc) (25 + Δc) (30 + Δc)	RC40/50 RC32/40 RC28/35
Horizontal elements with high saturation without de-icing agent and subject to freezing while wet [C)]	XC4+XF3	(20 + Δc) (30 + Δc) (35 + Δc)	RC40/50XF PAV2 PAV1
Reinforced or prestressed buried foundation in AC-1 where the hydraulic gradient is not greater than 5	XC2/AC-1	50 [D)] 75 [E)]	RC25/30
C25/30 reinforced or prestressed buried foundation in AC-2 or more aggressive ground conditions	AC-2 to AC-5m	50 [D)] 75 [E)]	See [F)]

Specification

BS 8500-2: 2006 (Table 5)

Concrete designation	Min. strength class	Slump class A)	Max. w/c ratio	Min. cement or combination content (kg/m³) for max. aggregate size (mm)				Cement and combination types
				⩾40	20	14	10	
GEN0	C6/8	S3	—	120	120	120	120	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN1	C8/10	S3	—	180	180	180	180	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN2	C12/15	S3	—	200	200	200	200	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN3	C16/20	S3	—	220	220	220	220	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
RC20/25	C20/25	S3	0.70	240	240	260	280	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
RC25/30	C25/30	S3	0.65	240	260	280	300	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC28/35	C28/35	S3	0.60	260	280	300	320	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC30/37	C30/37	S3	0.55	280	300	320	340	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC32/40	C32/40	S3	0.55	280	300	320	340	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC35/45	C35/45	S3	0.50	300	320	340	360	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)
RC40/50	C40/50	S3	0.45	320	340	360	360	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V B)

Designed Concretes

- Permit flexibility
- Suitable for most applications
- Strength, allowable cement types; water/cement ratios; use of recycled or secondary aggregates are specified

- Appropriate for concrete with focus on eCO_2
- To be used for specification of visual cast insitu concrete

Designed Concrete

Basic specification requirements

- Strength class
- Max. W/C ratio
- Cement type and min. content
- Max. aggregate size
- Consistence class
- Chloride class
- Density class

Other?

Designed Concrete

Additional specification options

- Aggregate type, including use of recycled aggregate
- Fibres if used
- Air entrainment
- Temperature of the fresh concrete
- Heat development during hydration
- Resistance to water penetration
- Tensile strength
- Resistance to abrasion

Prescribed Concretes

- Exact composition of concrete specified
- Specifier takes full design responsibility including testing

Standardised Prescribed Concretes

- Small construction sites, with small scale batching.
- Strength is not of critical importance

Proprietary Concretes

- Developed by concrete producer as a proprietary product
- Composition not disclosed.
- Specified performance requirements confirmed
- Low eCO_2 concretes available
- Used for pre-cast concrete specifications

Aggregates

- Major component of concrete by volume
- Inherently low carbon
- Mostly naturally occurring, local resource
- Also recycled aggregate (RA) recycled concrete aggregate (RCA) and secondary aggregates
- 28% of all aggregate in UK is recycled or secondary aggregate (highest in Europe)

Recycled Aggregates: Types

- **Recycled aggregate (RA)-** Resulting from reprocessing of inorganic material previously used in construction
- **Recycled concrete aggregate (RCA)** - RA principally comprising crushed concrete
- **Secondary aggregates** - Arising from other processes eg: blast furnace and zinc slag; foundry sand; slate aggregate; china clay sand or stent

Recycled aggregates

Table 1: Use of RA and RCA in BS 8500 for Designated Concrete

Designated concrete	Percentage of coarse aggregate in RA or RCA
GEN 0 to GEN 3	100%
RC20/25 to RC40/50	20%*
RC40/50XF	0%
PAV1 & PAV2	0%
FND2 to FND4	0%

*a higher proportion may be used if permitted in the specification

- Local virgin aggregates will have lower eCO_2 than RA transported longer distances (over 15km by road)

Use of Recycled Aggregates

- Recycled Aggregates are efficiently used as hardcore and in landscaping
- Very little (effectively none) goes into landfill
- Consistency of supply and source material are necessary for use in concrete
- Testing regimes for quality control is more rigorous than for natural/primary aggregates

Secondary aggregates

Granite sand/aggregate

(formerly known as stent)

- Waste granite rock material that has been separated from Kaolin (china clay) by high pressure water jets.

Secondary aggregates

Lytag:

- Sintered pulverised fuel ash lightweight aggregate
- Weight of structural concrete reduced by 25%

Primary aggregates

- Predominantly UK sourced
- Reserves in UK will last for hundreds of thousands of years
- Tightly regulated extraction for environmental impacts
- Life cycle of a quarry is environmentally positive
- Over 700 areas of Special Scientific Interest are former mineral extraction sites

Aggregate and cement content

- Size of aggregate impacts on cement content
- Smaller aggregate requires a higher cement content
- Some RA and RCA require higher cement content to achieve strength

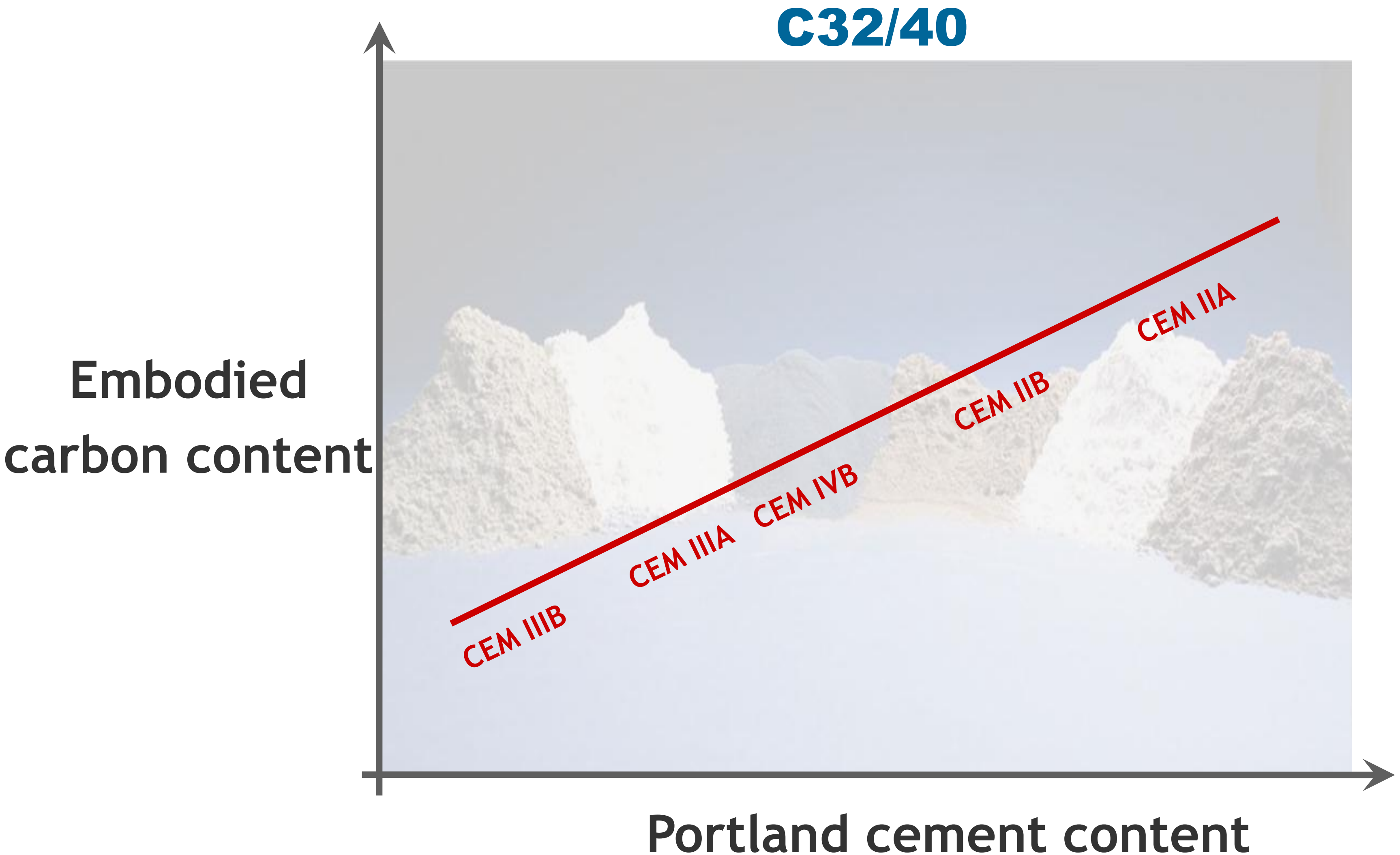
Specification tips

- Permit recycled and secondary aggregate but do not over specify
- Consider locally available natural sources to reduce ECO2
- Do not specify aggregate sizes below 10mm unless necessary
- If available and appropriate specify recycled or secondary aggregates in footings

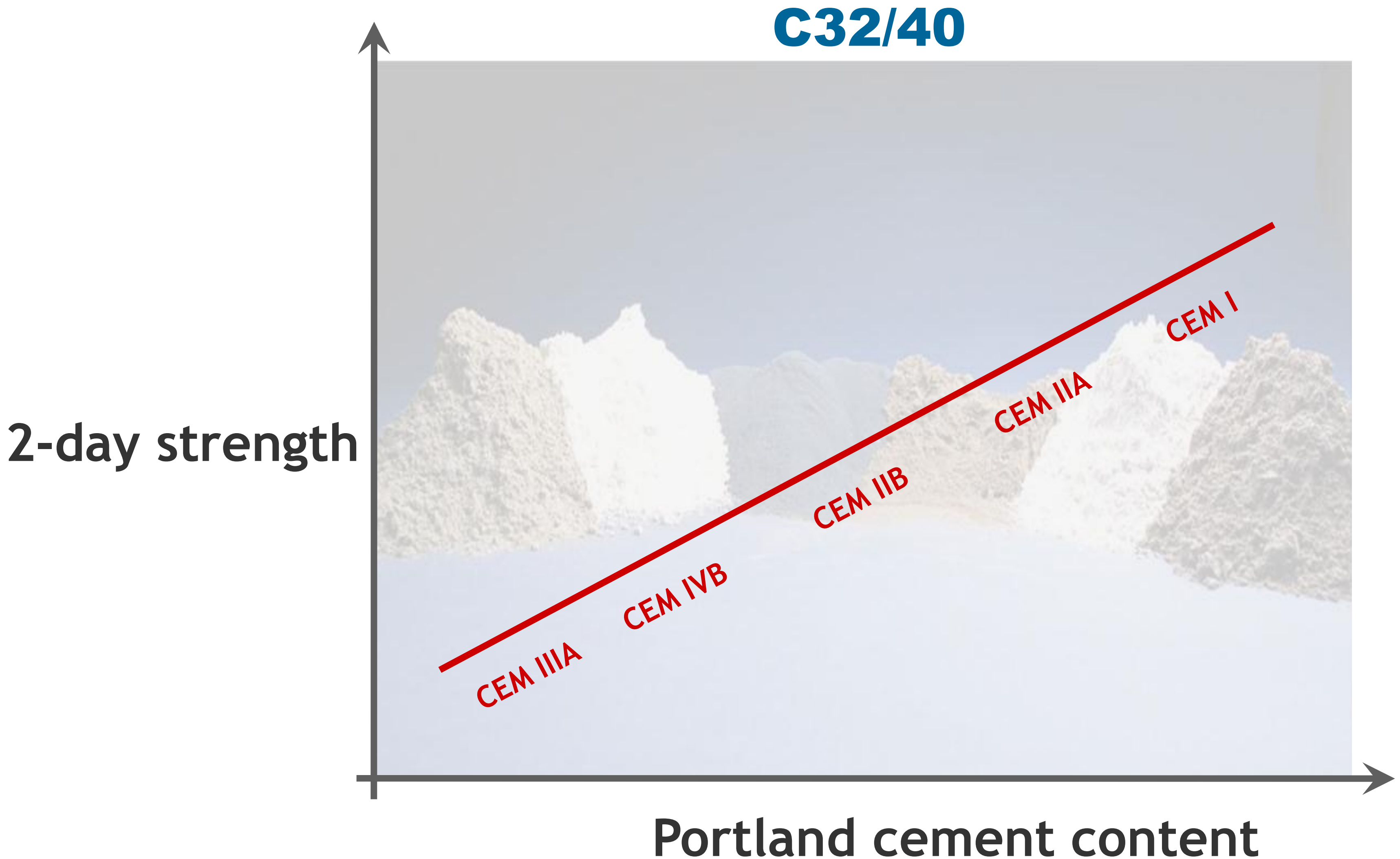
Cement Specification

Type	Addition	Portland cement replacement, %
CEM I	~	0 – 5
IIA	Silica fume	6 – 10
	Fly ash	6 – 20
IIB-V	Fly ash	21 – 35
IVB-V		36 – 55
IIB-S	GGBS	21 – 35
IIIA		36 – 65
IIIB		66 – 80

Cements and combinations



Cements and combinations



Portland Cement

Cement is an <u>ingredient</u> of concrete. The 'glue' that holds the mix together

Components of Ordinary Portland Cement (CEM1):

- Limestone or chalk
- Clay/Shale
- Sand
- Gypsum

Heated together at high temperature

Reduced energy use in cement production

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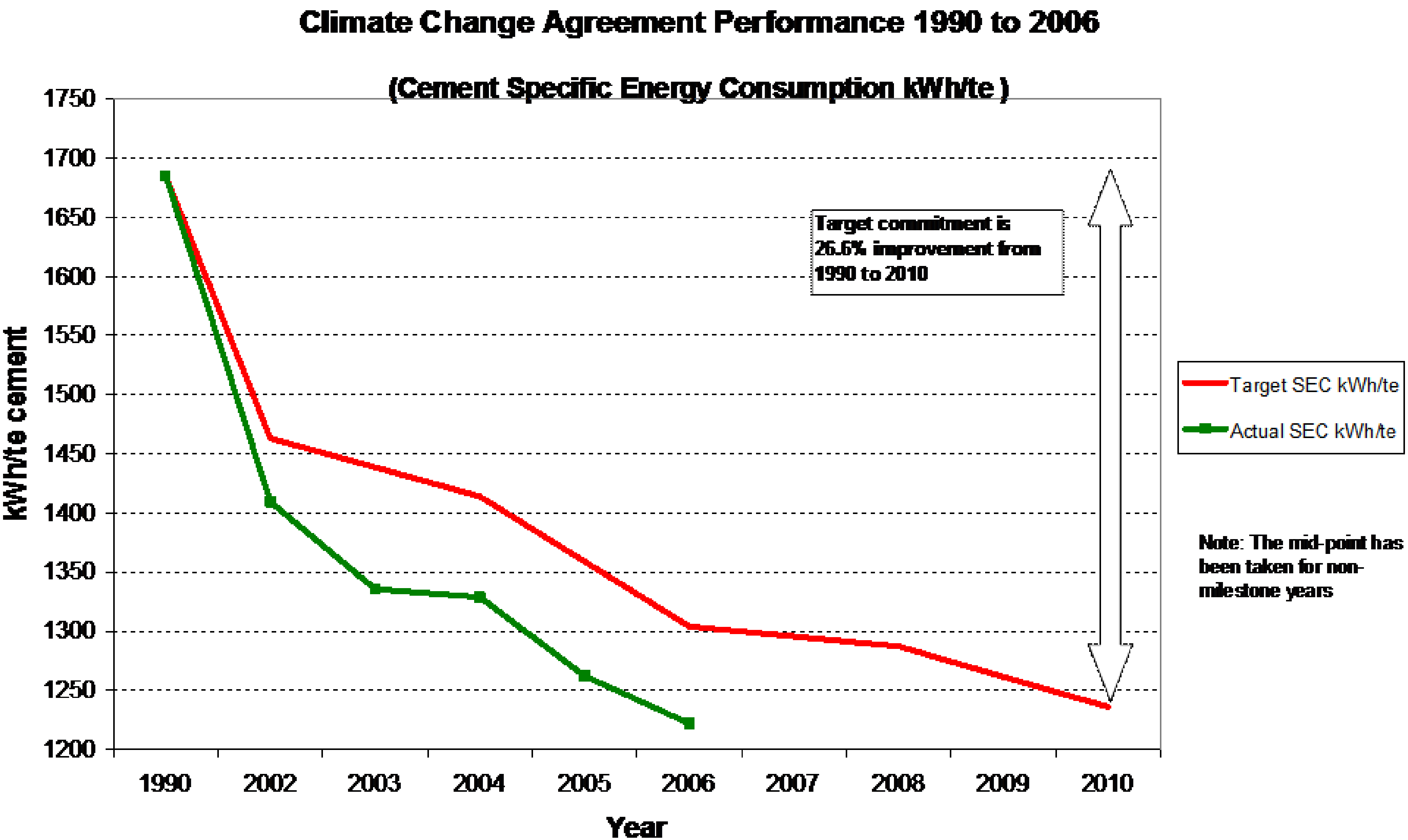

Embodied CO_2

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Material		Embodied CO_2 (kg / tonne)
Portland cement, CEM I		930
Addition or cement constituent	Ground granulated blastfurnace slag (ggbs)	52
	Fly ash	4
	Limestone	32
	Minor additional constituent	32
Aggregate		4
Reinforcement		427

GGBS

- Ground Granulated Blast Furnace Slag (GGBS) – by-product from iron
- Approx 1/3 all UK ready-mixed concrete deliveries contain GGBS.
- 6-80% replacement of OPC can be used, depending on application
- lower early-age temperature rise and slower early strength gain
- Below 35-40% no impact on striking times of formwork

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GGBS

- reduces eCO_2

  (50% GGBS reduces eCO_2 of concrete by 40%)
- recycled material so improves BREEAM and Green Guide rating
- inherent pale, creamy colour
- Reflectance level increased

GGBS

City of Westminster College

Schmidt Hammer Lassen / Buro Happold

- 50% GGBS - cast insitu frame

Fly Ash

- By-product from electricity generation sourced from coal fired power stations
- Used widely in block manufacture
- Improves workability and durability
- 6-55% possible depending on application
- lower early-age temperature rise and slower early strength gain
- Below 35-40% no impact on striking times of formwork

Fly Ash

- reduces ECO_2

(30% fly ash reduces ECO_2 of concrete by 20%)

- recycled material so improves BREEAM and Green Guide rating
- inherent smokey grey colour

Other cementitious materials

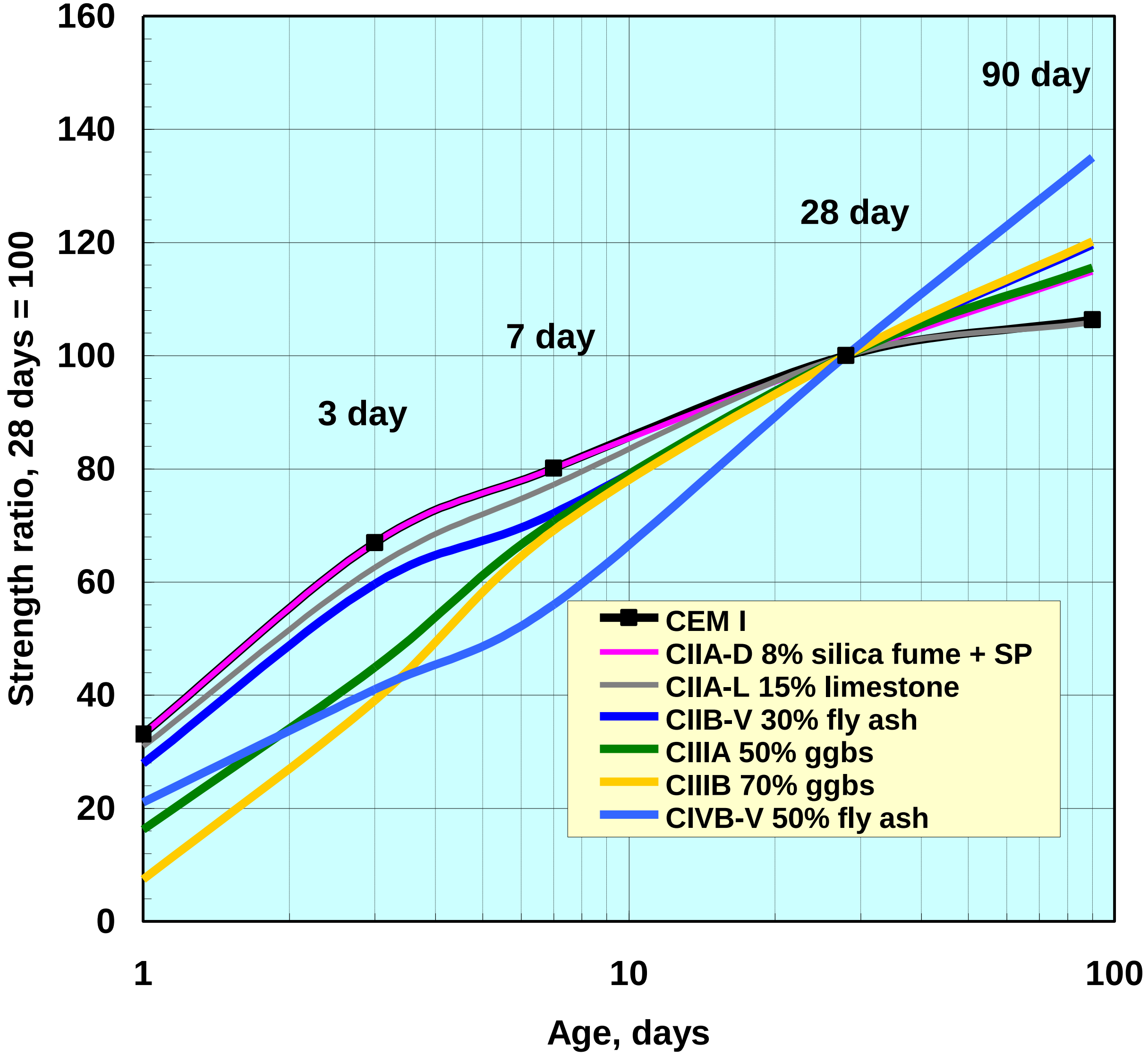
Silica Fume :

- By product of silicon manufacture
- Extremely fine powder
- Generally limited to high strength concretes or in very aggressive environmental conditions

Limestone fines:

- To produce Portland limestone cement
- Typically limited to 6-10% replacement

Strength development



Cement type, early age properties

Property	Cement (or equivalent combination)						
	Portland Cement CEM I	Silica fume cement CEM II/A-D (CIIA-D)	Portland Limestone Cement CEM II/A-LL or L	Portland fly ash cement CEM II/B-V (CIIB-V)	Blastfurnace Cements		Pozzolanic cement CEM IV/B-V (CIVB-V)
					CEM III/A (CIIIA)	CEM III/B (CIIIB)	
Early Strength	High	High	High	Moderate	Moderate	Low	Low
28 day Strength	Normal	High	As CEM I	As CEM I	As CEM I	< CEM I	< CEM I
Long term Strength	Normal	High	As CEM I	High	High	High	High
Workability retention	Normal	< CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I
Bleeding/plastic settlement	Normal	Less likely than CEM I	Less likely than CEM I	Less likely than CEM I	More likely than CEM I	More likely than CEM I	More likely than CEM I
Plastic shrinkage	Normal	High	As CEM I	As CEM I	Less likely than CEM I	Less likely than CEM I	Less likely than CEM I
Setting finishing times	Normal	Normal/ Moderate	Normal/ Moderate	Normal/ Moderate	Moderate	Slow	Slow
Low heat	Poor	As CEM I	Modest	Moderate	Moderate	Very good	Very good

Embodied CO_2 of cements

Cement Factory made cement	Combination CEM I and addition combined at concrete plant	Secondary Main Constituent (smc) or Addition Low - High Content %	Embodied CO2 smc content Low - High, (kg CO_2/ tonne)
CEM I Portland cement			930
CEM II/A-LL or L Portland limestone cement	CIIA-LL or L	6 - 20 limestone	880 - 750
CEM II/A-V Portland fly ash cement	CIIA-V	6 - 20 fly ash	870 - 750
CEM II/B-V Portland fly ash cement	CIIB-V	21 - 35 fly ash	730 - 610
CEM II/B-S Portland slag cement	CIIB-S	21 - 35 ggbs	740 - 620
CEM III/A Blastfurnace cement	CIIIA	36 - 65 ggbs	610 - 360
CEM III/B Blastfurnace cement	CIIIB	66 - 80 ggbs	340 - 230
CEM IV/B-V Siliceous fly ash cement	CIVB-V	36 - 55 fly ash	590 - 420

Admixtures

- Widely accepted as materials that contribute to the production of durable and cost-effective concrete structures
- Small dosages <5% by mass of cement
- Typically <1% eCO_2 of concrete
- Can assist with:
  - reducing overall eCO_2
  - reduced water use
  - extending design life of concrete

Example of use of admixtures

BS 8500 Designed concrete

Strength requirement = C32/40

- Corrosion induced by carbonation
  XC3/4 Moderate humidity or cyclic wet and dry
  cover = 25 + Δc mm

- From BS 8500-1: 2006 Table A.4 (50 years) then a maximum w/c of 0.55 and a minimum cement content of 260 kg/m^3 is recommended.

Strength requirement = C32/40

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Example of the cement content (kg/m^3) C32/40 at S3 slump with a marine sand and gravel aggregate			
Cement type	No admixture	Water reducing admixture (WRA)	High range water reducing admixture (HRWRA)
CEM I	315	285	250
CIIA-LL (15% limestone)	325	295	260
CIIB-V (30% fly ash)	335	300	270
CIIIA (50% ggbs)	325	295	260

S3 slump class = 80 to 180 mm from spot samples on initial discharge

Cement reduction with HRWRA
55
65
65
65

Cementitious content reduced to minimum of 260 kg/m^3

This is only one example:

Other materials may well give a different pattern of results.

In particular:

The example shown is for a medium slump S3, at higher workability the use of admixtures is essential

The example shown is for rounded marine gravel with a natural sand, where other type of aggregates have a higher water demand for a given workability where the use of water reducing admixtures will be more beneficial

Responsible Sourcing

BRE Environmental & Sustainability Standard

BRE GLOBAL LISTED

BES 6001: ISSUE 1.0

Framework Standard for the Responsible Sourcing of Construction Products

This BRE Environmental & Sustainability Standard describes the organisational governance, supply chain management and environmental and social aspects to be addressed in the certification and approval of the responsible sourcing of construction products

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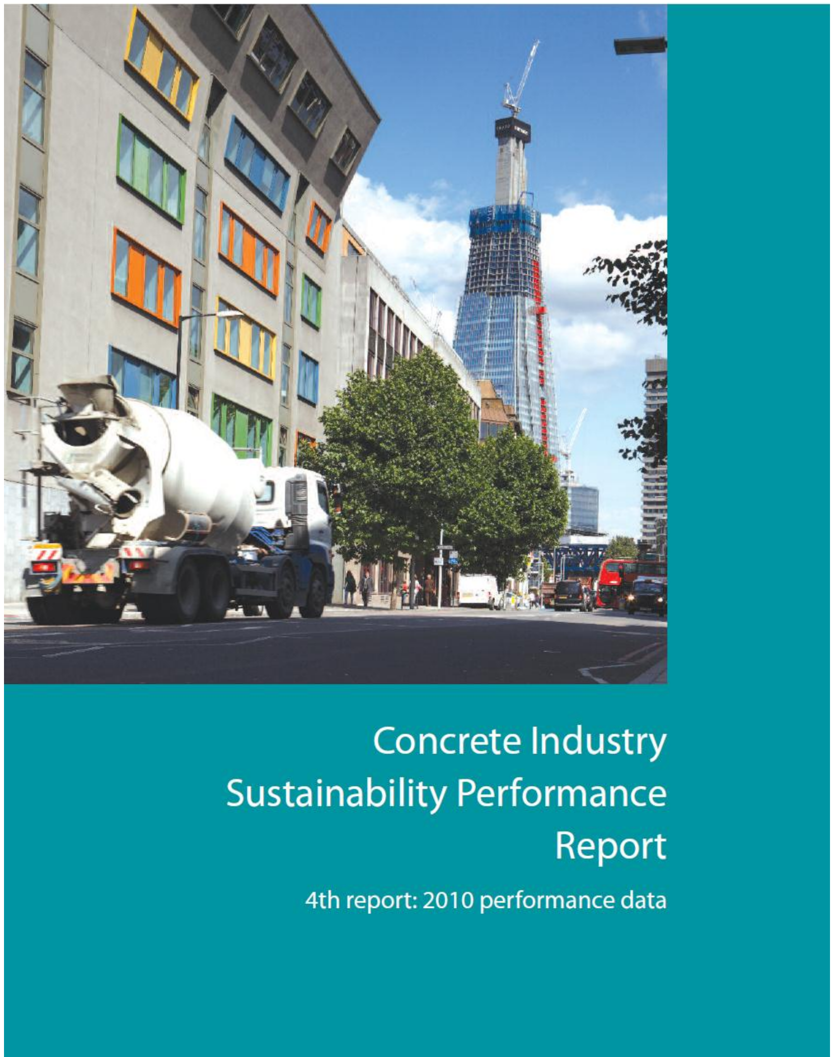
- BES 6001 is a framework standard for responsible sourcing of construction products and is the master standard against which to demonstrate compliance.
- Maximum points possible for accredited concrete products in BREEAM and The Code for Sustainable Homes.

  (RSMC - Responsible Sourcing Material Credits)

Sustainability Performance



- 4th pan-industry sustainability report
- Measures data and sets targets over various sustainability criteria
- Industry commitment to a Sustainable Construction Strategy
- 88% surveyed concrete responsibly sourced

Further information

How to specify concrete for civil engineering structures using BS 8500

T A Harrison BSc, PhD, CEng, MICE, FICT   O Brooker BEng, CEng, MICE, MIStructE

Introduction

BS 8500: Concrete – Complementary British Standard to BS EN 206–1[1] is the method of specifying concrete in the UK. It was revised in December 2006 principally to reflect changes made to BRE *Special Digest 1*[2] and to bring it into line with other standards.

Guidelines are given in BS 8500 to achieve durability of concrete structures and it recommends strength, cover, minimum cement content and maximum water/cement ratios for various exposure conditions.

This guide is intended to enable the designers of all types of civil engineering structures to specify concrete effectively, efficiently and with confidence. This guide sets out the requirements of BS 8500; some Highway Authorities have more onerous requirements that should be followed.

While this guide is intended to show how to use BS 8500 with Eurocode 2[3], the advice is also generally appropriate for use with British Standards; however, the approach to construction tolerances given in the latter may vary from the guidance given here.

Concrete design information

Exposure classification

Initially the relevant exposure condition(s) should be identified. In BS 8500 exposure classification is related to the deterioration processes of carbonation (XC), ingress of chlorides (XD or XS), chemical attack from aggressive ground (ACEC) and freeze–thaw (XF) (see Table 1). All these deterioration processes are sub-divided. The sub-divisions represent different exposure conditions, but it does not necessarily follow that, for example, XD2 is more onerous than XD1. The recommendations for concretes resistant to the XD and XS exposure classes are sufficient for resistance to the exposure class XC. The ACEC and XF exposure conditions can occur in combination with XD, XS and XC exposure classes.

Selecting concrete strength and cover

Having identified the relevant exposure condition(s), a recommended strength class and cover should be selected. Table 2 (see pages 4 and 5) indicates the nominal cover and strengths required to meet common exposure conditions for intended working lives of at least 50 or 100 years; further explanation is given below. The recommendations in Table 2 are for strength, maximum water/cement ratio and minimum cement content to meet both the primary and secondary exposure conditions assumed. The table is not intended to cover all concrete exposure situations and reference should be made to BS 8500 for those cases not included.

Intended working life

BS 8500 gives recommendations for an 'intended working life' of at least either 50 years or 100 years. However, the UK National Annex to the Eurocode[4] recommends an 'indicative design working life' of 120 years for category 5 structures (monumental building structures, highway and railway bridges, and other civil engineering structures). It can generally be assumed that the guidance given in BS 8500 for at least a 100-year working life will be appropriate for category 5 structures.

BS 8500 notes that the recommendations for a 100-year intended working life in chloride conditions are subject to a degree of uncertainty and consideration may be given to using barriers, coatings and corrosion inhibitors, and stainless steel or non-ferrous reinforcement, as additional measures. Further guidance can be found in Concrete Society Technical Report 61[5].

Compressive strength

BS 8500 uses the term 'compressive strength class' to define concrete strengths; the notation used gives the cylinder strength as well as the cube strength (see Table 3). It is important to quote the compressive strength class in full to avoid confusion.

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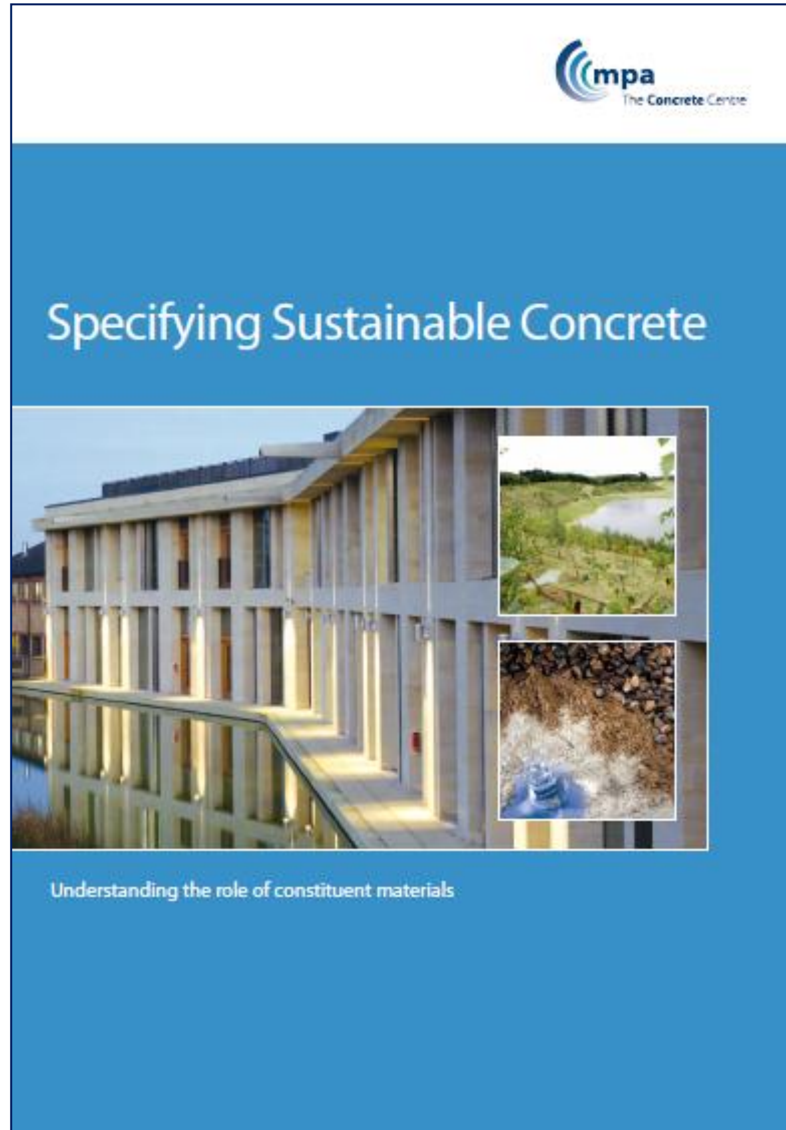
Specifying Sustainable Concrete



Enhancing durability

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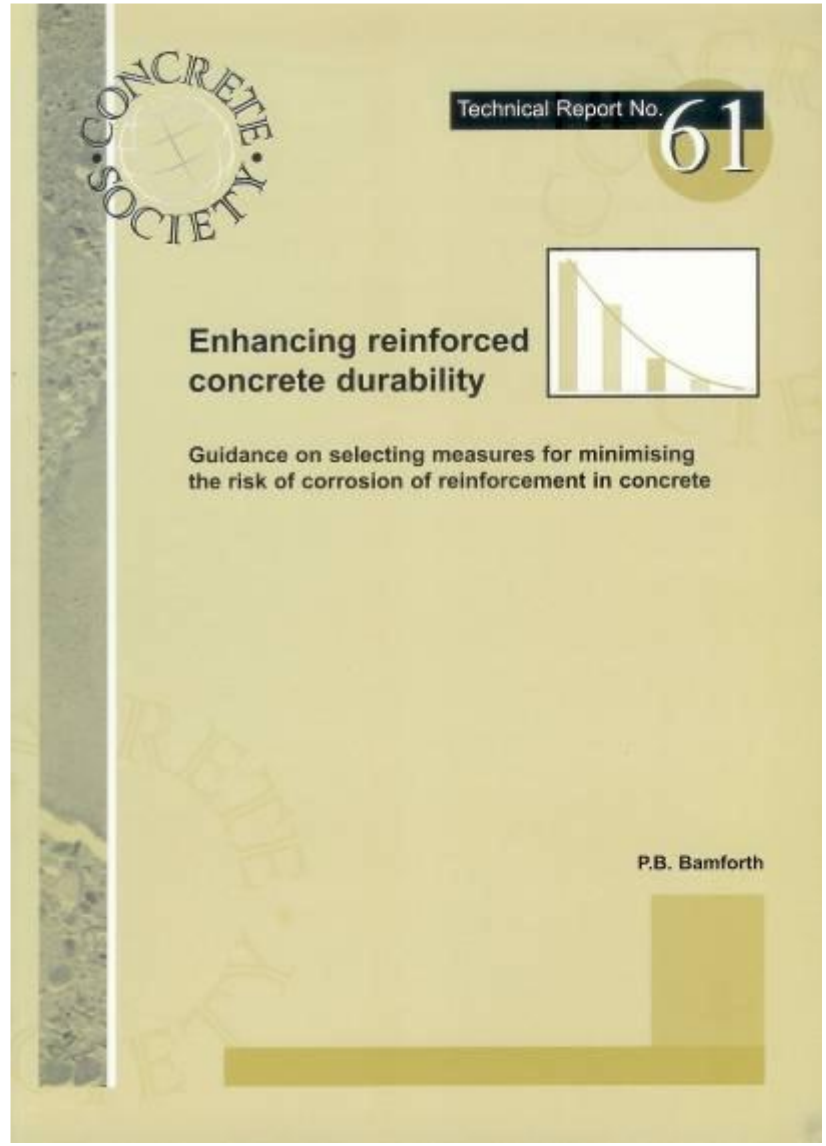
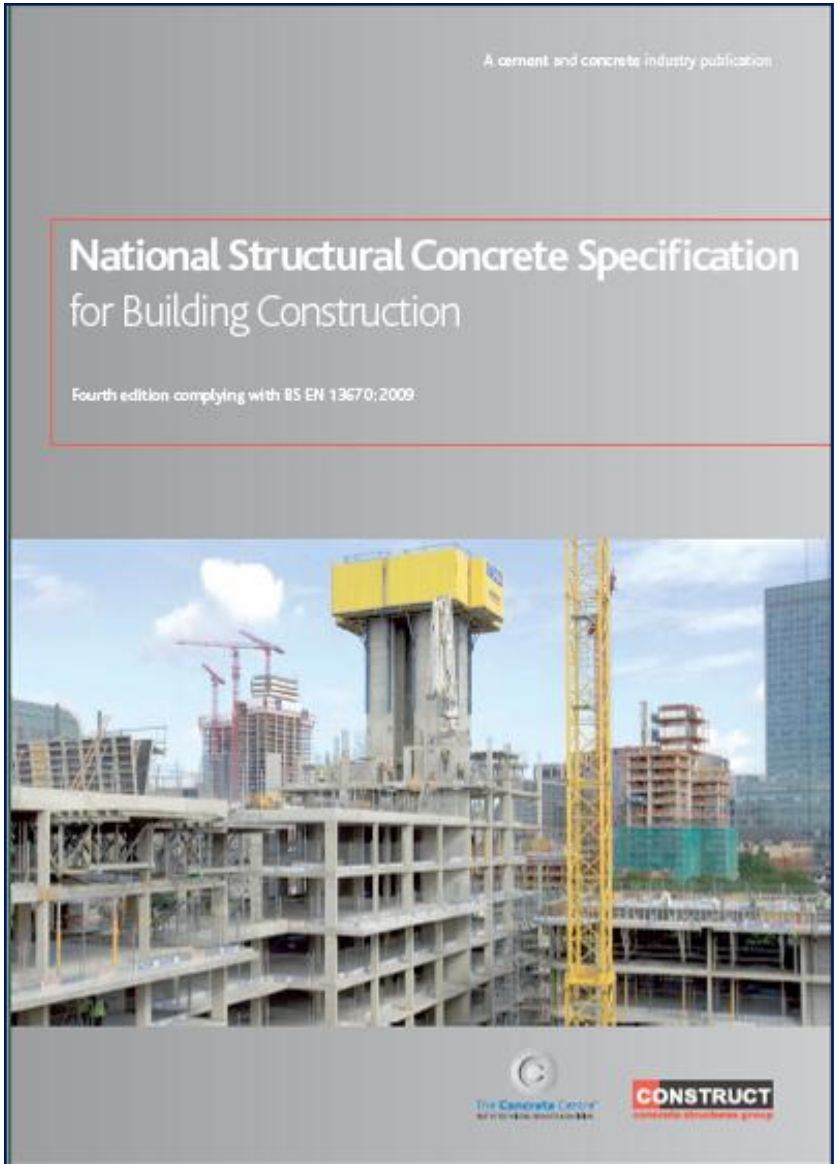
- Barriers
- Coatings
- Corrosion inhibitors
- Stainless steel
- Non-ferrous rebar



NSCS 4th Edition

- Complies with BS EN 13670:2009
- Covers responsible sourcing clauses



Concreting

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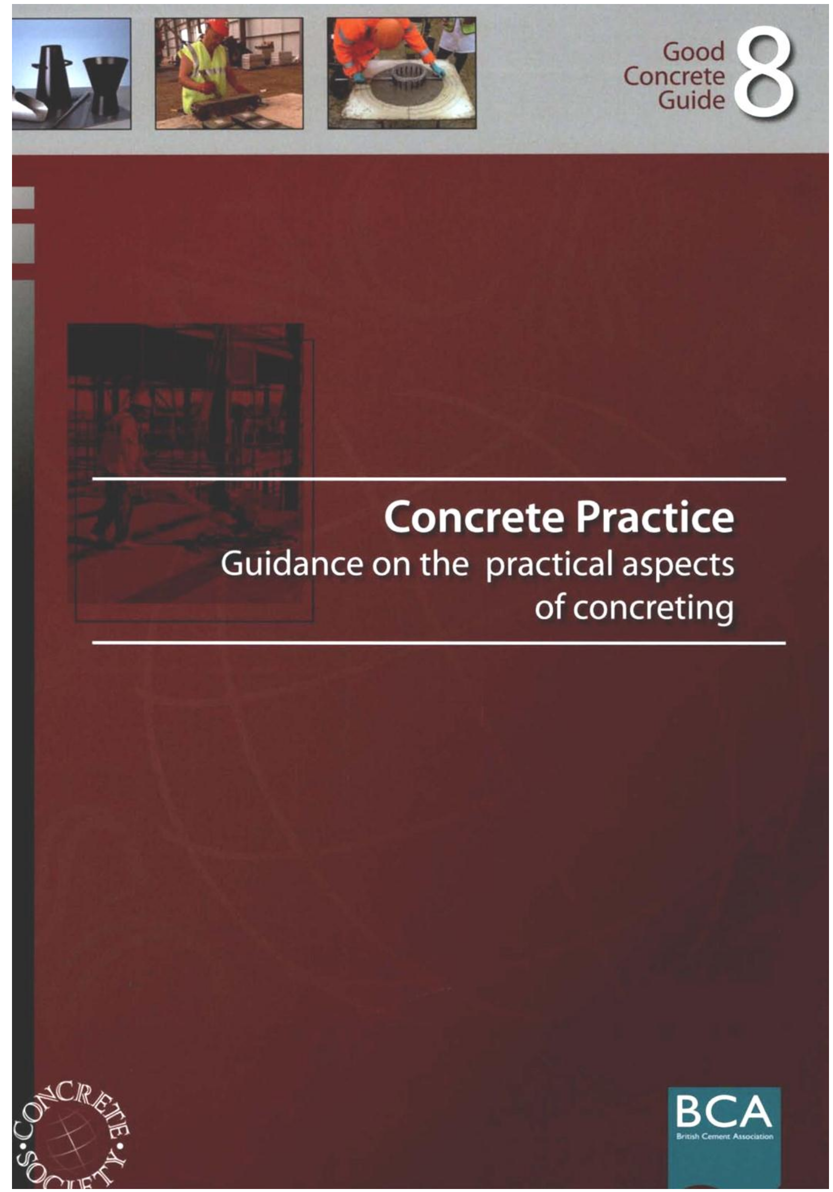
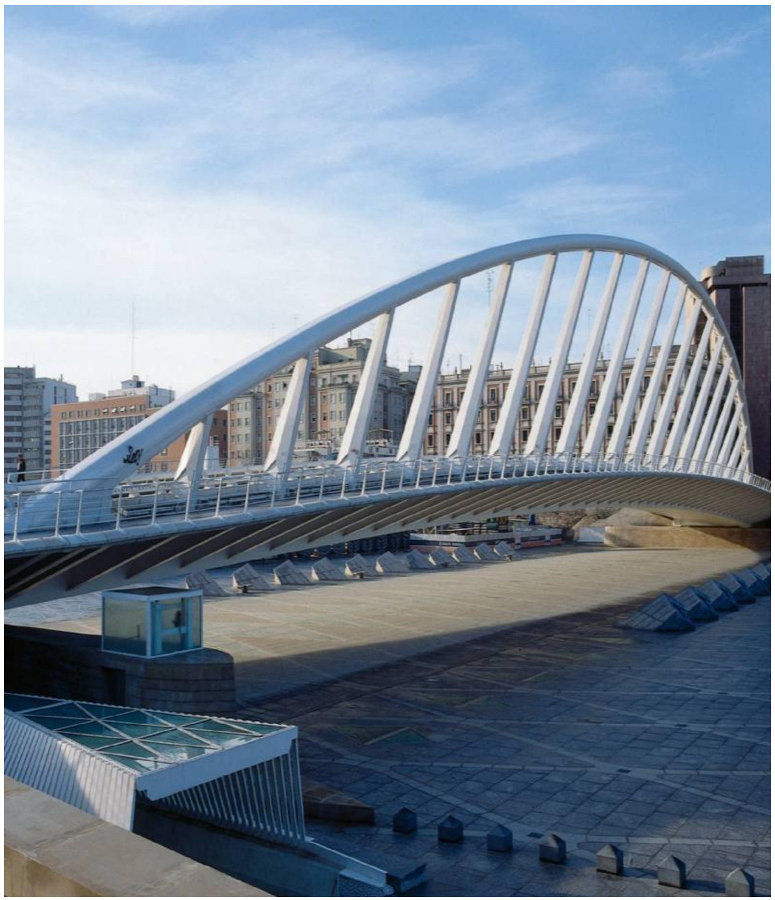
- Transporting
- Placing and compaction
- Construction joints
- Reinforcement
- Formwork
- Curing
- Surface finishes
- Testing



Thank you

Questions?

Specification example



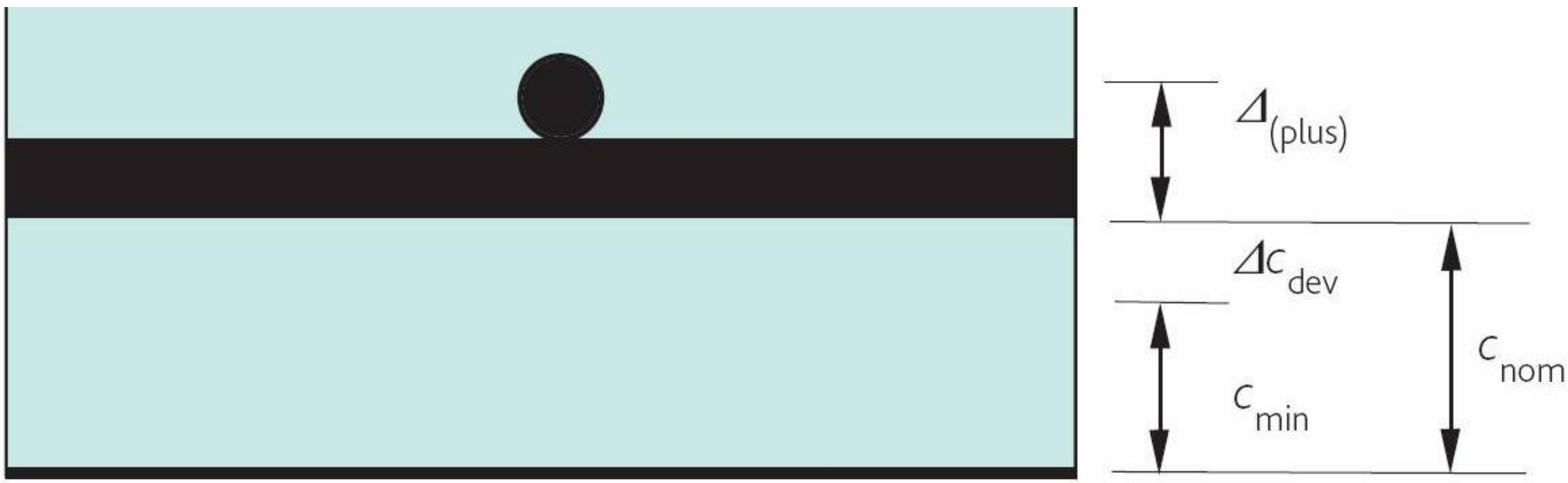
- **Corrosion** induced by carbonation **(XC3/4)**
- **Corrosion** induced by chlorides **(XD1)**
- **Corrosion** induced by chlorides from sea **(XS3)**
- **Freeze-thaw** attack **(XF4)**
- **Chemical** attack **(AC-5)**

Corrosion risk

Exposure condition		Compressive strength class, maximum water-cement ratio and minimum cement or combination content for normal weight concrete[c] with 20 mm maximum aggregate size[d]								Cement/Combination types		
	Nominal cover[b], mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc			
Corrosion induced by carbonation, XC exposure classes	XC1	C20/25 0.70 240								All in Table A.6		
	XC2	—	—	C25/30 0.65 260						All in Table A.6		
	XC3/4	—	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260				All in Table A.6 except IVB		
		—	—	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260					IVB
Corrosion induced by chlorides (XS from sea water, XD other than sea water) Requirements are also adequate for any associated carbonation induced corrosion (XC)	XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300				All in Table A.6		
	XS1	—	—	—	C45/55 0.35 380	C35/45 0.45 360	C32/40 0.50 340			CEM I, IIA, IIB-S, SRPC		
		—	—	—	C40/50 0.35 380	C32/40 0.45 360	C28/35 0.50 340				IIB-V, IIIA	
		—	—	—	C32/40 0.40 380	C25/30 0.50 340						IIIB, IVB
	XD2 or XS2	—	—	—	C40/50 0.40 380	C32/40 0.50 340	C28/35 0.55 320			CEM I, IIA, IIB-S, SRPC		
		—	—	—	C35/45 0.40 380	C28/35 0.50 340	C25/30 0.55 320				IIB-V, IIIA	
		—	—	—	C32/40 0.40, 380	C25/30 0.50, 340	C20/25 0.55 320					IIIB, IVB
	XD3	—	—	—	—	—	C45/55 0.35 380	C40/50 0.40 380	C35/45 0.45 360	CEM I, IIA, IIB-S, SRPC		
		—	—	—	—	—	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 340		IIB-V, IIIA	
		—	—	—	—	—	C32/40 0.40 380	C28/35 0.45 360	C25/30 0.50 340			IIIB, IVB
	XS3	—	—	—	—	—	—	C45/55 0.35 380	C40/50 0.40 380	CEM I, IIA, IIB-S, SRPC		
		—	—	—	—	—	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 340		IIB-V, IIIA	
		—	—	—	—	—	C32/40 0.40 380	C28/35 0.45 360	C25/30 0.50 340			IIIB, IVB

Cover to Reinforcement

$$c_{nom} = c_{min} + \Delta c_{dev}$$



Notes

c_{min} = Minimum cover

Δc_{dev} = Allowance made in design for deviation (towards face of concrete)

c_{nom} = $c_{min} + \Delta c_{dev}$ = nominal cover

Corrosion risk

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Exposure condition		Compressive strength class, maximum water-cement ratio and minimum cement or combination content for normal weight concrete[c] with 20 mm maximum aggregate size[d]								Cement/Combination types		
	Nominal cover[b], mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc			
Corrosion induced by carbonation, XC exposure classes	XC1	C20/25 0.70 240								All in Table A.6		
	XC2	—	—	C25/30 0.65 260						All in Table A.6		
	XC3/4	—	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260				All in Table A.6 except IVB		
		—	—	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260					IVB
Corrosion induced by chlorides (XS from sea water, XD other than sea water) Requirements are also adequate for any associated carbonation induced corrosion (XC)	XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300				All in Table A.6		
	XS1	—	—	—	C45/55 0.35 380	C35/45 0.45 360	C32/40 0.50 340			CEM I, IIA, IIB-S, SRPC		
		—	—	—	C40/50 0.35 380	C32/40 0.45 360	C28/35 0.50 340				IIB-V, IIIA	
		—	—	—	C32/40 0.40 380	C25/30 0.50 340						IIIB, IVB
	XD2 or XS2	—	—	—	C40/50 0.40 380	C32/40 0.50 340	C28/35 0.55 320			CEM I, IIA, IIB-S, SRPC		
		—	—	—	C35/45 0.40 380	C28/35 0.50 340	C25/30 0.55 320				IIB-V, IIIA	
		—	—	—	C32/40 0.40, 380	C25/30 0.50, 340	C20/25 0.55 320					IIIB, IVB
	XD3	—	—	—	—	—	C45/55 0.35 380	C40/50 0.40 380	C35/45 0.45 360	CEM I, IIA, IIB-S, SRPC		
		—	—	—	—	—	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 340		IIB-V, IIIA	
		—	—	—	—	—	C32/40 0.40 380	C28/35 0.45 360	C25/30 0.50 340			IIIB, IVB
	XS3	—	—	—	—	—	—	C45/55 0.35 380	C40/50 0.40 380	CEM I, IIA, IIB-S, SRPC		
		—	—	—	—	—	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 340		IIB-V, IIIA	
		—	—	—	—	—	C32/40 0.40 380	C28/35 0.45 360	C25/30 0.50 340			IIIB, IVB

Specification example *Corrosion risk*

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Exposure condition	Nominal cover[b], mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	Cement/Combination types		
		Compressive strength class, maximum water-cement ratio and minimum cement or combination content for normal weight concrete[c] with 20 mm maximum aggregate size[d]										
Corrosion induced by carbonation, XC exposure classes	XC1	C20/25 0.70 240								All in Table A.6		
	XC2	–	–	C25/30 0.65 260						All in Table A.6		
	XC3/4	–	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260				All in Table A.6 except IVB		
		–	–	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260					IVB
Corrosion induced by chlorides (XS from sea water, XD other than sea water) Requirements are also adequate for any associated carbonation induced corrosion (XC)	XD1	–	–	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300				All in Table A.6		
	XS1	–	–	–	C45/55 0.35 380	C35/45 0.45 360	C32/40 0.50 340			CEM I, IIA, IIB-S, SRPC		
		–	–	–	C40/50 0.35 380	C32/40 0.45 360	C28/35 0.50 340				IIB-V, IIIA	
		–	–	–	C32/40 0.40 380	C25/30 0.50 340						IIIB, IVB
	XD2 or XS2	–	–	–	C40/50 0.40 380	C32/40 0.50 340	C28/35 0.55 320			CEM I, IIA, IIB-S, SRPC		
		–	–	–	C35/45 0.40 380	C28/35 0.50 340	C25/30 0.55 320				IIB-V, IIIA	
		–	–	–	C32/40 0.40, 380	C25/30 0.50, 340	C20/25 0.55 320					IIIB, IVB
	XD3	–	–	–	–	–	C45/55 0.35 380	C40/50 0.40 380	C35/45 0.45 360	CEM I, IIA, IIB-S, SRPC		
		–	–	–	–	–	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 340		IIB-V, IIIA	
		–	–	–	–	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	XS3	–	–	–	–	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		–	–	–	–	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		–	–	–	–	–	C32/40 0.40 380	C28/35 0.45 360	C25/30 0.50 340			IIIB, IVB

C45/55

0.35, 380

CEM I, IIA

IIB-S, SRPC

Specification example *Corrosion risk*

Exposure condition		Compressive strength class, maximum water-cement ratio and minimum cement or combination content for normal weight concrete[c] with 20 mm maximum aggregate size[d]								Cement/Combination types		
	Nominal cover[b], mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc			
Corrosion induced by carbonation, XC exposure classes	XC1	C20/25 0.70 240								All in Table A.6		
	XC2	–	–	C25/30 0.65 260						All in Table A.6		
	XC3/4	–	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260				All in Table A.6 except IVB		
		–	–	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260					IVB
Corrosion induced by chlorides (XS from sea water, XD other than sea water) Requirements are also adequate for any associated carbonation induced corrosion (XC)	XD1	–	–	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300				All in Table A.6		
	XS1	–	–	–	C45/55 0.35 380	C35/45 0.45 360	C32/40 0.50 340			CEM I, IIA, IIB-S, SRPC		
		–	–	–	C40/50 0.35 380	C32/40 0.45 360	C28/35 0.50 340				IIB-V, IIIA	
		–	–	–	C32/40 0.40 380	C25/30 0.50 340						IIIB, IVB
	XD2 or XS2	–	–	–	C40/50 0.40 380	C32/40 0.50 340	C28/35 0.55 320			CEM I, IIA, IIB-S, SRPC		
		–	–	–	C35/45 0.40 380	C28/35 0.50 340	C25/30 0.55 320				IIB-V, IIIA	
		–	–	–	C32/40 0.40, 380	C25/30 0.50, 340	C20/25 0.55 320					IIIB, IVB
	XD3	–	–	–	–	–	C45/55 0.35 380	C40/50 0.40 380	C35/45 0.45 360	CEM I, IIA, IIB-S, SRPC		
		–	–	–	–	–	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 340		IIB-V, IIIA	
		–	–	–	–	–	C32/40 0.40 380	C28/35 0.45 360	C25/30 0.50 340			IIIB, IVB
	XS3	–	–	–	–	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		–	–	–	–	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		–	–	–	–	–	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

C32/40

0.45, 360

IIIB-V

IIIA

Specification example *Corrosion risk*

Exposure condition		Compressive strength class, maximum water-cement ratio and minimum cement or combination content for normal weight concrete[c] with 20 mm maximum aggregate size[d]								Cement/Combination types		
	Nominal cover[b], mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc			
Corrosion induced by carbonation, XC exposure classes	XC1	C20/25 0.70 240								All in Table A.6		
	XC2	—	—	C25/30 0.65 260						All in Table A.6		
	XC3/4	—	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260				All in Table A.6 except IVB		
		—	—	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260					IVB
Corrosion induced by chlorides (XS from sea water, XD other than sea water) Requirements are also adequate for any associated carbonation induced corrosion (XC)	XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300				All in Table A.6		
	XS1	—	—	—	C45/55 0.35 380	C35/45 0.45 360	C32/40 0.50 340			CEM I, IIA, IIB-S, SRPC		
		—	—	—	C40/50 0.35 380	C32/40 0.45 360	C28/35 0.50 340				IIB-V, IIIA	
		—	—	—	C32/40 0.40 380	C25/30 0.50 340						IIIB, IVB
	XD2 or XS2	—	—	—	C40/50 0.40 380	C32/40 0.50 340	C28/35 0.55 320			CEM I, IIA, IIB-S, SRPC		
		—	—	—	C35/45 0.40 380	C28/35 0.50 340	C25/30 0.55 320				IIB-V, IIIA	
		—	—	—	C32/40 0.40, 380	C25/30 0.50, 340	C20/25 0.55 320					IIIB, IVB
	XD3	—	—	—	—	—	C45/55 0.35 380	C40/50 0.40 380	C35/45 0.45 360	CEM I, IIA, IIB-S, SRPC		
		—	—	—	—	—	C35/45 0.40 380	C32/40 0.45 360	C28/35 0.50 340		IIB-V, IIIA	
		—	—	—	—	—	C32/40 0.40 380	C28/35 0.45 360	C25/30 0.50 340			IIIB, IVB
	XS3	—	—	—	—	—	—	C45/55 0.35 380	C40/50 0.40 380	CEM I, IIA, IIB-S, SRPC		
		—	—	—	—	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		—	—	—	—	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

C28/35

0.45, 360

IIIB

IVB

Corrosion risk

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Exposure condition		Compressive strength class, maximum water-cement ratio and minimum cement or combination content for normal weight concrete[c] with 20 mm maximum aggregate size[d]								Cement/Combination types		
	Nominal cover[b], mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc			
Corrosion induced by carbonation, XC exposure classes	XC1	C20/25 0.70 240								All in Table A.6		
	XC2	–	–	C25/30 0.65 260						All in Table A.6		
	XC3/4	–	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260				All in Table A.6 except IVB		
		–	–	C40/50 0.45 340	C32/40 0.55 300	C28/35 0.60 280	C25/30 0.65 260					IVB
Corrosion induced by chlorides (XS from sea water, XD other than sea water) Requirements are also adequate for any associated carbonation induced corrosion (XC)	XD1	–	–	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300				All in Table A.6		
	XS1	–	–	–	C45/55 0.35 380	C35/45 0.45 360	C32/40 0.50 340			CEM I, IIA, IIB-S, SRPC		
		–	–	–	C40/50 0.35 380	C32/40 0.45 360	C28/35 0.50 340				IIB-V, IIIA	
		–	–	–	C32/40 0.40 380	C25/30 0.50 340						IIIB, IVB
	XD2 or XS2	–	–	–	C40/50 0.40 380	C32/40 0.50 340	C28/35 0.55 320			CEM I, IIA, IIB-S, SRPC		
		–	–	–	C35/45 0.40 380	C28/35 0.50 340	C25/30 0.55 320				IIB-V, IIIA	
		–	–	–	C32/40 0.40, 380	C25/30 0.50, 340	C20/25 0.55 320					IIIB, IVB
	XD3	–	–	–	–	–	C45/55 0.35 380	C40/50 0.40 380	C3[illegible]/45 0.4[illegible] 360	CEM I, IIA, IIB-S, SRPC		
		–	–	–	–	–	C35/45 0.40 380	C32/40 0.45 360	C2[illegible]/35 0.5[illegible] 340		IIB-V, IIIA	
		–	–	–	–	–	C32/40 0.40 380	C28/35 [illegible]	C2[illegible]30 [illegible]			IIIB, [illegible]B
	XS3	–	–	–	–	–	–	[illegible]	[illegible]	CEM [illegible] IIB-S, [illegible]	[illegible]	[illegible]
		–	–	–	–	–	C3[illegible]/45 0.40 38[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		–	–	–	–	–	C32/40 0.40 38[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

C28/35

0.50, 340

IIB-V

IIIA

Freeze-thaw risk

Exposure class	Requirements for designed concretes							
	Minimum strength class	Maximum w/c ratio	Min. air content[a] and minimum cement or combination content (kg/m3)for maximum aggregate size				Other requirements	Cements and combinations
			32 mm or 40 mm	20 mm	14 mm	10 mm		
XF1	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	All in Table A.6
	C28/35 LC28/31	0.60	— 260	— 280	— 300	— 320	—	
XF2	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	
	C32/40 LC32/35	0.55	— 280	— 300	— 320	— 340	—	
XF3	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	Freeze/thaw resisting aggregates[b]	All in Table A.6 excluding cement and combination type IVB
	C40/50 LC40/44	0.45	— 320	— 340	— 360	— 360		
XF4	C28/35 LC28/31	0.55	3.0 280	3.5 300	4.5 320	5.5 340		All[c] in Table A.6 excluding cement and combination type IVB
	C40/50 LC40/44	0.45	— 320	— 340	— 360	— 360		

Freeze-thaw risk

Exposure class	Requirements for designed concretes							
	Minimum strength class	Maximum w/c ratio	Min. air content[a] and minimum cement or combination content (kg/m3)for maximum aggregate size				Other requirements	Cements and combinations
			32 mm or 40 mm	20 mm	14 mm	10 mm		
XF1	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	All in Table A.6
	C28/35 LC28/31	0.60	— 260	— 280	— 300	— 320	—	
XF2	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	
	C32/40 LC32/35	0.55	— 280	— 300	— 320	— 340	—	
XF3	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	Freeze/thaw resisting aggregates[b]	All in Table A.6 excluding cement and combination type IVB
	C40/50 LC40/44	0.45	— 320	— 340	— 360	— 360		
XF4	C28/35 LC28/31	0.55	3.0 280	3.5 300	4.5 320	5.5 340		All[c] in Table A.6 excluding cement and combination type IVB
	C40/50 LC40/44	0.45	— 320	— 340	— 360	— 360		

Freeze-thaw risk

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Exposure class	Requirements for designed concretes							
	Minimum strength class	Maximum w/c ratio	Min. air content[a] and minimum cement or combination content (kg/m3) for maximum aggregate size				Other requirements	Cements and combinations
			32 mm or 40 mm	20 mm	14 mm	10 mm		
XF1	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	All in Table A.6
	C28/35 LC28/31	0.60	— 260	— 280	— 300	— 320	—	
XF2	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	
	C32/40 LC32/35	0.55	— 280	— 300	— 320	— 340	—	
XF3	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	Freeze/thaw resisting aggregates[b]	All in Table A.6 excluding cement and combination type IVB
	C40/50 LC40/44	0.45	— 320	— 340	— 360	— 360		
XF4								
	C40/50 LC40/44	0.45	— 320	— 340	— 360	— 360		combination type IVB

C28/35, 0.55, 300, 3.5

All (except IVB)

Freeze-thaw risk

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Exposure class	Requirements for designed concretes							
	Minimum strength class	Maximum w/c ratio	Min. air content[a] and minimum cement or combination content (kg/m3) for maximum aggregate size				Other requirements	Cements and combinations
			32 mm or 40 mm	20 mm	14 mm	10 mm		
XF1	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	All in Table A.6
	C28/35 LC28/31	0.60	— 260	— 280	— 300	— 320	—	
XF2	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	—	
	C32/40 LC32/35	0.55	— 280	— 300	— 320	— 340	—	
XF3	C25/30 LC25/28	0.60	3.0 260	3.5 280	4.5 300	5.5 320	Freeze/thaw resisting aggregates[b]	All in Table A.6 excluding cement and combination type IVB
	C40/50 LC40/44	0.45	— 320	— 340	— 360	— 360		
XF4	C28/35 LC28/31	0.55	3.0 280	3.5 300	4.5 320	5.5 340		All[c] in Table A.6

C40/50, 0.45, 340

All (except IVB)

Chemical risk

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ACEC Class	Lowest nominal cover[e, f], mm	Intended working life	
		At least 50 years [g, h]	At least 100 years
AC-1s, AC-1	(25 + Δc)	DC-1 (RC25/30 if reinforced)	DC-1 (RC25/30 if reinforced)
AC-2s, AC-2	(25 + Δc)	DC-2 (FND2)	DC-2 (FND2)
AC-2z	(25 + Δc)	DC-2z (FND2z)	DC-2z (FND2z)
AC-3s	(25 + Δc)	DC-3 (FND3)	DC-3 (FND3)
AC-3z	(25 + Δc)	DC-3z (FND3z)	DC-3z (FND3z)
AC-3	(25 + Δc)	DC-3 (FND3)	DC-3 + one APM of choice , FND3 + one APM of choice, DC-4 or FND4
AC-4s	(25 + Δc)	DC-4 (FND4)	DC-4 (FND4)
AC-4z	(25 + Δc)	DC-4z (FND4z)	DC-4z (FND4z)
AC-4	(25 + Δc)	DC-4 (FND4)	DC-4 + one APM from APM2 to APM5, or FND4 + one APM from APM2 to APM5
AC-4ms	(25 + Δc)	DC-4m (FND4m)	DC-4m (FND4m)
AC-4m	(25 + Δc)	DC-4m (FND4m)	DC-4m + one APM from APM2 to APM5, or FND4m + one APM from APM2 to APM5
AC-5z	(25 + Δc)	DC-4z (FND4z) + APM3[i]	[illegible]
AC-5	(25 + Δc)	DC-4 (FND4) + APM3[i]	[illegible]
AC-5m	(25 + Δc)	DC-4m (FND4m)+ APM3[i]	[illegible]

DC-4 (+ APM3)

Chemical risk

DC-class	Maximum w/c ratio	Minimum cement or combination content in kg/m³ for maximum aggregate sizes (mm) of:				Cement and combination types
		≥ 40	20	14	10	
DC-1[a]	—	—	—	—	—	All in Table A.6
DC-2	0.55	300	320	340	360	IIB-V+SR, IIIA+SR, IIIB+SR, IVB
	0.50	320	340	360	380	CEM I, SRPC, IIA-D, IIA-Q, II-S, II-V, IIIA, IIIB
	0.45	340	360	380	380	IIA-L or LL ≥ 42,5
	0.40	360	380	380	380	IIA-L or LL 32,5
DC-2z	0.55	300	320	340	360	All in Table A.6
DC-3	0.50	320	340	360	380	IIIB+SR
	0.45	340	360	380	380	IVB
	0.40	360	380	380	380	IIB-V+SR, IIIA+SR, SRPC
DC-3z	0.50	320	340	360	380	All in Table A.6
DC-4	0.45	340	360	380	380	IIIB+SR
	0.40	360	380	380	380	IVB
	0.35	380	380	380	380	IIB-V+SR, IIIA+SR, SRPC
DC-4z	0.45	340	360	380	380	All in Table A.6
DC-4m	0.45	340	360	380	380	IIIB+SR

Chemical risk

DC-class	Maximum w/c ratio	Minimum cement or combination content in kg/m³ for maximum aggregate sizes (mm) of:				Cement and combination types
		≥ 40	20	14	10	
DC-1[a]	—	—	—	—	—	All in Table A.6
DC-2	0.55	300	320	340	360	IIB-V+SR, IIIA+SR, IIIB+SR, IVB
	0.50	320	340	360	380	CEM I, SRPC, IIA-D, IIA-Q, II-S, II-V, IIIA, IIIB
	0.45	340	360	380	380	IIA-L or LL ≥ 42,5
	0.40	360	380	380	380	IIA-L or LL 32,5
DC-2z	0.55	300	320	340	360	All in Table A.6
DC-3	0.50	320	340	360	380	IIIB+SR
	0.45	340	360	380	380	IVB
	0.40	360	380	380	380	IIB-V+SR, IIIA+SR, SRPC
DC-3z	0.50	320	340	360	380	All in Table A.6
DC-4	[illegible]	340	[illegible]	380	380	[illegible]
	[illegible]	360	[illegible]	380	380	IVB
	0.35	380	380	380	380	IIB-V+SR, IIIA+SR, SRPC
DC-4z	0.45	340	360	380	380	All in Table A.6
DC-4m	0.45	340	360	380	380	IIIB+SR

0.45 → 360 → IIIB+SR

Chemical risk

DC-class	Maximum w/c ratio	Minimum cement or combination content in kg/m³ for maximum aggregate sizes (mm) of:				Cement and combination types
		≥ 40	20	14	10	
DC-1[a]	—	—	—	—	—	All in Table A.6
DC-2	0.55	300	320	340	360	IIB-V+SR, IIIA+SR, IIIB+SR, IVB
	0.50	320	340	360	380	CEM I, SRPC, IIA-D, IIA-Q, II-S, II-V, IIIA, IIIB
	0.45	340	360	380	380	IIA-L or LL ≥ 42,5
	0.40	360	380	380	380	IIA-L or LL 32,5
DC-2z	0.55	300	320	340	360	All in Table A.6
DC-3	0.50	320	340	360	380	IIIB+SR
	0.45	340	360	380	380	IVB
	0.40	360	380	380	380	IIB-V+SR, IIIA+SR, SRPC
DC-3z	0.50	320	340	360	380	All in Table A.6
DC-4	[illegible]	340	[illegible]	380	380	[illegible]
	[illegible]	360	[illegible]	380	380	[illegible]
	[illegible]	380	[illegible]	380	380	[illegible], IIIA+SR, SRPC
DC-4z	0.45	340	360	380	380	All in Table A.6
DC-4m	0.45	340	360	380	380	IIIB+SR

0.40 → 380 → IVB

Chemical risk

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DC-class	Maximum w/c ratio	Minimum cement or combination content in kg/m³ for maximum aggregate sizes (mm) of:				Cement and combination types
		≥ 40	20	14	10	
DC-1[a]	—	—	—	—	—	All in Table A.6
DC-2	0.55	300	320	340	360	IIB-V+SR, IIIA+SR, IIIB+SR, IVB
	0.50	320	340	360	380	CEM I, SRPC, IIA-D, IIA-Q, II-S, II-V, IIIA, IIIB
	0.45	340	360	380	380	IIA-L or LL ≥ 42,5
	0.40	360	380	380	380	IIA-L or LL 32,5
DC-2z	0.55	300	320	340	360	All in Table A.6
DC-3	0.50	320	340	360	380	IIIB+SR
	0.45	340	360	380	380	IVB
	0.40	360	380	380	380	IIB-V+SR, IIIA+SR, SRPC
DC-3z	0.50	320	340	360	380	All in Table A.6
DC-4	0.45	340	360	380	380	IIIB+SR
	[illegible]	360	[illegible]	380	380	[illegible]
	[illegible]	380	[illegible]	380	380	[illegible]
DC-4z	[illegible]	340	[illegible]	380	380	[illegible]
DC-4m	0.45	340	360	380	380	IIIB+SR

0.35 → 380 → IIB-V+SR, IIIA+SR, SRPC

Chemical risk

Table A.10 — Additional protective measures (APMs)	
Option code	**APM**
APM1	Enhanced concrete quality
APM2	Use of controlled permeability formwork
APM3	Provide surface protection
APM4	Provide sacrificial layer
APM5	Address drainage of site

Example specification

Exposure class	Strength class	Maximum W/C ratio	Minimum cement content (kg/m^3)	Air content (%)	Allowable cements
X3S	C45/55	0.35	380	~	CEMI, IIA, IIB-S
	C32/40	0.45	360		IIB-V, IIIA
	C28/35	0.45	360		IIIB, IVB
XF4	C28/35	0.55	300	3.5	All (except IVB)
	C40/50	0.45	340	~	
DC-4	~	0.45	360	~	IIIB + SR
		0.35	380		IVB
		0.30	380		IIB + SR; IIIA + SR

Example specification

Option A

Exposure class	Strength class	Maximum W/C ratio	Minimum cement content (kg/m^3)	Air content (%)	Allowable cements
X3S	C45/55	0.35	380	~	CEMI, IIA, IIB-S
	C32/40	0.45	360		IIB-V, IIIA
	C28/35	0.45	360		IIIB, IVB
XF4	C28/35	0.55	300	3.5	All (except IVB)
	C40/50	0.45	340	~	
DC-4	~	0.45	360	~	IIIB + SR
		0.35	380		IVB
		0.30	380		IIB + SR; IIIA + SR

Example specification

Option B

Exposure class	Strength class	Maximum W/C ratio	Minimum cement content (kg/m^3)	Air content (%)	Allowable cements
X3S	C45/55	0.35	380	~	CEMI, IIA, IIB-S
	C32/40	0.45	360		IIB-V, IIIA
	C28/35	0.45	360		IIIB, IVB
XF4	C28/35	0.55	300	3.5	All (except IVB)
	C40/50	0.45	340	~	

DC-4	~	0.45	360	~	IIIB + SR
		0.35	380		IVB
		0.30	380		IIB + SR; IIIA + SR

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