

Achieving concrete cover in construction

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Introduction

Design for and achieving durability in concrete are major considerations in the construction of concrete structures. The role of the correctly specified concrete cover and its attainment during construction is crucial to a concrete structure remaining serviceable, and maintenance-free, for its design life.

Concrete cover is the quality and thickness of concrete between the outer surface of the structure and the nearest embedded steel reinforcement. It is relied upon in attainment of the design life (T_0), thereby ensuring adequate durability. It is therefore of critical importance that this relatively thin layer be afforded every opportunity to meet specified requirements. Attainment of correct cover must be verified and recorded as complying on the process control quality assurance documents prior to commencement of concrete placement.

The cover concrete should be well compacted, effectively cured and essentially crack-free. These properties will ensure capillary discontinuity is achieved and limit the ingress over time of carbon dioxide, oxygen, water and harmful ions of chloride and sulphate based salts.

Background to current codes concerning cover

In 1979 Beresford and Ho¹ identified the extent and cost of durability failures in building structures as approximating 10% of the cost of those buildings then constructed. Also in 1979, Guirguis² confirmed that durability distress was of major concern as up to 69% of buildings 15 years old or less showed signs of distress. In 1987 Marosszky et al³ reported from a site study of 95 buildings in the Sydney basin that 227 distress locations involved faults due to mean cover-to-reinforcement being as little as 5.45 mm, clearly indicating that inadequate detailing and workmanship and supervision during construction were of major concern.

These reports were central to the introduction of the durability provisions into Section 4 in the AS 3600 code⁴ published in

1988. Potter⁵ gave a detailed explanation of the 1988 code durability provisions (including minimum cover and curing) and these requirements have essentially remained unchanged. The bridge design code AS 5100.5 has, wherever possible, aligned its requirements with AS 3600.

From the construction contractors' viewpoint, the code provisions are simple, easy to understand and easy to apply. The compliance test methods are practical, well understood and concrete test results are obtained in a short period of time. Practical specification clauses are usually helpful and have been readily accepted when incorporated into construction contracts. The contractual risk of dispute over durability issues with concrete were seemingly low and the financial risk due to dispute within manageable proportions.

In effect, the design and construction procedure for cover and curing amounted to three simple steps. First, identify the exposure classification in which the structure or component is located (A1 to C), then determine the 28 day compressive concrete strength linked to a curing regime and from that choose the thickness of concrete cover to reinforcement. One could imagine that all the difficulties of prior years had been eliminated in one fell swoop. This however, has not been the case and durability failures due to inadequate cover continue as major concerns that require corrective action involving costly repairs.

Current code provisions for strength, cover and curing

AS 3600, AS 5100.5 and the RTA B80 concrete specification for bridgeworks all rely on the exposure/strength and curing/cover relationship for durability design. The links between concrete cover and some other important design parameters are shown in Tables 1 to 4.

The provision in AS 3600 contains only minimum requirements for a design life of concrete members ranging from 40 to 60 years. Obviously the asset owner will expect a 60 year durability design life and the contractor will assert that a 40 year life meets requirements. Therein exists an immediate

Table 1. AS3600 (2009 draft) – Strength, curing & cover.

Specification requirement	Normal Class A1	Normal Class A2	Normal Class B1	Special Class B2	Special Class C1	Special Class C2
F _c (MPa)	20	25	32	40	50	50
Ambient Curing (days)	3	3	7	7	7	7
Cover (mm)	20	30	40	45	50	65
Design life (years)	40-60	40-60	40-60	40-60	40-60	40-60

Table 2. AS 5100.5 – Bridges – Strength, curing & cover.

Specification requirement	Normal Class A	Special class B1	Special Class B2	Special Class C
F'c (MPa)	25	32	40	50
Ambient Curing (days)	7	7	7 14 slag/FA	7 14 slag/FA
Cover (mm)	35	45	55	70
Design life (years)	100	100	100	100

Table 3. RTA B80 – Provision A – Performance – Strength, curing & cover.

Specification requirement	Normal Class A	Special class B1	Special Class B2	Special Class C
F'c (MPa)	25	32	40	50
Sorptivity (mm)	35	25	20	8
Ambient Curing (days) (Min)	3	3	7 14 slag/FA	7 14 slag/FA
Cover (mm)	35	45	55	70
Design life (years)	100	100	100	100

Table 4. RTA B80 – Provision B – Deemed to Comply – Strength, curing & cover.

Specification requirement	Normal Class A	Special class B1	Special Class B2	Special Class C
F'c (MPa)	25	32	40	50
Ambient Curing (days)	7	7	7 14 slag/FA	7 14 slag/FA
Cover (mm)	35	45	55	70
Design life (years)	100	100	100	100

contractual and/or legal conflict that the code does not address. The 2009 draft states in Clause 4.1 that: “durability is a complex topic and compliance with these requirements may not be sufficient to ensure a durable structure”. The code is silent on design and/or construction enhancements but the contractor is still required to comply with AS 3600 as part of the approval process and compliance with the Building Code of Australia (BCA). How do we resolve this matter and still retain adequate durability? This is a very contentious issue.

Attainment of adequate durability

The attainment of adequate durability in concrete structures is directly affected by technical understanding and correctly implemented construction practices. Major concerns involve not understanding the need for cover to reinforcement and

curing for the various exposure conditions and concrete grades.

In 2002 the National Precast Concrete Association of Australia (NPCAA) at its annual conference, in part raised the matter of cover and curing.

The conference discussion made it obvious that the subject was not well understood⁶ and there was much misconception, some ignorance as well, and a small body of people having a clear understanding of the technical concepts involved. This realisation prompted the NPCAA to embark upon some training sessions⁷ that explained the importance of cover and curing in complying with AS 3600 and the BCA. This example is probably not an isolated case but rather, we suspect, it is prevalent throughout the construction industry.

Clearly, ongoing education of industry practitioners is a matter to be addressed and the Concrete Institute of Australia is in a position to play a significant role in raising the awareness of

the importance of cover and curing.

Cover to reinforcement

Codes and contract specifications provide requirements for concrete cover to reinforcement. It is not always clear what cover is being referred to. There are differences of interpretation on what is meant by:

- Cover to reinforcement shall be as noted on the drawings
- The minimum cover shall be ...
- The minimum cover shall not be encroached upon
- Cover is the distance between the outside of the reinforcing steel and the nearest permanent surface of the member
- The nominal cover shall be as shown in Table "X".

There is a need to eliminate the confusion in definition so that contract disputes are minimised and the contractor has a clear direction on what is required. We need a single definition applicable in all circumstances with the basis being minimum cover, i.e. that dimension that cannot be encroached upon under any circumstances and the additional allowable cover for tolerance on placement of reinforcement shown as an additional value, e.g. +5 mm / -0 mm. The tolerance on reinforcement placement needs to be clearly noted on construction drawings for the different surfaces and member location and reinforcement details shown in a manner that ensures the tolerances can in fact be utilised.

There is also confusion with the existing Tables in AS 3600 that specify cover to reinforcement. The basis for those rules was examined by Guirguis⁸ in 1987. She recommended that minimum covers be adopted by the BD2 code committee as shown in Table 5. The values are based on depth of water penetration for exposure classifications A1 and A2, CO₂ ingress as carbonation depth for B1 and chloride diffusion for B2 and are based on a design life T₀ (being initiation phase only) of 30 years and 7 days moist curing. The values included a tolerance on placing reinforcement of +5 mm. In the case of 20 mm cover in A1 and A2 the cover is a minimum value based on placement and compaction considerations and cannot be encroached upon. This is ambiguous in the code.

Guirguis also recommended covers of 65 mm and 80 mm for B2 exposure. The BD2 committee believed that the proposals for the more severe exposure classifications represented too great a change from existing practice. The values would be difficult to justify and probably would be resisted in practice. Accordingly, the values for cover were amended. Table 6 shows the values adopted and specified in the Standard. The design life is increased to 40 to 60 years and the curing requirement for A1 and A2 has been relaxed to 3 days moist curing. In the 2009 Draft, C has been replaced with C1 and C2 and C2 takes a value of 65 mm.

In light of the trend to design and construct contracts,

Table 5. Guirguis⁸ recommended minimum concrete covers (mm) for AS 3600 (Design Life of 30 years).

Exposure Classification	Characteristic Strength of Concrete f'c (MPa)				
	20	25	32	40	50+
A1	20	20	20	20	20
A2		30	20	20	20
B1			50	40	30
B2				80	65
* If curing is longer than 7 days, preferably 28 days				60*	50*

Table 6. AS 3600-2009 required cover (mm) for standard formwork and compaction – (Design Life of 40 to 60 years).

Exposure Classification	Characteristic Strength of Concrete f'c (MPa)				
	20	25	32	40	50+
A1	20	20	20	20	20
A2	(50)	30	25	20	20
B1		(60)	40	30	25
B2			(65)	45	35
C1				(70)	50
C2					65

what are the possibilities that the current code proposals are inadequate with respect to the latest durability models for chloride penetration and design life modelling based on chloride diffusion?

Chloride diffusion through the cover concrete

In moving from prescriptive to performance based durability design, researchers and specifiers have focused on comparing the concrete resistance to the anticipated deterioration process encountered in aggressive and marine conditions. In the case where special concrete mixes with very low water/binder (0.29-0.30) ratios, high cement content and super-plasticisers are employed, very little information exists on the likely long-term resistance of such concrete to the rate of chloride ingress over time. In this context the most important and relevant material resistance parameter is the chloride diffusion coefficient (D_c). The determination of coefficients is a complex and time-consuming procedure that has created extreme contractual difficulties for contractors when applied to contracts for quality control acceptance testing.

Current practice is to immerse the concrete specimens in saline solutions at constant salt concentrations for various time intervals ranging from 28, 35, 56 or 90 days depending on the specification. After immersion, the chloride profile is determined by taking samples from the exposed face at various depths to determine a chloride profile and then the diffusion coefficient (D_c) is calculated using Fick's second law by curve fitting. The Nordtest Method NT Build 443-1995 is one such

56-Day Nordtest standard cure diffusion coefficient

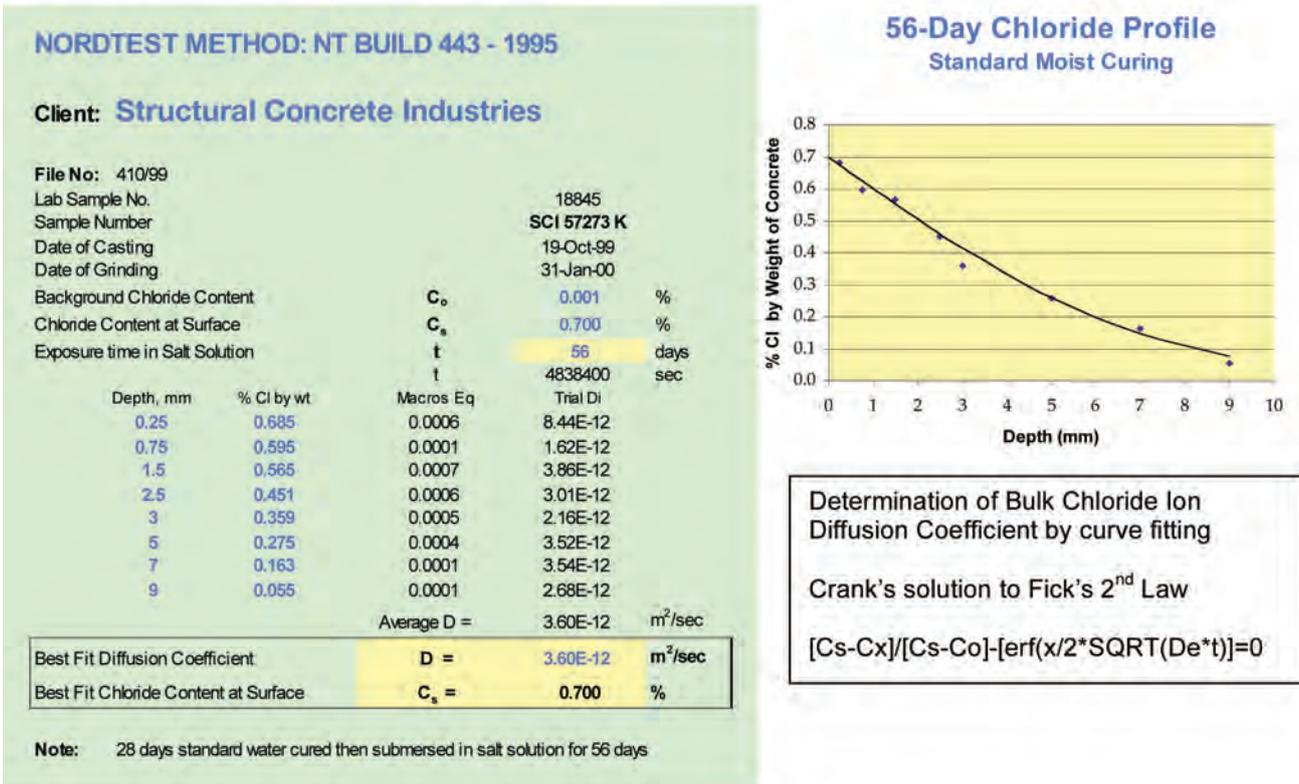


Figure 1. Field results of chloride ion profiles and diffusion coefficients for standard moist curing.

test for this property.

The binder composition determines the time required for chemical reaction in the formation of hydration products. The rate of chloride diffusion is therefore dependent on the completeness of the hydration process. For a given design life (T_0 years) and a corresponding critical threshold chloride ion concentration ($C_{x,t}$) of 0.06% by weight of concrete at the inner concrete cover depth, the variables are the chloride concentration at the surface (C_s), the distance from the surface, or concrete cover (x) and the age factor (m) where supplementary cementitious materials are used in the concrete mix. It follows that a range of acceptable cover thicknesses will provide an equivalent design life depending on the binder proportions and the assumed or derived value of C_s . There is a high level of uncertainty about both of these variables. Figures 1, 2 and 3 show the field results of chloride ion profiles and diffusion coefficients (D_c) after 56 days immersion in a saline solution determined in accordance with the Nordtest procedure for the precast girders comprising the elevated viaducts of the M5-East motorway project in Sydney⁹.

Tests were performed on concrete samples cured under standard 28-day moist curing conditions in the laboratory and also on 1-day steam cured plus 27-day air curing conditions prior to immersion in the saline solution.

The diffusion coefficient nominated in the specification at

age 56-days was achieved. The rapid chloride penetrability test (ASTM C1202) requirement at age 28-days was, however, not achieved. This was because reliable correlation had not been established and it was not until age 84-days that technical compliance for chloride penetrability was achieved. Quality control compliance by the contractor, albeit outside the limitations imposed by the specification became a matter of dispute on this contract and also on subsequent contracts. Because of the issues raised, it is not surprising the CIA document "Performance Criteria for Concrete in Marine Environments" (Z13) states in its conclusion¹⁰ "There is significant debate as to the appropriateness of a diffusion coefficient obtained from a 28- to 56-day test to provide a reasonably accurate estimate of design life. Caution needs to be exercised in using performance criteria for marine environment exposures, especially where correlations with field performance or long-term test results are not available."

Results of the ASTM C 1202 test in Appendix A show high chloride permeability at 28 days (4000 Coulombs). However, by age 84 days the charge passed has reduced significantly (1050 Coulombs). This is largely due to the pozzolans (25% highly reactive flyash) taking a long time to contribute to a reduction in pore porosity. The above illustrates the danger to contractors of working with diffusion based acceptance criteria in specifications for QC under contract.

56-Day Nordtest steam cure diffusion coefficient

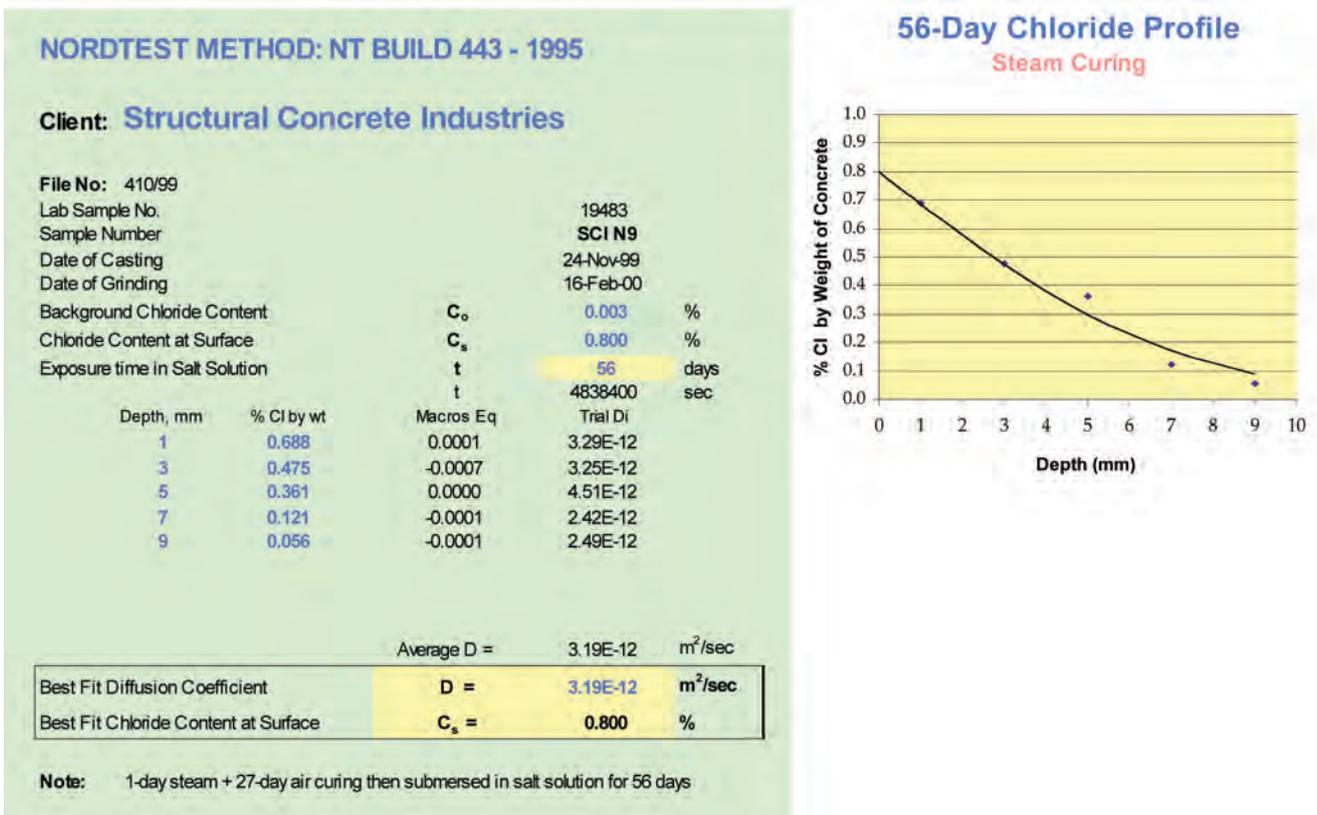


Figure 2. Field results of chloride ion profiles and diffusion coefficients for steam curing.

Cover as affected by poor detailing and construction tolerances

The effect of poor reinforcement detailing practices on the practical achievement of design intent is huge in comparison to some of the other more scientific/academic concrete technology issues.

Simply put, reinforcement detailing is the art of designing and drawing to scale the specified bar shapes and fitment sizes so that everything will actually fit together in the construction phase with no clashes with either prestressing strand, penetrations, fittings, embedments, post tensioning hardware and ensuring the specified cover is met taking into consideration the allowable tolerances associated with reinforcement processing and placement. It is the effect of reinforcement detailing on the achievement of cover that is crucial in understanding its effect on long-term durability.

Today, with modern CAD systems, the exercise of ensuring fit and buildability has been made so simple. Despite the availability of these brilliant tools most designers and detailers fail to utilise them such that the drawings provided "For Construction" in so many cases contain unworkable and unachievable details.

The 25 year old site study by Marosszky et al³ in 1987 of factors leading to a reduction in durability of reinforced concrete involved a survey of 95 buildings in the Sydney metropolitan region. The buildings were distributed between 150 m and 27

km from the coastline and ranged from 5 to 36 storeys. The study concluded as follows:

- The 95 buildings surveyed were less than 16 years old
- Tall buildings were found to have significantly fewer failures than shorter buildings. It was assumed that this is due to an increase in the supervision of the construction process
- Multiple regression analysis did not indicate a higher density of failures on buildings near the coast or harbour than buildings up to 27 km from the coast
- Precast concrete surfaces were found to experience fewer faults than in-situ concrete surfaces. The density of faults forecast was approximately one-third that for in-situ buildings. Again, this was assumed to be the consequence of higher levels of supervision together with improved reinforcement detailing for fit and cover
- The mean cover to reinforcement at 227 faults was found to be 5.45 mm, clearly indicating that lack of cover is a major problem associated with failures

Bad detailing is akin to planning to fail in achievement of durability. There is little evidence to suggest that the quality of detailing has improved as a result of the availability of sophisticated CAD software. On the contrary, in the authors' opinion, the opposite is true as clients and asset owners

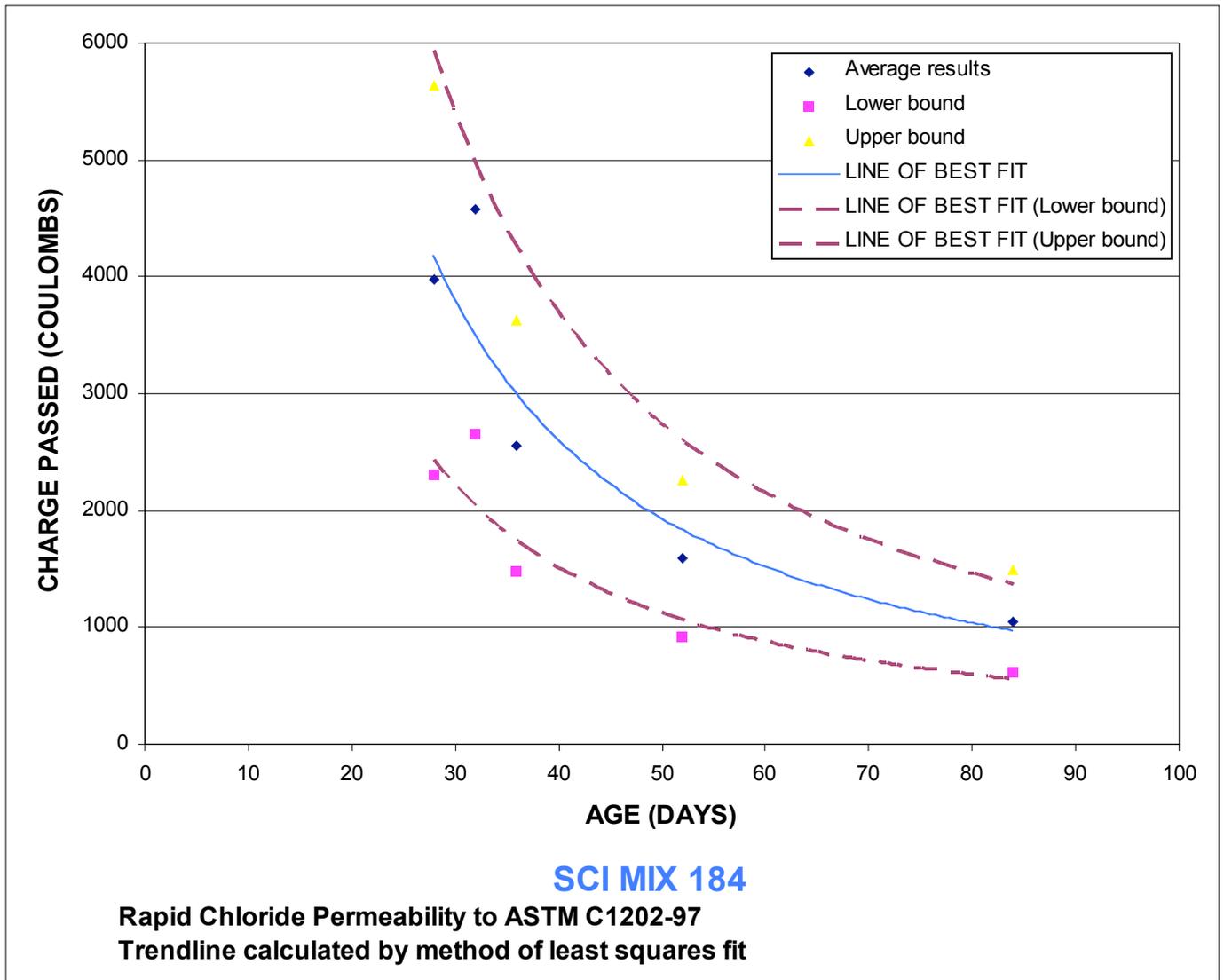


Figure 3. Rapid chloride permeability.

continue to seek least-first-cost solutions in construction. Design and detailing of reinforcement must ensure that the covers can be practically achieved without undue, inappropriate effort.

All material manufacturers and processors work within allowable tolerances or deviations. The way that the various tolerances interact must be clearly understood by the designer and detailer and is paramount to successful detailing of design intent. Zero tolerance solutions cannot and will not work. Contractors must use reinforcement fixing processes that ensure reinforcement does not move (and reduce cover) during concrete placement and compaction.

Reinforcing bars have actual dimensions which are greater than their nominal sizes due to the rolling tolerances in manufacture and the presence of the rib pattern.

True sizes for detailing purposes are:

- N12 = 14 mm
- N16 = 18 mm
- N20 = 23 mm

- N24 = 27 mm
- N32 = 36 mm
- N36 = 40 mm

When a number of ligatures are assembled into barsets the thickness of the barset as a whole will always be larger than the summation of the individual parts due to imperfect fit-up and inbuilt twist (this is normally +12% of the summation of bar thicknesses).

Post-tensioning systems are all different and without contacting the specialist suppliers for advice on their system, proper detailing of these systems is not possible. Other important areas for consideration with post-tensioning systems are:

- Duct size –
 - Duct ID + 6 mm = Duct OD
 - Duct ID + 12 mm = Duct Coupler OD
- Must maintain a minimum 5 mm clearance right around duct and coupler after all tolerances are taken into account to allow for efficient assembly.
- Cast-in anchorages, trumpets, anchor heads and anchorage

recesses – contact a specialist P/T supplier to verify the actual sizes.

- The anti-burst steel should always be drawn at full scale to check for cover and/or material interference.

The other important consideration of construction tolerance and cover requirements is the concrete section itself within which the reinforcement and prestressing need to fit. Typical tolerances for concrete sections are as follows:

(RTA Specification B110 / B115 Concrete Profile)

- Length: The greater of 0.06% Length or +/- 10 mm
- Cross section (< 2000 mm wide): +/- 4 mm
- Cross section (> 2000 mm wide): +/- 7 mm
- Cored holes / openings – location: +/- 7 mm
- Cored holes / openings diameter or side dimension: +/- 4 mm

Proper attention to material tolerances will ensure that they have no adverse effect on the long-term durability of the concrete element being constructed.

Concrete cover – a reality check

The most prominent causes of durability distress in concrete structures are, put very simply, due to the failure of designers and their detailers to properly address the reinforcement design and the tolerances associated with reinforcement processing and placement together with the failure of constructors to properly address the 3 C's in construction workmanship. The 3 C's are: Cover, Compaction and Curing. Remember the CCC. In this paper the authors have assumed that the concrete mix has been designed and manufactured to ensure compliance with durability requirements.

In many instances durability failure can be directly attributed to a lack in experienced supervision and workmanship where cover has not been achieved, compaction of concrete has been inadequate or curing of concrete has been either non-existent or ineffective or any combination of the above.

In reality, all three are easily achievable with proper, diligent work practices in place.

To ensure cover is met during construction will require several processes to be established and that are routinely explained to the formwork and concrete placement crews. These include:

- Put in place a process whereby the adequacy of formwork is checked by a competent person prior to reinforcement placement to ensure movement of the form will not occur during concrete placement and thus jeopardise the assurance of maintaining cover to the reinforcement
- Put in place a process whereby reinforcement and its cover to formwork is rigorously checked prior to concrete being placed
- Put in place a process whereby concrete is placed and compacted under the direction and scrutiny of a competent concrete placement supervisor
- Put in place a process that ensures the specified curing regime is effectively achieved in practice

None of the above is new. It is how things were done in the past (50s, 60s and early 70s) by competent and diligent asset owners and competent and diligent constructors. There is a need to revisit and embrace those practices.

It is the authors' view that these processes should be

incorporated into the "Durability Plan" – a concept being championed by the concrete durability consultants.

It is a misplaced notion that the above processes cost money and it's the same misplaced notion that has driven the quality assurance process in the expectation that the practice of getting things right would become the responsibility of someone else.

Bureaucrats, accountants and other financial controllers embraced quality assurance in the belief that they were saving enormous amounts of money. This belief was founded on the hope that quality assurance would be affected through competent, technical administrators. This has not been reflected in the real world. There is nothing quite as good and effective as a competent, firm (even a tough) inspector to ensure that work is carried out to the highest of standards. Box ticking does not necessarily lead to a structure being durable. There is a need to get back to basics.

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