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A Scrutiny on Local Specification for Concrete – How does it compare with others?

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Types of Specification for Concrete

- Prescribed
- Constrained
- Performance based

Prescribed Concrete Specification

- Mix proportions including cementitious content, composition of cementitious materials, water/cementitious content, etc., are basically prescribed.

- There is normally not any room for alteration to the prescribed mix proportions irrespective to different source/class/grade of materials used.

- No mix design is required/allowed.

Concrete Specifications with constraints to mix design

- Mix design parameters including cementitious content, composition of cementitious materials, water/cementitious content, etc., are constrained with upper and/or lower limits.

- Concrete designers can have some freedom to design the concrete mix proportions within limitations of the constrained parameters.

- Sometimes there are also some other performance requirements in addition to the design parameter limitations.

Performance Based Specification

- One or more performance requirements governing the design mix proportions
- Little or no constraint for design parameters of concrete
- Much freedom for concrete designers to employ the best approach of choice of materials, combination of cementitious materials, latest admixture technologies, etc. to meet the performance requirements of concrete

Comparison among the specification approaches

Type of Specification	Prescribed	Constrained	Performance based
Advantages	• Predictable performance • Competence and experience of concrete designer/supplier is less important	• Controlled quality level of both strength and durability • Suitable for specifying both high strength & durable concrete • Predictable performance with limits of design parameters	• Flexibility in concrete mix design • Freedom to introduce latest concrete technologies • Specified performance becomes the minimum requirement
Disadvantages	• Normally only for low to medium strength concrete • Cannot cope with specific application of the concrete mix • Hindering deployment of new concrete technologies	• Cannot catch up the pace of latest concrete technologies • Lower limits of the constraints are often used (e.g. 5 – 10% silica fume in marine concrete specification)	• Intensive initial type testing is demanded to confirm the concrete performance • Expensive and risky routine tests may be needed • Dependent on competence and experience of concrete designers/suppliers

Comparison among various concrete specifications

Mix Design Requirements - General

- Classification of exposure conditions:
- BS EN 206-1: 2013

Table 1 — Exposure classes *(1 of 2)*

Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: All exposures except where there is freeze/thaw, abrasion or chemical attack. For concrete with reinforcement or embedded metal: Very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
Where concrete containing reinforcement or other embedded metal is exposed to air and moisture, the exposure shall be classified as follows:		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity; Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact; Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity; External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2

Table 1 *(2 of 2)*

Class designation	Description of the environment	Informative examples where exposure classes may occur
3 Corrosion induced by chlorides other than from sea water		
Where concrete containing reinforcement or other embedded metal is subject to contact with water containing chlorides, including de-icing salts, from sources other than from sea water, the exposure shall be classified as follows:		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools; Concrete exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides. Pavements, Car park slabs
4 Corrosion induced by chlorides from sea water		
Where concrete containing reinforcement or other embedded metal is subject to contact with chlorides from sea water or air carrying salt originating from sea water, the exposure shall be classified as follows:		
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures
5 Freeze/thaw attack with or without de-icing agents		
Where concrete is exposed to significant attack by freeze/thaw cycles whilst wet, the exposure shall be classified as follows:		
XF1	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3	High water saturation, without de-icing agent	Horizontal concrete surfaces exposed to rain and freezing
XF4	High water saturation, with de-icing agent or sea water	Road and bridge decks exposed to de-icing agents; Concrete surfaces exposed to direct spray containing de-icing agents and freezing Splash zones of marine structures exposed to freezing
6 Chemical attack		
Where concrete is exposed to chemical attack from natural soils and ground water, the exposure shall be classified as follows:		
XA1	Slightly aggressive chemical environment	Concrete exposed to natural soil and ground water according to Table 2
XA2	Moderately aggressive chemical environment	Concrete exposed to natural soil and ground water according to Table 2
XA3	Highly aggressive chemical environment	Concrete exposed to natural soil and ground water according to Table 2

Mix Design Requirements - General

- Classification of exposure conditions:
- BS EN 206-1: 2013

Table 2 — Limiting values for exposure classes for chemical attack from natural soil and ground water

Chemical characteristic	Reference test method	XA1	XA2	XA3
Ground water				
SO_4^{2-} mg/l	EN 196-2	$\geq$ 200 and $\leq$ 600	$>$ 600 and $\leq$ 3 000	$>$ 3 000 and $\leq$ 6 000
pH	ISO 4316	$\leq$ 6,5 and $\geq$ 5,5	$<$ 5,5 and $\geq$ 4,5	$<$ 4,5 and $\geq$ 4,0
CO_2 mg/l aggressive	EN 13577	$\geq$ 15 and $\leq$ 40	$>$ 40 and $\leq$ 100	$>$ 100 up to saturation
NH_4^+ mg/l	ISO 7150-1	$\geq$ 15 and $\leq$ 30	$>$ 30 and $\leq$ 60	$>$ 60 and $\leq$ 100
Mg^{2+} mg/l	EN ISO 7980	$\geq$ 300 and $\leq$ 1 000	$>$ 1 000 and $\leq$ 3 000	$>$ 3 000 up to saturation
Soil				
SO_4^{2-} mg/kg[a] total	EN 196-2[b]	$\geq$ 2 000 and $\leq$ 3 000[c]	$>$ 3 000[c] and $\leq$ 12 000	$>$ 12 000 and $\leq$ 24 000
Acidity according to Baumann Gully ml/kg	prEN 16502	$>$ 200	Not encountered in practice	

a Clay soils with a permeability below 10^{-5} m/s may be moved into a lower class.

b The test method prescribes the extraction of SO_4^{2-} by hydrochloric acid; alternatively, water extraction may be used, if experience is available in the place of use of the concrete.

c The 3 000 mg/kg limit shall be reduced to 2 000 mg/kg, where there is a risk of accumulation of sulfate ions in the concrete due to drying and wetting cycles or capillary suction.

Mix Design Requirements - General

- Classification of exposure conditions:
- BS 8500-1: 2015+A1: 2016

Table A.1 Exposure classes

Class designation	Class description	Informative examples applicable in the United Kingdom
No risk of corrosion or attack (X0 class)		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze-thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Unreinforced concrete surfaces inside structures Unreinforced concrete completely buried in soil classed as AC-1 and with a hydraulic gradient not greater than 5 Unreinforced concrete permanently submerged in non-aggressive water Unreinforced concrete surfaces in cyclic wet and dry conditions not subject to abrasion, freezing or chemical attack Reinforced concrete surfaces exposed to very dry conditions
Corrosion induced by carbonation (XC classes) [A)] *(where concrete containing reinforcement or other embedded metal is exposed to air and moisture)*		
XC1	Dry or permanently wet	Reinforced and prestressed concrete surfaces inside enclosed structures except voided superstructures and areas of structures with high humidity Reinforced and prestressed concrete surfaces permanently submerged in non-aggressive water
XC2	Wet, rarely dry	Reinforced and prestressed concrete surfaces permanently in contact with soil not containing chlorides [B)]
XC3 and XC4 (XC3/4)	Moderate humidity or cyclic wet and dry	External reinforced and prestressed concrete surfaces sheltered from, or exposed to, direct rain Reinforced and prestressed concrete surfaces subject to high humidity (e.g. poorly ventilated bathrooms, kitchens) Reinforced and prestressed concrete surfaces exposed to alternate wetting and drying Interior concrete surfaces of pedestrian subways not subject to de-icing salts, voided superstructures or cellular abutments Reinforced or prestressed concrete surfaces protected by waterproofing [A1] [C)] [A1]
Corrosion induced by chlorides other than from sea water (XD classes) [A)] *(where concrete containing reinforcement or other embedded metal is subject to contact with water containing chlorides, including de-icing salts, from sources other than from seawater)*		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides Reinforced and prestressed concrete wall and structure supports more than 10 m horizontally from a carriageway Bridge deck soffits more than 5 m vertically above the carriageway Parts of structures exposed to occasional or slight chloride conditions
XD2	Wet, rarely dry	Reinforced and prestressed concrete surfaces totally immersed in water containing chlorides [D)] Buried highway structures more than 1 m below adjacent carriageway [E)]

Mix Design Requirements - General

- Classification of exposure conditions:
- BS 8500-1: 2015+A1: 2016

Table A.1 Exposure classes

XD3	Cyclic wet and dry	Reinforced and prestressed concrete walls and structure supports within 10 m of a carriageway Bridge parapet edge beams Buried highway structures less than 1 m below carriageway level Reinforced pavements and car park slabs[F)]
Corrosion induced by chlorides from sea water (XS classes)[A) G)] *(where concrete containing reinforcement or other embedded metal is subject to contact with sea water or airborne salt originating from sea water)*		
XS1	Exposed to airborne salt but not in direct contact with sea water	External reinforced and prestressed concrete surfaces in coastal areas
XS2	Permanently submerged	Reinforced and prestressed concrete surfaces completely submerged or remaining saturated, e.g. concrete below mid-tide level[D)]
[A1] XS3[D)] [A1]	Tidal, splash and spray zones	Reinforced and prestressed concrete surfaces in the upper tidal zones and the splash and spray zones[H)], including exposed soffits above sea water
Freeze-thaw attack (XF classes) *(where concrete is exposed to significant attack from freeze-thaw cycles whilst wet)*		
XF1	Moderate water saturation without de-icing agent	Vertical concrete surfaces such as façades and columns exposed to rain and freezing Non-vertical concrete surfaces not highly saturated, but exposed to freezing and to rain or water
XF2	Moderate water saturation with de-icing agent	Concrete surfaces such as parts of bridges, which would otherwise be classified as XF1, but which are exposed to de-icing salts either directly or as spray or run-off
XF3	High water saturation without de-icing agent	Horizontal or near horizontal concrete surfaces, which are exposed to freezing whilst wet Concrete surfaces subjected to frequent splashing with water and exposed to freezing
[A1] XF4[D)] [A1]	High water saturation with de-icing agent or sea water [A1] *Text deleted* [A1]	Horizontal concrete surfaces, such as roads and pavements, exposed to freezing and to de-icing salts either directly or as spray or run-off Concrete surfaces subjected to frequent splashing with water containing de-icing agents and exposed to freezing
Chemical attack (XA classes) *(where concrete is exposed to chemical attack)* *Chemical attack by aggressive ground (ACEC classes)*		
XA1	Slightly aggressive chemical environment	Concrete exposed to natural soil and ground water according to BS EN 206. These European exposure classes are not used in the UK where Table A.2 shall be used to determine the ACEC-class. See BRE Special Digest 1 [1] for guidance on site investigation.
XA2	Moderately aggressive chemical environment	
XA3	Highly aggressive chemical environment	
Chemical attack from seawater (XAS class) *(where concrete is exposed to chemical attack from seawater)*		
XAS[I)]	Exposed to sea water	Concrete surfaces in contact with sea water

Mix Design Requirements - General

- Classification of exposure conditions:
- BS 8500-1: 2015+A1: 2016

Table A.3 Typical reinforced concrete applications in buildings (intended working life at least 50 years) for designated concretes

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 RC30/37 RC28/35
Horizontal elements with high saturation without de-icing agent and subject to freezing while wet [C)]	XC3/XC4 + XF3	(20 + Δc) (25 + Δc) (30 + 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	(25 + Δc) [D)]	RC25/30
C25/30 reinforced or prestressed buried foundation in AC-2 or more aggressive ground conditions	AC-2 to AC-5m	(25 + Δc) [D)]	See [E)]

A) Check the appropriate design code to see if it is recommended that the minimum cover to prestressing steel is adjusted by a factor $\Delta c_{dur,\gamma}$.

B) See **A.4.7** (Table A.14) for details of the specification associated with the designation.

C) If IVB-V cements and combinations are to be specifically permitted under **4.2.3a**), increase the minimum cover by 5 mm.

D) The minimum allowance for deviation, Δc, should be at least 15 mm for concrete to be cast against blinding or prepared ground and at least 50 mm for concrete to be cast directly against soil. Where the ground contains chlorides, the nominal cover should comprise the recommended minimum cover for the associated XD or XS class plus an the allowance for deviation, Δc, and the more onerous limiting values for the concrete should be selected.

E) Provided that a minimum compressive strength class of C25/30 is adequate, use **A.4.5** (Table A.10) to determine the DC-class and replace the "DC-" with "FND" to obtain the designation of the appropriate designated concrete, e.g. "DC-3z" becomes "FND3Z". If a higher compressive strength class is required, specify a designed concrete using the required compressive strength class and the DC-class.

• Classification of exposure conditions: BS 8500-1: 2015+A1: 2016

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[C], maximum w/c ratio and minimum cement or combination content for normal-weight concrete[D] with 20 mm maximum aggregate size[E]											Cement/combination types
	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	60 + Δc	70 + Δc	80 + 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	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	C32/40 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	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	C32/40 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	C25/30 0.65 260	C25/30 0.65 260	IVB-V
Corrosion induced by chlorides other than sea water (XD exposure classes) 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	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XD2	—	—	—	C40/50[F] 0.40 380	C32/40[F] 0.50 340	C28/35 0.55 320	C28/35 0.55 320	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, CEM I-SR0, CEM I-SR3
	—	—	—	C35/45[F] 0.40 380	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	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40[F] 0.40 380	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	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V
XD3	—	—	—	—	—	C45/55[F] 0.35[G] 380	C40/50[F] 0.40 380	C35/45[F] 0.45 360	C35/45[F] 0.45 360	C35/45[F] 0.45 360	C35/45[F] 0.45 360	CEM I, IIA, IIB-S, CEM I-SR0, CEM I-SR3
	—	—	—	—	—	C35/45[F] 0.40 380	C32/40[F] 0.45 360	C28/35 0.50 340	[A1) C25/30 0.55 320 (A1]	[A1) C25/30 0.55 320 (A1]	[A1) C25/30 0.55 320 (A1]	IIB-V, IIIA
	—	—	—	—	—	C32/40[F] 0.40 380	C28/35 0.45 360	C25/30 0.50 340	C25/30 0.50 340	C25/30 0.50 340	C25/30 0.50 340	IIIB, IVB-V

• Classification of exposure conditions: BS 8500-1: 2015+A1: 2016

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[C], maximum w/c ratio and minimum cement or combination content for normal-weight concrete[D] with 20 mm maximum aggregate size[E]											Cement/ combination types
	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	55 + Δc	60 + Δc	65 + Δc	70 + Δc	75 + Δc	80 + Δc	
Corrosion induced by chlorides from sea water (XS exposure classes) adequate for any associated carbonation induced corrosion (XC)												
XS1	—	—	—	C45/55[F] 0.35[G] 380	C40/50[F] 0.40 380	C35/45[F] 0.45 360	C32/40[F] 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
	C40/50[F] 0.35[G] 380	C32/40[F] 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	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[F] 0.40 380	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	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	C32/40[F] 0.40 380	C25/30[H] 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IV-B, IIIB
XS2	—	—	—	—	—	—	C45/55[F] 0.35[G] 380	C40/50[F] 0.40 380	C40/50[F] 0.40 380	C35/45[F] 0.45 360	C32/40[F] 0.50 340	CEM I, IIA, IIB-S
	—	—	C35/45[F] 0.40 380	C32/40[F] 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	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	C40/50[F] 0.35[G] 380	C32/40[F] 0.45[G] 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	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	—	C35/45[F] 0.35[G] 380	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	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IV-B, IIIB
XS3	—	—	—	—	—	—	—	—	—	—	C45/55 0.35[G] 380	CEM I, IIA, IIB-S
	—	—	—	—	C40/50[F] 0.35[G] 380	C35/45[F] 0.40 380	C32/40[F] 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C40/50[F] 0.35[G] 380	C32/40[F] 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	C25/30 0.55 320	IIB-V ≥25% fly ash, IIIA ≥46% ggbs
	—	—	—	C35/45[F] 0.35[G] 380	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	C20/25 0.55 320	IV-B, IIIB

• Classification of exposure conditions: BS 8500-1: 2015+A1: 2016

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[C], maximum w/c ratio and minimum cement or combination content for normal-weight concrete[D] with 20 mm maximum aggregate size[E]												Cement/ combination types
	$15 + \Delta c$	$20 + \Delta c$	$25 + \Delta c$	$30 + \Delta c$	$35 + \Delta c$	$40 + \Delta c$	$45 + \Delta c$	$50 + \Delta c$	$55 + \Delta c$	$60 + \Delta c$	$70 + \Delta c$	$80 + \Delta c$	
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	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	C25/30 0.65 260	All in Table A.6
XC3/4	—	—	—	C40/50 0.45 340	C35/45 0.50 320	C32/40 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	C25/30 0.65 260	All in Table A.6 except IVB-V
	—	—	—	—	C40/50 0.45 340	C35/45 0.50 320	C32/40 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	IVB-V
Corrosion induced by chlorides other than sea water (XD exposure classes) 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	C28/35 0.60 300	All in Table A.6
XD2	—	—	—	—	—	C35/45[F] 0.45 360	C32/40 0.50 340	C28/35 0.55 320	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, CEM I-SR0, CEM I-SR3
	—	—	—	—	—	C32/40[F] 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	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	C20/25 0.55 320	IIIB, IVB-V
XD3	—	—	—	—	—	—	—	—	C45/55[F] 0.35[G] 380	C40/50[F] 0.40 380	C35/45[F] 0.45 360	C35/45[F] 0.45 360	CEM I, IIA, IIB-S, CEM I-SR0, CEM I-SR3
	—	—	—	—	—	—	C40/50[F] 0.35[G] 380	C35/45[F] 0.40 380	C32/40[F] 0.45 360	C28/35 0.50 340	[A1) C25/30 0.55 320 (A1]	[A1) C25/30 0.55 320 (A1]	IIB-V, IIIA
	—	—	—	—	—	—	C32/40[F] 0.40 380	C28/35 0.45 360	C25/30 0.50 340	[A1) C25/30 0.55 320 (A1]	C25/30 0.55 320	C25/30 0.55 320	IIIB, IVB-V

Mix Design Requirements - General

- Classification of exposure conditions:
- CoP 2013

Exposure condition	Type of exposure
1	**Mild** Internal concrete surfaces. External concrete surfaces protected from the effects of severe rain or cyclic wetting and drying e.g. concrete finish with mosaic tiles, painting or rendering. Concrete surfaces continuously under water, or rarely dry - not sea water. Concrete in contact with non-aggressive soil.
2	**Moderate** Internal concrete surfaces exposed to high humidity e.g. bathrooms and kitchens. External concrete surfaces exposed to the effects of severe rain or cyclic wetting and drying e.g. fair faced concrete, concrete with cladding secured by dry or mechanical fixing, curtain walling.
3	**Severe** Concrete surfaces exposed to sea water spray through airborne contact but not direct exposure, i.e. structures on or near the coast. Concrete surfaces exposed to corrosive fumes.
4	**Very Severe** Concrete surfaces frequently exposed to sea or flowing water with pH $\leq$ 4.5. Concrete in sea water tidal zone down to 1 m below lowest low water level.
5	**Abrasive** Concrete surfaces exposed to abrasive action machinery, metal tyred vehicles or water carrying solids.
Note: 1. Cement bedding for finishes should be ignored in exposure considerations.	

Table 4.1 - Exposure conditions

Mix Design Requirements - General

- Classification of exposure conditions:
- ACI-318-14

Table 19.3.1.1—Exposure categories and classes

Category	Class	Condition	
Freezing and thawing (F)	F0	Concrete not exposed to freezing-and-thawing cycles	
	F1	Concrete exposed to freezing-and-thawing cycles with limited exposure to water	
	F2	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water	
	F3	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals	
Sulfate (S)		Water-soluble sulfate (SO_4^{2-}) in soil, percent by mass[1]	Dissolved sulfate (SO_4^{2-}) in water, ppm[2]
	S0	$SO_4^{2-} < 0.10$	$SO_4^{2-} < 150$
	S1	$0.10 \leq SO_4^{2-} < 0.20$	$150 \leq SO_4^{2-} < 1500$ or seawater
	S2	$0.20 \leq SO_4^{2-} \leq 2.00$	$1500 \leq SO_4^{2-} \leq 10,000$
	S3	$SO_4^{2-} > 2.00$	$SO_4^{2-} > 10,000$
In contact with water (W)	W0	Concrete dry in service Concrete in contact with water and low permeability is not required	
	W1	Concrete in contact with water and low permeability is required	
Corrosion protection of reinforcement (C)	C0	Concrete dry or protected from moisture	
	C1	Concrete exposed to moisture but not to an external source of chlorides	
	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	

[1]Percent sulfate by mass in soil shall be determined by ASTM C1580.

[2]Concentration of dissolved sulfates in water, in ppm, shall be determined by ASTM D516 or ASTM D4130.

Mix Design Requirements - General

- Classification of exposure conditions:
- GB50476: 2008

3.2 环境类别与作用等级

3.2.1　结构所处环境按其对钢筋和混凝土材料的腐蚀机理可分为 5 类，并应按表 3.2.1 确定。

表 3.2.1 环境类别

环境类别	名称	腐蚀机理
I	一般环境	保护层混凝土碳化引起钢筋锈蚀
II	冻融环境	反复冻融导致混凝土损伤
III	海洋氯化物环境	氯盐引起钢筋锈蚀
IV	除冰盐等其他氯化物环境	氯盐引起钢筋锈蚀

注：一般环境系指无冻融、氯化物和其他化学腐蚀物质作用。

3・2・2　环境对配筋混凝土结构的作用程度应采用环境作用等级表达，并应符合表 3.2.2 的规定。

表 3.2.2 环境作用等级

环境作用等级 / 环境类别	A 轻微	B 轻度	C 中度	D 严重	E 非常严重	F 极端严重
一般环境	I-A	I-B	I-C	—	—	—
冻融环境	—	—	II-C	II-D	II-E	—
海洋氯化物环境	—	—	III-C	III-D	III-E	III-F
除冰盐等其他氯化物环境	—	—	V-C	V-D	V-E	—
化学腐蚀环境	—	—	V-C	V-D	V-E	—

3・2・3　当结构构件受到多种环境类别共同作用时.应分别满足每种环境类别单独作用下的

Comparison among the Standards – Classification of exposure conditions

- BS EN 206 includes the most types of exposure conditions covering a wide range of climatic and locality situations . Very intensive requirements for concrete cover, water cementitious ratio and minimum cementitious contents are given for various exposure conditions

- ACI 318 has simpler classification for exposure conditions including "exposure to sulfate" and "in contact with water". Its classification for exposure conditions is closer to that in CoP 2013.

- GB 50476 covers more exposure conditions to chemical attack.

- In general, the classification for exposure conditions in CoP 2013 is deemed appropriate to local environment.

Mix Design Requirements – Min. Cementitious Content for Reinforced Concrete with 20 mm Max. Aggregate Size

Strength Class (Standard Cube)	CoP 2013 (kg/m³)	G.S. for CE Works 2006 (kg/m³)	BS EN 206-1: 2013 & BS 8500-1: 2015+A1:2016 (kg/m³)	ACI 301-05 (kg/m³)	JGJ 55—2011 (kg/m³)	
C30	310	310	280 Note 1	341 kg/m3	W/C	Min. Ct.
C40	350	350	280/300 (C37) Note 2	for all mixes	0.60	280
C45	375	375	320/340 Note 3	(564 ld/yd³)	0.55	300
C50	400	400	--		0.50	320
≥ C55	400	400	--		≤ 0.45	330

Mix Design Requirements – Max. Water to Cementitious Content Ratio

Strength Class (Standard Cube)	CoP 2013 (kg/m³)	G.S. for CE Works 2006 (kg/m³)	BS EN 206-1: 2013 & BS 8500-1: 2015+A1:2016 (kg/m³)	ACI 301-05 (kg/m³)	JGJ 55—2011 (kg/m³)	
C30	0.65	0.50 (for water retaining structures)	Refer to tables below	-	W/C	Min. Ct.
C40	0.55				0.60	280
C45	0.45				0.55	300
C50	0.40				0.50	320
≥ C55	0.35				≤ 0.45	330

- Limited values for concrete mix designs for DC Class Concrete in BS 8500-1: 2015+A1: 2016

- Note: DC-Class means "design chemical class used to classify the resistance to concrete to chemical attack (e.g. foundation works)

Table A.12 Limiting values of composition and properties for concrete where a DC-class is specified

DC-class	Max. w/c ratio	Min. cement or combination content (kg/m^3) for max. aggregate size				Cement and combination types	Grouping used in BRE SD1:2005 [1]
		≥40 mm	20 mm	14 mm	10 mm		
DC-1 [A)]	—	—	—	—	—	All in Table A.6	A to G
DC-2	0.55	300	320	340	360	IIB-V+SR, IIIA+SR, IIIB+SR, IVB-V	D, E, F
	0.50	320	340	360	380	CEM I, A1⟩ CEM I-SR 0, CEM I-SR 3 ⟨A1, IIA-D, IIA-Q, IIA-S, IIA-V, IIB-S, IIB-V, IIIA, IIIB	A, G
	0.45	340	360	380	380	IIA-L or LL ≥42,5	B
	0.40	360	380	380	380	IIA-L or LL 32,5	C
DC-2z	0.55	300	320	340	360	All in Table A.6	A to G
DC-3	0.50	320	340	360	380	IIIB+SR	F
	0.45	340	360	380	380	IVB-V	E
	0.40	360	380	380	380	IIB-V+SR, IIIA+SR, A1⟩ CEM I-SR 0, CEM I-SR 3 ⟨A1	D, G
DC-3z	0.50	320	340	360	380	All in Table A.6	A to G
DC-4	0.45	340	360	380	380	IIIB+SR	F
	0.40	360	380	380	380	IVB-V	E
	0.35	380	380	380	380	IIB-V+SR, IIIA+SR, A1⟩ CEM I-SR 0, CEM I-SR 3 ⟨A1	D, G
DC-4z	0.45	340	360	380	380	All in Table A.6	A to G
DC-4m	0.45	340	360	380	380	IIIB+SR	F

A) If the concrete is reinforced or contains embedded metal, the minimum concrete quality for 20 mm maximum aggregate size is C25/30, 0.65, 260 or designated concrete RC25/30.

- Limited values for concrete mix designs for Housing and other applications in BS 8500-1: 2015+A1: 2016

Note:

- GEN: Housing or other applications
- RC: reinforced or prestressed concrete
- PAV: pavement applications
- FND: foundation applications

Table A.15 Summary of requirements for designated concretes[A)]

Concrete designation	Min. strength class	Default slump class	Max. w/c ratio	Min. cement or combination content (kg/m³) for 20 mm max. aggregate size	Cement and combination types
GEN0	C6/8	S3	—	120	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN1	C8/10	S3	—	180	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN2	C12/15	S3	—	200	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
GEN3	C16/20	S3	—	220	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
RC20/25	C20/25	S3	0.70	240	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V
RC25/30	C25/30	S3	0.65	260	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V [B)]
RC28/35	C28/35	S3	0.60	280	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V [B)]
RC30/37	C30/37	S3	0.55	300	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V [B)]
RC32/40	C32/40	S3	0.55	300	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V [B)]
RC35/45	C35/45	S3	0.50	320	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V [B)]
RC40/50	C40/50	S3	0.45	340	CEM I, IIA, IIB-S, IIB-V, IIIA, IVB-V [B)]
RC40/50XF	C40/50	S3	0.45	340	CEM I, IIA, IIB-S, IIB-V, IIIA [C)]
PAV1	C28/35 [D)]	S2	0.55	300	CEM I, IIA, IIB-S, IIB-V, IIIA [C)]
PAV2	C32/40 [D)]	S3	0.45	340	CEM I, IIA, IIB-S, IIB-V, IIIA [C)]
FND2	C25/30	S3	0.55	320	IIB-V+SR, IIIA+SR, IIIB+SR, IVB-V
			0.50	340	CEM I, [A1) CEM I-SR 0, CEM I-SR 3 (A1], II-S, II-V, IIIA, IIIB
			0.45	360	IIA-L or LL class 42,5
			0.40	380	IIA-L or LL class 32,5
FND2Z	C25/30	S3	0.55	320	All in Table A.6
FND3	C25/30	S3	0.50	340	IIIB+SR
			0.45	360	IVB-V
			0.40	380	IIB-V+SR, IIIA+SR, [A1) CEM I-SR 0, CEM I-SR 3 (A1]
FND3Z	C25/30	S3	0.50	340	All in Table A.6
FND4	C25/30	S3	0.45	360	IIIB+SR
			0.40	380	IVB-V
			0.35	380	IIB-V+SR, IIIA+SR, [A1) CEM I-SR 0, CEM I-SR 3 (A1]
FND4Z	C25/30	S3	0.45	360	All in Table A.6
FND4M	C25/30	S3	0.45	360	IIIB+SR

[A)] See BS 8500-2:2015+A1:2016, Clause 6 for the full set of requirements for designated concretes.

[B)] Only if specifically permitted under 4.2.3a).

[C)] With a maximum proportion of ggbs of 55% unless a higher proportion is specifically permitted in accordance with 4.2.3a).

[D)] The concrete shall contain an air-entraining admixture to give a minimum air content by volume of 4.0%, 4.5%, 5.5% or 6.5% with aggregate of 40 mm, 20 mm, 14 mm, and 10 mm maximum aggregate size respectively at delivery.

Comparison among the Standards – Min. Cementitious Content & Max. Water Cementitious Ratio

- All specifications give requirements for minimum cementitious contents for specified concrete grades except that ACI 301-05 only gives a specified minimum cementitious content for all concrete grades
- BS 8500 gives very intensive specifications for Min. Cementitious Contents & Max. W/C Ratios w.r.t. to various exposure conditions, applications of concrete and concrete grades
- Instead of referring to specified concrete grades, JGJ 55-2011 stipulates minimum cementitious contents with respect to the maximum water to binder ratios

Comparison among the Standards – Min. Cementitious Content & Max. Water Cementitious Ratio

- Basically, the min. cementitious content and max. W/C ratios given in local specifications are similar to those given in other national standards

- In view of concrete mixes with various grades adopted in the industry, the normal cementitious contents used in various concrete grades exceed in general in excess of the specified minimum quantities

Other design parameters constrained in specifications

- % of supplementary cementitious materials (e.g. PFA, GGBS, Silica Fume)
- Water cementitious ratio (e.g. 0.42) and maximum cementitious materials (450 kg/m^3) for water retaining structures
- Performance requirements such as Rapid Chloride Permeability Test (RCPT) Value, Fresh Concrete Temperature (e.g. 25^{o}C, 30^{o}C), Peak Temperature in concrete during hydration period (e.g. 70^{o}C, 80^{o}C)
- Other performance requirements related to durability under special exposure conditions or application

Compliance Criteria for Concrete Strength (focused on Grade 20 or above)

Specimen & Curing Condition

Compliance Criteria	CoP 2013	G.S. for CE Works 2006	BS EN 12390 as referred by BS EN 206-1: 2013 & BS 8500-1: 2015+A1:2016	ACI 318-14	JGJ 55—2011
Specimen & Curing Condition					
Test Specimen	100 or 150 mm cube	100 mm cube	100, 150, 200, 250 or 300 mm cube (depending on agg. size)	100 or 150 mm ϕ cylinder	100, 150 or 200 mm (depending on agg. size)
Test Standard	CS1: 2010	CS1: 2010	BS EN 12390-3: 2009	ASTM C39/39M-18	GB/T 50081-2002
Curing Temp.	27 ± 3 °C	27 ± 3 °C	20 ± 2 °C	23 ± 2 °C	20 ± 2 °C

Compliance Criteria	CoP 2013	G.S. for CE Works 2006	BS EN 12390 as referred by BS EN 206-1: 2013 & BS 8500-1: 2015+A1:2016	ACI 318-14	GB/T 50107—2010 (Statistical Assessment method for concrete with continuous production)
Individual cube test result	100 mm cube: $\geq f_{cu} - 2$ MPa 150 mm cube: $\geq f_{cu} - 3$ MPa (f_{cu} = concrete grade strength)		$\geq f_{ck} - 4$ MPa (f_{ck} = conc. characteristic strength)	If $f_{c'} \leq 5000$ psi (~35MPa): Individual Cylinder str. $\geq f_{c'} - 500$ psi (3.5 MPa) If $f_{c'} > 5000$ psi (~35MPa): Individual Cylinder str. $\geq 0.9 f_{c'}$ ($f_{c'}$ = concrete cylinder strength)	(a) Grade ≤ C20: $f_{cu.min} \geq 0.85 f_{cu.k}$ (b) Grade > C20: $f_{cu.min} \geq 0.9 f_{cu.k}$ ($f_{cu.min}$ = min. cube strength $f_{cu.k}$= characteristic strength)
Running Average	Av. of 4 consecutive results: (a) 100 mm cube: C1 (S.D. > 5.5): ≥ grade strength + 7 MPa C2: (S.D. ≤ 5.5): ≥ grade strength + 5 MPa (b) 150 mm cube: C1: (S.D. > 5) ≥ grade strength + 5 MPa C2: (S.D. ≤ 5): ≥ grade strength + 3 Mpa		Av. of 3 overlapping or non-overlapping results: (a) For initial production: $\geq f_{ck} + 4$ MPa (b) For continuous production: (No. of results ≥15 but ≤ 35) $\geq f_{ck} + 1.48\sigma$ $f_{ck:}$ Characteristic strength σ: standard deviation	Av. of 3 consecutive results $\geq f_{c'}$ ($f_{c'}$ = concrete cylinder strength)	Av. of 3 consecutive results : Mean $\geq f_{cu.k} + 0.7\sigma$ Min. $\geq f_{cu.k} - 0.7\sigma$ $f_{cu.k}$= characteristic strengt σ = standard deviation of the 3 consecutive results but not less than 2.5 MPa

Comparison among the Standards – Compliance criteria for compressive strength

- The criteria extracted from local specifications, BS EN and GB are based on cube strengths while that from ACI 318 is based on cylinder strength
- The curing temperature in CS1: 2010 is the highest (27 ± 3^{o}C). Specified curing temperatures in other specifications are much lower (20 ± 2^{o}C and 23 ± 2^{o}C). However, there should not be too much effect on 28-day cube strength.
- The requirements in local specifications seem to be the most stringent one giving the highest safety margin for concrete strength.
- The criteria given in ACI 318 seem to be the simplest.
- Compliance criteria given in BS EN & GB standards are more statistically based (noted that the criteria given in the previous table were simplified).

Conclusions

- Local specifications can be viewed as "Constrained Specification" type supplemented with some performance requirements

- Other specifications deem to give less constraints and more rooms are provided for concrete mix designs to achieve the designated performance (e.g. different durability classes). However, higher competence may be required for all parties involved.

- In BS EN 206 & BS 8500, requirements for concrete and its raw materials cover a wide range of classifications and quality grades. If these standards are to be referred, it cannot be simply stated to be "………in accordance with BS EN 206."

- In case local specifications are to be amended to cope in line with any of these national standard(s), care shall be taken when choosing clauses to adopt (full adopted is highly not recommended). Unavoidably, concrete professionals and the industry shall be consulted.

Recommendations for Future Development of local specifications

- Before adopting any other overseas specification, study its suitability under local conditions and practices
- Where practically viable, consider replacing some of the design constraints by performance requirements
- Remove unnecessary barriers to innovations and new technologies
- Promote product assessment and reliability by:
    - Upstream control of certifications
    - Establishing professionalism for interested parties: concrete producers, specifiers, engineers, supervisors, etc. through professional and training requirements

END OF PRESENTATION