STRUCTURAL
CONCRETE
INDUSTRIES Aust Pty Ltd

Achieving Durability in Construction

CIA Concrete Durability Workshop – June 2009

W Merretz – Director Engineering, Structural Concrete Industries
G Smith – Managing Director, Structural Concrete Industries
J Borgert – Director Operations, Structural Concrete Industries

1 Introduction

Achieving durability in concrete should be a very important consideration in the design and construction of new structures and when assessing the condition of existing structures. Concrete construction is becoming increasingly complex and the importance of building structures that are both cost effective and durable has never been higher. An overlying factor, too, is the desire that projects be built very quickly.

An understanding of concrete durability is fundamental to establishing the service life of new or existing structures. Whether the concrete is within a severe environment such as near coastal highway bridges and high-rise holiday apartments or marine structures, knowledge of the concrete durability potential is key to its long-term performance.

In order to understand the important parameters that affect concrete durability, we must first define what it is we mean by *durability* and also, identify the parameters that have an effect either on administering construction specifications under contract in terms of performance construction practices and performance outcomes.

A widely accepted definition of durability is: *the resistance of concrete to weathering action, chemical attack, abrasion and other degradation processes*.

Although all concrete is likely to deteriorate to some extent over time, ensuring adequate durability is about minimising the rate of deterioration. Concrete durability is therefore related to the design process, specification of materials, construction practices, quality of workmanship, environmental effects and quality of defects repair.

Previous speakers have discussed the theoretical framework for durability design in aggressive and marine environments. This has included considerations of design life (T_0), key desirable material characteristics, performance outcomes for concrete mix design during pre-qualification and a suitable testing regime for quality control during project execution.

From a construction perspective, the attainment of durability in construction practices involve an understanding and elimination of those undesirable effects that may be imparted to the concrete both in its plastic and hardened state due to lack of control, bad attitude and oversight. This involves consideration of the importance of the quality of the cover concrete, water/binder ratio, concrete manufacture procedures, placement and compaction, bleeding, setting time, slump loss, finishing, curing, thermal stresses, drying shrinkage, design detailing, constructability and post pour cover checks. These matters are considered further in this workshop.

2 Background to current codes of practice

In 1979 Beresford and Ho [1] identified the extent and cost of durability failures as approximating 10% of the expenditure on new buildings. Also in 1979 Guirguis [2] confirmed that durability distress was of major concern as up to 69% of buildings, 15 years old or less, suffered distress. In 1987 Marosszeky et al [3] 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 5.45mm, clearly indicating that inadequate detailing and workmanship on site were of major concern.

The above reports were central to introduction of the durability provisions in Section 4 in the code [4] published in 1988. Potter [5] provided a detailed explanation of the 1988 code durability provisions and these requirements have essentially remained unchanged. The bridge design codes have wherever possible aligned their requirements with AS 3600.

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

In effect, the design and construction procedure amounted to three simple steps. First, identify the exposure classification the structure or component is located in (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 faults of prior years had been eliminated in one fell swoop. This however, was not the case and durability issues are still of major concern in certain construction areas.

3 Current code and specification provisions

As 3600, AS 5100 and the RTA B80 concrete specification for bridgeworks all rely on the exposure / strength and curing / cover relationship in the design approach. The links between the design parameters are shown in Tables 1, 2, 3 and 4 below.

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**
Min binder (kg/m3)	Not Required	Not Required	Not Required	350 Suggested	400 Suggested	400 suggested
Max W/B	Not Required	Not Required	Not Required	To be specified	To be specified	To be specified
Binder type	Not Required	Not Required	Not Required	To be specified	To be specified	To be specified
Ambient Curing (days)	**3**	**3**	**7**	**7**	**7**	**7**
Fc.min at Stripping	15	15	20	25	32	32
Cover (mm)	**20**	**30**	**40**	**45**	**50**	**65**
Design life (years)	40-60	40-60	40-60	40-60	40-60	40-60

Table 1 - S3600 (2007 draft) - Minimum strength curing & cover

Specification requirement	Normal Class A	Special class B1	Special Class B2	Special Class C
F'c (MPa)	**25**	**32**	**40**	**50**
Min cement content	Not Required	To be specified	To be specified	To be specified
Max W:C	Not Required	To be specified	To be specified	To be specified
Binder type	Not Required	To be specified	To be specified	To be specified
Ambient Curing (days)	**7**	**7**	**7** **14 slag/FA**	**7** **14 slag/FA**
Steam Curing	15	20	25	32
Cover (mm)	**35**	**45**	**55**	**70**
Design life (years)	100	100	100	100

Table 2 – AS 5100 - Bridges - Minimum strength curing & cover

Specification requirement	Normal Class A	Special class B1	Special Class B2	Special Class C
Fc (MPa)	**25**	**32**	**40**	**50**
Min cement content	320	320	370	420
Max W:C	0.56	0.50	0.46	0.40
Binder type	SL	SL or Slag/FA	Blend or Slag/FA	Blend or Slag/FA
Ambient Curing (days)	**7**	**7**	**7** **14 slag/FA**	**7** **14 slag/FA**
Steam Curing (MPa)	**350 C.hrs**	**350 C.hrs**	**350 C.hrs**	**350 C.hrs**
Sorptivity (mm)	35	25	17 PC 20 blend	8 Blend only
Cover (mm)	**35**	**45**	**55**	**70**
Design life (years)	100	100	100	100

Table 3 – RTA B80 – Concrete specification bridges
Provision A – Performance - Minimum strength curing & cover

Specification requirement	Normal Class A	Special class B1	Special Class B2	Special Class C
Fc (MPa)	**32**	**40**	**50**	**50**
Min cement content	320	370	420	420
Max W:C	0.5	0.46	0.4	0.40
Binder type	SL	SL	SL	Blend or Slag/FA
Ambient Curing (days)	**7**	**7**	**7** **14 slag/FA**	**7** **14 slag/FA**
Steam Curing (MPa)	**350 C.hrs**	**350 C.hrs**	**350 C.hrs**	**350 C.hrs**
Cover (mm)	**35**	**45**	**55**	**70**
Design life (years)	100	100	100	100

Table 4 – RTA B80 – Concrete specification bridges
Provision B – Deemed to comply - Minimum strength curing & cover

The provision in AS 3600 contains MINIMUM requirements only for a design life of concrete members ranging from 40 to 60 years. Obviously the asset owner will have expectancy for a 60 year durability design life and the contractor will assert that a 40 year life meets requirements. Therein exists an immediate contractual and / or legal conflict that the code does not cover. The 2007 draft states in Cl 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. How do we resolve this matter and still retain adequate durability? This is a very contentious issue.

4 Attainment of adequate durability

The attainment of adequate durability in concrete structures is directly affected by technical understanding and implemented construction practices. Major elements involve not understanding the need for curing and cover to reinforcement for 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 curing. The discussion made it obvious that the subject was understood by few [6] and that there was plenty of misconception and a deal of ignorance as well as some clear understanding of the technical concepts involved. This realisation prompted the NPCAA to embark upon some training sessions [7] that explained the importance of curing in complying with AS 3600 and the BCA. This example is probably not an isolated situation but rather, that it is prevalent throughout the construction industry. Clearly, ongoing education of industry practitioners is a matter for the Concrete Institute Australia (CIA) to address through TAFE and other training institutions concerned with concrete construction. Should the CIA play a role and what should it be?

5 The curing conundrum

The Concrete Institute of Australia (CIA) recommended practice on curing [8] defines curing as: "*a procedure for ensuring that the hydration of Portland and blended cements in newly placed concrete continues for sufficient time for the concrete to develop its design strength and durability."*

It goes on to say that "*the two fundamental requirements for satisfactory curing are to prevent premature drying of the concrete and to maintain a favourable temperature throughout the concrete section.*"

The objective of curing is to ensure that the pores and capillaries within the concrete become filled with hydration products and this can happen only in the presence of unhydrated cement and water. It follows of course that concrete mix design and placing procedures which minimise the number of pores and capillaries and which provide sufficient cement to allow the products of hydration to fill them will need less curing for the same result.

The above appears to be the logic supporting the proposed changes to AS 3600. For example, using a Classification C environment the current 2001 code requires concrete to be *"initially cured continuously for at least 7 days … OR* ***cured by accelerated methods*** *so that the average compressive strength … at completion of curing is not less than 32 MPa …".*

The 2007 Draft requires concrete to be *"cured continuously for at least 7 days … OR* ***have a minimum average compressive strength*** *of the concrete at the time of stripping of forms … of 32 MPA …".*

The contractor rightly can challenge the need for sorption or diffusion testing and indeed will argue that curing is in fact optional when working under the latest code which is legally binding under the BCA. The contractor will rely upon curing not being a requirement where minimum strengths are met. Is this the intent of the code? Is this the path we want to follow in attainment of durable structures? Why is so much attention being given to development of short-term test methods based on diffusion principles when the last 8 years of code durability thinking has resulted in the above described requirements?

6 Mix Design

Apart from organisations such as RTA NSW and DMR QLD most project specifications are sufficiently varied in the requirements for concrete that individual mix designs become necessary on consecutive contracts. The resulting plethora of mixes is generally subject to an individual person's assessment for compliance that can result in contract disputes, relinquishes an organisation's control of the intellectual ownership and also wastes a great amount of time.

Accordingly, the industry needs deemed-to-comply requirements across a range of performance criteria. The requirements need to be simple, with test methods for conformance able to be routinely carried out with high repeatability and a short duration for test. Should deemed-to-comply provisions be limited to compressive strength, type and amount of cement, max w/c, amount of pozzolanic additions and demonstrated mimimum curing?

7 Relevance of NordTest 443 testing in contracts

In moving from prescriptive to performance based durability design, researchers and specifiers have focused on comparing the concrete resistance to the anticipated design 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 material resistance parameter is the chloride diffusion coefficient. The determination of coefficients is a complex and time-consuming procedure that has created extreme difficulties 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 and 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 using Fick’s second law by curve fitting. The NORDTEST Method NT Build 443-1995 is one such 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. Appendix A shows the field results of chloride profiles and diffusion coefficients (D_e) after 28 and 56 days immersion in a saline solution determined in accordance with the NORDTEST procedure for the precast viaduct girders of the M5-East motorway project in Sydney [10].

Tests were performed on 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, albeit outside the limitations imposed by the specification became a matter of dispute and also on subsequent contracts. Because of the issues raised, it is not surprising the CIA document (Z13) states in its conclusion “*there is significant debate as to the appropriateness of a diffusion coefficient obtained from a 28-56 day test to provide a reasonably accurate estimate of design life”.*

Results of the ASTM C 1202 test in Appendix A show a quite 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.

It should also be noted that steam cured concrete after 24 hours is generally considered to have the equivalent of 7 days standard moist curing. Site placed concrete however is not representative of 7 days standard moist curing (i.e. it is always less effective than steam). The steam cured concrete was then air cured for a further 27 days whilst the reference concrete was 28 day standard cured. At age 28 days the steam cured concrete appeared to possess inferior diffusion properties to the reference concrete whilst at age 56 days the coefficient was lower than the reference concrete.

The above illustrates the danger of applying diffusion based acceptance criteria into specifications for QC.

Finally, the following is an extract from the concrete specification that deals with chloride ion penetration for the Circular Quay West Promenade, Sydney, for which tenders closed recently.

"Concrete is to be treated by admixture of corrosion inhibiting chemicals to protect the steel reinforcement from corrosion arising from chloride ion ingress. Concrete works (including precast) cast above the waterline shall be protected by the application of a liquid inorganic silicate based compound such as ….. or equivalent. Concrete shall be of low permeability to chloride ion penetration to reduce the risk of corrosion to embedded reinforcement. Chloride ion penetration shall be less than 1,000 coulomb at 28 days, in accordance with ASTM C1202."

The above is a wish-list. It is not specification. Coupled with the 1,000 coulomb rhetoric, any experienced lawyer will have a field day ensuring the contractor is free of liability. A major contract dispute is staring all who will be involved directly in the face.

8 The cover concrete

It is solely the quality and thickness of concrete between the outer surface of an element and the nearest embedded steel reinforcement that is relied upon in attainment of the design life (T_0), thereby ensuring adequate durability. It is therefore of critical importance that this thin layer be afforded every opportunity to meet specification 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 essentially free of cracks, be well compacted and effectively cured to ensure capillary discontinuity is achieved so as to limit the ingress over time of carbon dioxide, oxygen, water and harmful ions of chloride and sulphate based salts.

9 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 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 / -0 mm. The tolerance on reinforcement placement needs to be clearly noted on construction drawings for the different surfaces and member location.

There is also confusion with the existing Tables in AS 3600 that specify cover to reinforcement. The basis for those rules was examined by Guirguis [9] 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 clauses A1 and A2, carbonation depth for B1 and chloride diffusion depth for B2 and are based a design life (T_0 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.

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 5 – Guirguis [9] recommended minimum concrete covers (mm) for AS 3600

Guirguis also recommended covers of 65 and 80 mm for B2. 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. Therefore, the values for cover were amended. Table 6 shows the values specified in the Standard. The design life is 40 to 60 years and the curing requirement for A1 and A2 has been relaxed to 3 days moist curing. In the 2007 Draft, C has been replaced with C1 and C2 and C2 takes a value of 65 mm.

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

Table 6 – AS 3600 required cover where standard formwork and compaction are used (mm)

In light of the trend to design and construct contracts, what are the risks 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?

10 Cracks

For concrete structures with cracks in the cover concrete, the electrolytic conditions for the commencement of corrosion may be significantly affected. For cracked concrete, it is reasonable to assume that increased crack widths lead to increased penetration of corrosive substances described above and resulting in the probability of increased corrosion of steel.

Based on detailed procedures for calculation of crack widths, many codes and recommendations specify upper limits on crack width in the order of 0.4 mm for non-aggressive environments and 0.3 mm for more aggressive environments. Earlier codes such as AS 1480 limited crack width to 0.1 mm for precast concrete facades of buildings in exposed environments and the RTA specification B80 requires non-conformance reporting and acceptance evaluation for cracks exceeding 0.05 mm.

Cracking that may result from construction practice whilst the concrete is still in a plastic state is largely in control of the contractor. Cause and prevention of cracking of surfaces under the control of the contractor include:

- Crazing – a pattern of fine cracks that do not penetrate much below the surface and are usually a cosmetic problem only. However, they do indicate that the surface may have been overworked during finishing leaving a layer of inferior matrix in the cover concrete that may affect long-term durability.

- Plastic shrinkage cracking – may occur when water evaporates from the surface of freshly placed concrete prior to set faster than it is replaced by bleed water. Prevention techniques include employment of competent manpower, equipment and supplies so as to complete finishing promptly, shading, erection of wind barriers, early commencement of concrete pour when temperatures are lower, covering surfaces with impermeable membranes, use of fog sprays, application of uniform layers of aliphatic alcohol surface spray, early application of curing and concrete mixture adjustments. For an indication of exactly how much bleed water is likely to be lost on any particular day consult a chart (e.g. RTA B80) where air temperature, wind speed, concrete temperature and relative humidity form the variables. Once evaporation of more than 0.6 litres/m^2/hr is likely the possibility of plastic shrinkage cracking is high. If evaporation losses are predicted to be greater than 1.5 l/m^2/hr serious consideration should to be given to postponing the pour until the weather improves.

- Settlement cracking – is a consequence of sudden changes in the depth of slabs and bands. They can also be seen to mirror the pattern of the top reinforcement in deep beam elements. The normal cause of the problem is poor compaction or mix segregation. It is often prudent to form the bottom half of very deep beams to slab soffit level as a separate pour. This is also true of columns, which need to be poured separately to the beams and slabs they support. Re-vibration prior to set is a common technique to close the cracks. To merely trowel over the cracks will lead to early durability problems.

- Early-age flexure cracking – caused by loss of support beneath the concrete element due to formwork being stripped prematurely and / or inadequate back propping. Ensure the required minimum concrete strength for removal of forms has been achieved and the maximum distance between temporary supports is not exceeded.

- Thermal cracking – resulting from temperature rise in large, thick mass concrete due to heat of hydration of cementitious materials. As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. This causes tensile stresses that may result in thermal cracks at the surface if the differential temperature between inner and outer concrete is too great. This cracking can be eliminated by the contractor using optimised concrete mix proportions and material type, using chilled water or ice as the added water.

- Form restraint cracking – caused by differential movement of the forms and the concrete. This is particularly so where abrupt changes of cross section occur and may be eliminated by introduction of cushions in the form, release or removal of restraint to fixtures in the concrete and partial loosening of non structural function supporting form.

- Blistering and reduction of abrasion resistance – may result when concreting in hot weather and commencement of finishing the concrete is not timed correctly. This is because commencing finishing operations too early seals the surface of the concrete before all of the bleed water has risen to the surface. This situation can result in small blisters of concrete around 20 to 30 mm in size and 1 mm deep (sometimes referred to as laitance) peeling off during the power trowelling operation. In some cases larger delamination will occur but the depth is always around 1 to 3 mm. It is critical for the contractor to not commence finishing prior to all bleed water having risen to the surface.

11 Durability Plan and its relationship to the construction Quality Plan

Having given due consideration to the design/ specification of the concrete itself and an appropriate corresponding curing regime it is necessary to specify and quantify those requirements into the contract documentation in the form of a *Durability Plan*. These plans are similar to the project specific *Quality Plan* that has been in use on most projects for strength and serviceability conformance in the form of written technical procedures, work method statements and inspection and test plans (ITP's). The inclusion of specific conformance requirements of the Durability Plan into the working ITP's and technical procedures at a practical level will then form the basis for conformance control during performance of a contract.

Durability Plans are emerging as fundamental concrete conformance requirements on large infrastructure projects. The current Ballina Bypass project on the Pacific Highway in NSW, the Port Botany Expansion project in Sydney and the Sydney Desalination Plant serve as prominent examples.

The Durability Plan details the basis for durability design and construction conformance to ensure that the project structures and elements will achieve the design life requirements in the expected exposure conditions using the materials, construction methods, workmanship and proposed later year maintenance.

Therefore, achieving compliance for durability requires developing a clear understanding of what is required, evaluating the lowest cost construction method and articulating the durability logic during quality control.

It is recommended that the Quality Plan and ITP's be written to fully embrace the durability requirements and that the ITP's be a living document structured in the logical format following the construction sequence trail. Compliance verification should be progressive and consistent with procedures, properly signed off on task completion. Technical Procedures and Work Method Statements should be prepared, explained to construction personnel, supervised and verified as the work takes place in particular for those matters that cannot be verified as conforming after the event. The RTA of NSW has deemed those construction activities as *Special Processes* that must be verified as correct when the activity occurs. A *Special Process* cannot be verified after the event has occurred. This includes supply, handling, placement, compaction, prestressing and curing of concrete.

12 Durability as affected by poor detailing

The effect of poor reinforcement detailing practices on the practical achievement of design intent is huge in comparison to some of the other more high-tech 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. It is the effect of reinforcement detailing on the achievement of cover that is crucial in understanding its effect on long-term durability.

The site study by Marosszeky et al [3] 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 metres and 27 km from the coastline and ranged from 5 to 36 storeys. They 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 professionalism of design detailing and construction on larger projects
- 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 insitu concrete surfaces. The density of faults forecast was approximately one-third that for insitu buildings. This was assumed to be true because shop drawings and reinforcement detailing for fit and cover attainment were generally contractual requirements
- 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 nothing in the published technical literature that would suggest that the quality of detailing has continued to improve. On the contrary, in the authors' opinion, the opposite is true as clients and building owners continue to seek least first cost solutions in construction.

13 Durability as affected by construction tolerances

All material manufacturers 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.

Zero tolerance solutions can not and will not work.

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 shown below:

- N12 = 14mm
- N16 = 18mm
- N20 = 23mm
- N24 = 27mm
- N32 = 36mm

- N36 = 40mm
- 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 (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. The other important areas for consideration with Post tensioning systems are;

- Duct size –
  - Duct ID + 6mm = Duct OD
  - Duct ID + 12mm = Duct Coupler OD
- Must maintain a minimum 5mm 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 ant-burst steel should always be drawn at full scale to check for interference

The other important consideration of construction tolerance 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 +/- 10mm
- Cross section (< 2000mm wide): +/- 4mm
- Cross section (> 2000mm wide): +/- 7mm
- Cored holes / openings - location: +/- 7mm
- Cored holes / openings diameter or side dimension: +/- 4mm

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

APPENDIX A

28-Day Nordtest standard cure diffusion coefficient

NORDTEST METHOD: NT BUILD 443 - 1995

Client: Structural Concrete Industries

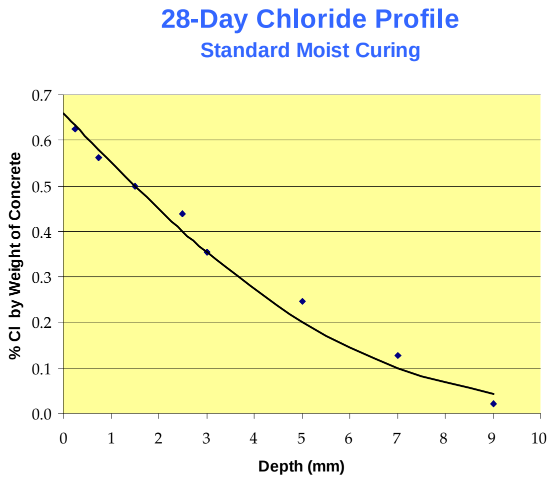
File No: 410/99

Lab Sample No.		18845	
Sample Number		**SCI 57273-H -1**	
Date of Casting		19-Oct-99	
Date of Grinding		17-Jan-00	
Background Chloride Content	C_o	0.001	%
Chloride Content at Surface	C_s	0.660	%
Exposure time in Salt Solution	t	28	days
	t	2419200	sec

Depth, mm	% Cl by wt	Macros Eq	Trial Di
0.25	0.625	0.0000	2.91E-12
0.75	0.562	0.0007	3.28E-12
1.5	0.499	0.0001	4.80E-12
2.5	0.439	0.0001	6.87E-12
3	0.355	0.0002	4.88E-12
5	0.246	0.0001	6.48E-12
7	0.127	0.0001	5.93E-12
9	0.022	-0.0001	3.64E-12
		Average D =	4.85E-12 m^2/sec

Best Fit Diffusion Coefficient	**D =**	**4.85E-12**	**m^2/sec**
Best Fit Chloride Content at Surface	**C_s =**	**0.660**	**%**

Note: 28 days standard water cured then submersed in salt solution for 28 days



Determination of Bulk Chloride Ion Diffusion Coefficient by curve fitting

Crank's solution to Fick's 2nd Law

[Cs-Cx]/[Cs-Co]-[erf(x/2*SQRT(De*t)]=0

28-Day Nordtest steam cure diffusion coefficient

NORDTEST METHOD: NT BUILD 443 - 1995

Client: Structural Concrete Industries

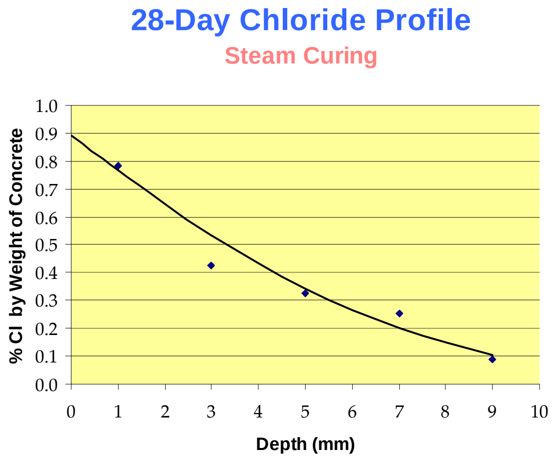
File No: 410/99

Lab Sample No.		19483	
Sample Number		**SCI N4**	
Date of Casting		24-Nov-99	
Date of Grinding		19-Jan-00	
Background Chloride Content	C_o	0.003	%
Chloride Content at Surface	C_s	0.890	%
Exposure time in Salt Solution	t	28	days
	t	2419200	sec

Depth, mm	% Cl by wt	Macros Eq	Trial Di
1	0.784	0.0001	9.13E-12
3	0.425	0.0005	3.65E-12
5	0.326	0.0002	6.27E-12
7	0.254	0.0001	8.78E-12
9	0.088	-0.0007	6.06E-12
		Average D =	6.78E-12 m^2/sec

Best Fit Diffusion Coefficient	**D =**	**6.78E-12**	**m^2/sec**
Best Fit Chloride Content at Surface	**C_s =**	**0.890**	**%**

Note: 1-day steam + 27-day air curing then submersed in salt solution for 28 days



56-Day Nordtest standard cure diffusion coefficient

NORDTEST METHOD: NT BUILD 443 - 1995

Client: Structural Concrete Industries

File No: 410/99

Lab Sample No.		18845	
Sample Number		**SCI 57273 K**	
Date of Casting		19-Oct-99	
Date of Grinding		31-Jan-00	
Background Chloride Content	C_o	0.001	%
Chloride Content at Surface	C_s	0.700	%
Exposure time in Salt Solution	t	56	days
	t	4838400	sec

Depth, mm	% Cl by wt	Macros Eq	Trial Di
0.25	0.685	0.0006	8.44E-12
0.75	0.595	0.0001	1.62E-12
1.5	0.565	0.0007	3.86E-12
2.5	0.451	0.0006	3.01E-12
3	0.359	0.0005	2.16E-12
5	0.275	0.0004	3.52E-12
7	0.163	0.0001	3.54E-12
9	0.055	0.0001	2.68E-12

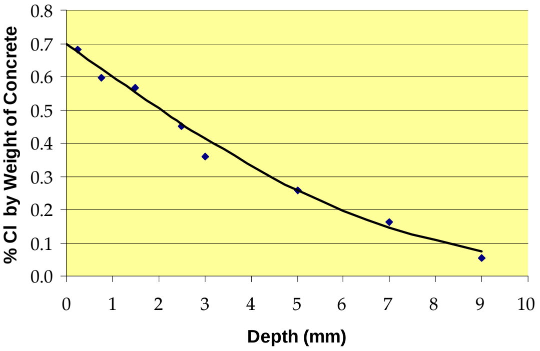
Average D = 3.60E-12 m^2/sec

Best Fit Diffusion Coefficient	**D =**	3.60E-12	**m^2/sec**
Best Fit Chloride Content at Surface	**C_s =**	**0.700**	**%**

Note: 28 days standard water cured then submersed in salt solution for 56 days

56-Day Chloride Profile

Standard Moist Curing



Determination of Bulk Chloride Ion Diffusion Coefficient by curve fitting

Crank's solution to Fick's 2nd Law

[Cs-Cx]/[Cs-Co]-[erf(x/2*SQRT(De*t)]=0

56-Day Nordtest steam cure diffusion coefficient

NORDTEST METHOD: NT BUILD 443 - 1995

Client: Structural Concrete Industries

File No: 410/99

Lab Sample No.		19483	
Sample Number		**SCI N9**	
Date of Casting		24-Nov-99	
Date of Grinding		16-Feb-00	
Background Chloride Content	C_o	0.003	%
Chloride Content at Surface	C_s	0.800	%
Exposure time in Salt Solution	t	56	days
	t	4838400	sec

Depth, mm	% Cl by wt	Macros Eq	Trial Di
1	0.688	0.0001	3.29E-12
3	0.475	-0.0007	3.25E-12
5	0.361	0.0000	4.51E-12
7	0.121	-0.0001	2.42E-12
9	0.056	-0.0001	2.49E-12

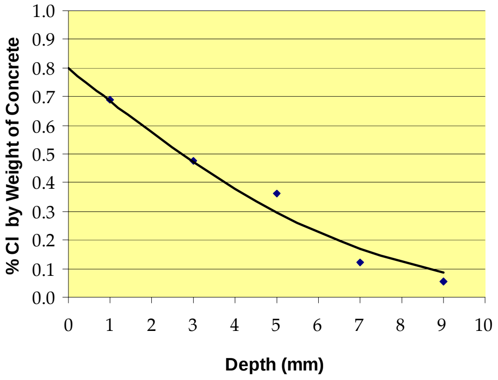
Average D = 3.19E-12 m^2/sec

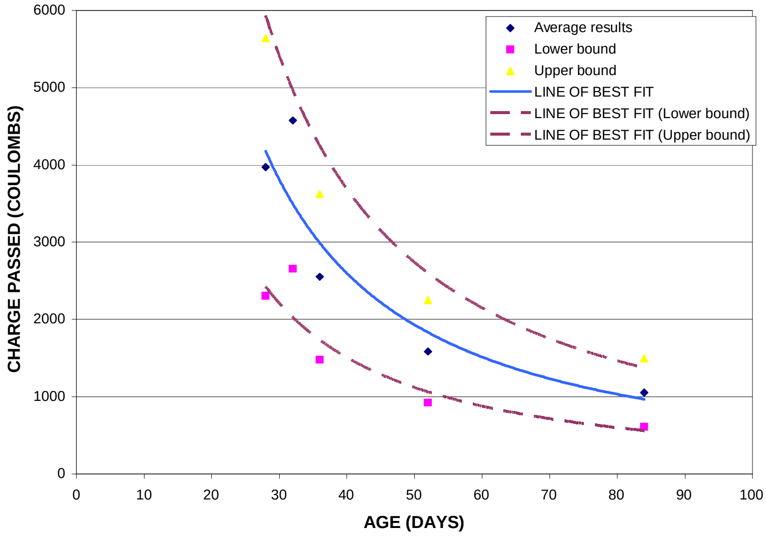
Best Fit Diffusion Coefficient	**D =**	3.19E-12	**m^2/sec**
Best Fit Chloride Content at Surface	**C_s =**	**0.800**	**%**

Note: 1-day steam + 27-day air curing then submersed in salt solution for 56 days

56-Day Chloride Profile

Steam Curing





SCI MIX 184

Rapid Chloride Permeability to ASTM C1202-97
Trendline calculated by method of least squares fit

References

1. Beresford, F.D. and Ho, D.W.S., “The repair of concrete structures – a scientific assessment”, Concrete Institute of Australia, Biennial Conference, Concrete 79, Canberra.

2. Guirguis, S. “Extent of deterioration survey – North Sydney”, Cement and Concrete Association of Australia, TR46, Sydney, 1979.

3. Marosszeky, M., Griffiths, D., Sade, D., “Site study of factors leading to a reduction in durability of reinforced concrete”, American Concrete Institute SP-100, p1703-1726, 1987.

4. Standards Association of Australia, AS 3600, “Concrete structures”, 1988.

5. Potter, R. J., “Background to design for durability in AS 3600”, Pacific Concrete Conference, 8-11 November 1988, p559-567.

6. Burke, J., “The curing Conundrum”, Letter report to National Precast Concrete Association of Australia, 2002.

7. Merretz, W.E., “Design for durability – curing of concrete – the relationship between AS 3600 and the BCA”, National Precast Concrete Association of Australia, 2002.

8. Concrete Institute of Australia, “Recommended practice – curing of concrete”, Z9, Second edition, 1999.

9. Guirguis, S., “A basis for determining cover requirements for durability”, American Concrete Institute SP-100, p447-467, 1987.

10. Merretz, W.E., Smith, G.F.A., Borgert, J.U., “Chloride diffusion in concrete specifications – A contractual minefield”, Concrete Institute of Australia, Biennial Conference,