Performance Specifications in Projects, and Proposed Inclusion in IS456

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Workshop on ICI Concrete Durability Handbook

Bangalore, Apr 29. 2023

Outline

- Examples of performance specs in major construction projects (Courtesy: Dr Sivakumar Kandasami, L&T Construction)
- Proposed IS456 inclusions for durability design (Courtesy: Dr V V Arora, Former Dy. Director NCCBM, Chairperson, IS456 Materials committee)

Durability specifications in construction projects

- Oresund link (Denmark – Sweden)
- Confederation bridge (Canada)
- New Panama Canal
- Metros – Riyadh, Doha, Chennai
- Statue of Unity

Oresund Link

- 16 km long – Copenhagen to Malmo; 3 components – tunnel, dredging and reclamation, and bridge
- 100 year design service life – achieved with Cementitious contents of 345 – 450 kg/m^3!! The w/b ranged between 0.32 and 0.42
- For tunnel – ternary blend with fly ash and silica fume
- Particle packing for aggregates

(*Source*: https://www.google.com/search?rlz=1C1EKKP_enIN776IN776&q)

Confederation bridge

- 12.9 km long multi-span box girder structure
- Apart from seawater attack, freeze-thaw and abrasion also!
- 100 year design life
- Low alkali cement with fly ash and silica fume
- w/b 0.25 to 0.36; air entrainment
- Target chloride diffusion coefficient $=3.5 \times 10^{-13}$ m^2/s

(*Source*: https://www.google.com/search?rlz=1C1EKKP_enIN776IN776&q)

New Panama Canal

- 5 million tonnes of concrete; 50 – 60 MPa
- RCPT limit of 1000 C
- Max temperature restriction
- On-site resistivity testing used for quality monitoring
- Resistivity of 200 ohm cm benchmarked to RCPT of 1000 C

(*Source:* Civil Engineering, ASCE, June 2017)

Riyadh metro

- 400 km away from the sea – carbonation mechanism considered
- Carbonation depth after 100 year exposure estimated to be 35 mm, which was less than the cover provided
- No risk of chemical attack

Element	Concrete Grade	Cement	water/cement ratio
Precast columns and beams	C50	100% OPC	0.31-0.42
Bridge piers, column walls and slab	C40	100% OPC	0.31-0.42
Viaduct segments	C50	95% OPC + 5% micro silica	0.31-0.42
Viaduct EJ segments and superstructures in-situ	C50	95% OPC + 5% micro silica	0.31-0.42

Standard	Test	Unit	Acceptance Limit
AASHTO T277	Rapid Chloride Permeability	Coulombs	1500
DIN 1046	Water Permeability	mm	10
BS1881 Part 122	Absorption after 30 minutes	%	1.5
BS1881 Part 5	ISAT	$mlm^2.s$	0.05

Standard	Test	Unit	Acceptance Limit
BS1881: Part 201 1986 Cl. 2.2	Depth of Carbonation of Concrete	mm	Measured value*

Doha metro

- 120 year design life
- Risk of carbonation and chemical attack
- Cover adopted 50 to 75 mm
- Limiting crack width of 0.15 mm

Parameters	In-situ concrete in contact with the ground	In-situ concrete not in contact with the ground	High strength concrete for internal columns
Compressive strength class (Cylinder/Cube)	C40/50	C40/50	C60/75
Concrete Mix Constituents	OPC 25% to 30% GGBS 65% to 70% silica fume 5%	OPC 30% to 35% GGBS 65% to 70%	OPC 30% to 35% GGBS 65% to 70%
Minimum cement content (kg/m^3)	380	380	420
MSA (mm)	20	20	20
APM	Fully bonded waterproofing membrane	Coating	Not required

Durability Parameters	C40/50	C40/50	C60/75
Exposed to atmosphere	Yes	No	No
Water absorption, %	1.6	3.5	3.5
Chloride migration, m^2/s (28 – 90 days)	1.2×10^{-12}	5.0×10^{-12}	5.0×10^{-12}
RCPT, Coulombs	1000	3000	3000
Resistance to Sulphate(difference in expansion mm/m at 91 days)	0.5	Not applicable	Not applicable

Chennai Metro

- 120 year design life
- M35 – M60 grades used
- Minimum cement content of 360 kg/m^3 adopted, with max w/b of 0.45
- WPT < 10 mm, RCPT < 600 C

Element	Durability exposure condition	Maximum crack width, mm	Cover for 4 hour FRP, mm	Nominal cover for crack width*, mm
Diaphragm wall	Severe	0.25	80	45
Pile cap (side and bottom faces) resting on layer of blinding concrete not less than 50mm	Severe	0.2	80	45
Base slab – Top surface	Moderate	0.30	45**	30
Base slab – bottom surface (cast against ground/blinding)	Severe	0.20	70	45
Basement walls				
a) Face in contact with soil	Severe	0.20	50	45
b) Other face	Moderate	0.30	40	30
Columns (internal)	Moderate	0.30	40	30
Load bearing walls (internal)	Moderate	0.30	40	30

Statue of Unity

- 100 year design life
- No direct risk of chlorides or sulphates; carbonation also not a major issue due to cladding
- Controlled temperature concreting because of massive size of shear walls

Structure	Concrete grade		Nominal cover, mm	
	Required	Provided	Required	Provided
Retaining wall	M50	M50	40	50
Foundations (Main)	M50	M60	40	75
Foundations (Auxiliary)	M50	M60	40	75
Concrete cores	M50	M65	40	50

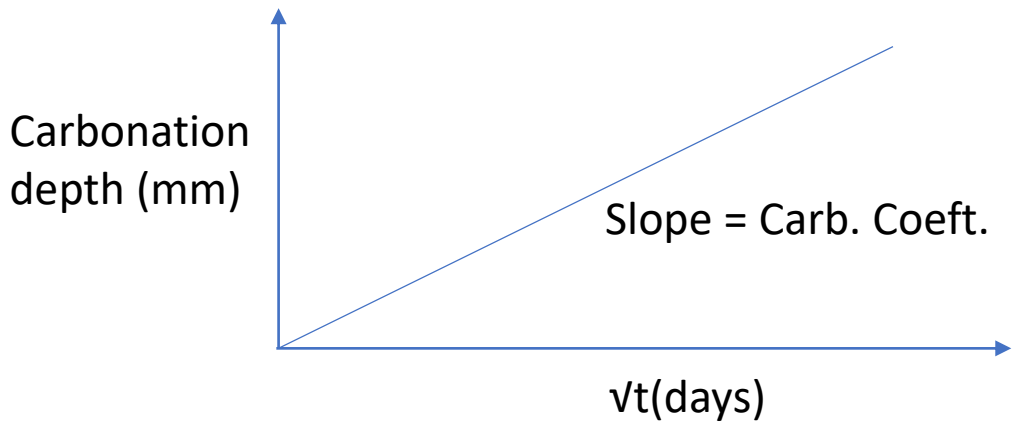
New IS456 – Durability provisions

- Concept of service life and durability design introduced (provisions of durability design from 50 to 120 years)
- Deterioration mechanism based exposure classification proposed
- Climatic map linked to durability problems
- QC levels for durability
- Limit state design for carbonation and chloride ingress
- Durability testing at mix design and QC stage
- Additional protective measures included

Carbonation induced corrosion

- Up to 50 years service life, design table provided
  - Min. cover to rebar
  - Limiting values for w/b, cement content and grade of concrete
  - Min. nominal cover
  - Durability test requirements (electrical resistivity)
- Beyond 50 years (up to 120 years), durability design to be followed
  - Limit state – initiation of cracks by corrosion (initiation and propagation period considered)

- Design parameters
  - Actions: CO_2 level and weather coefficients
  - Resistance: Carbonation rate (coefficient) and cover
- Verification
  - Carb. Coeft. From durability tests



Carbonation induced corrosion (contd.)

- Partial safety factors
  - Design value of carb. Coeft.
  - Design value of cover
- Initiation period determination based on

$$C = W^* K_{1d}^*(ti \,^*\gamma f \,^*CO_{2ck}/500)^x$$

- Propagation period approximated based on grade of concrete, exposure class, type of member (internal / external) and type of cement

Chloride induced corrosion

- Up to 50 years service life, design table provided
  - Min. cover to rebar
  - Limiting values for w/b, cement content and grade of concrete
  - Min. nominal cover
  - Durability test requirements (electrical resistivity and RCPT)
- Beyond 50 years (up to 120 years), durability design to be followed
  - Limit state – build up of chlorides to threshold concentration at the level of steel
- Design parameters
  - Actions: Threshold and surface chloride contents
  - Resistance: Chloride diffusion coefficient and cover
- Verification
  - Diff. Coeft. From durability tests (such as ASTM C1556)
  - Other chloride based durability parameters (RCPT / RMT)

Chloride induced corrosion (contd.)

- Partial safety factors
  - Design value of surface chloride content (the surface chloride content is suggested in a table for different exposure classes)
  - Design value of chloride diffusion coeft.
- Values for threshold chloride content from literature
- Initiation period – chloride level at steel surface determination based on Fick's second law of diffusion (Error Function soln)

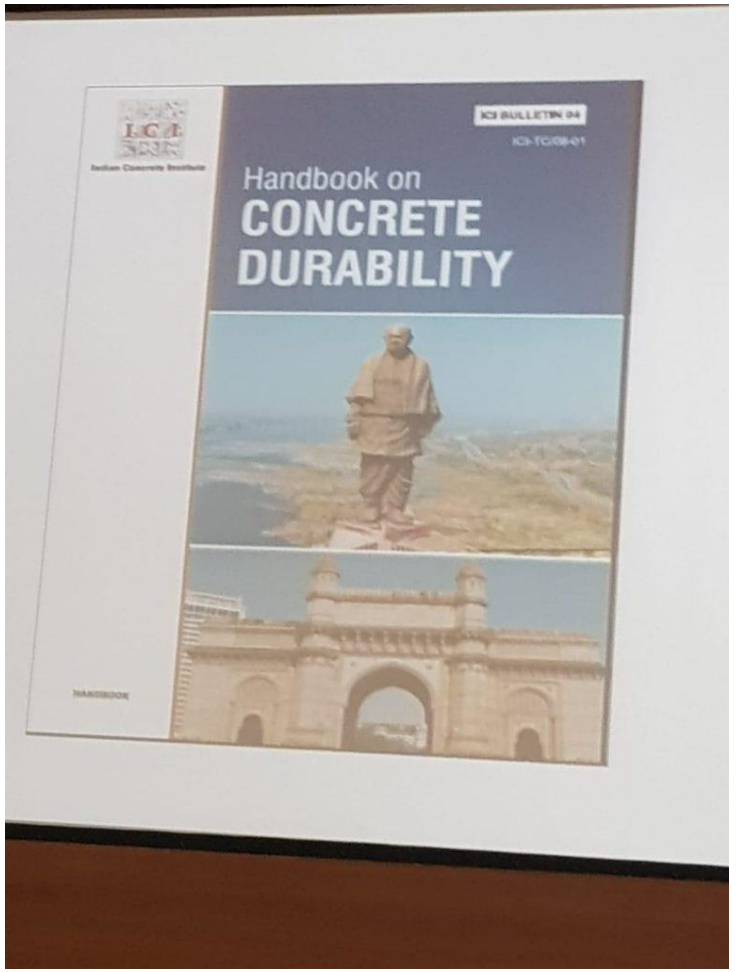
$$C(x,t) = C_s - (C_s - C_i) \times erf\left(\frac{x}{2 \times \sqrt{Cd \times t}}\right)$$

Other durability provisions

- Sulphate attack – modified tables with better definition of exposure environment
- Freezing and thawing – table for mean air content
- Alkali aggregate reactions – prescription of accelerated mortar bar test and mitigation measures
- Suggestions of Additional Protective Measures (APM)

Summary

- Common tests in foreign and Indian construction projects include RCPT, WPT, and Rapid Migration test
- Limiting values are strictly adhered to, without addressing the acceptance criteria
- IS456 plans to include durability design as an important ingredient of material selection process



Thank you!

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