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REPORT TITLE:	**DURABILITY PERFORMANCE OF CRONULLA MARINA A CONCRETE SLAB MODIFIED WITH XYPEX WATER-PROOFING ADMIXTURE**		
CLIENT:	Xypex Australia		
REPORT AUTHORS:	Dr Zhen Tian Chang		Marton Marosszeky
REPORT DATE:	16 July 2013	**FILE REF:**	Document BCRC0372

SUMMARY

The condition of a concrete deck slab modified with Xypex admixture was investigated after nearly 19 years exposure to a severe marine environment at the Cronulla Marina. The slab was in good condition, free of concrete spalls, cracks and rust stains.

A concrete core sample was taken from the slab and was analysed in a NATA accredited laboratory for the chloride contents at 5 average depths of 3, 10, 20, 30 and 40mm. The results clearly showed that the chloride content in the slab drops rapidly with the slab depth beyond the first 15mm. The chloride diffusion coefficient calculated from Fick's second law was found to be 0.080 x 10^{-12} (m^2/s), which is a very low value compared to those of normal concretes described in the literature. Based on this chloride diffusion coefficient and Fick's second law, the predicted time for the chloride level in the slab to reach the critical threshold level of 0.4% by weight of cement at 40mm (the reinforcement cover depth) would be 129 years.

The half-cell potential readings measured on a 3x1.2 m^2 area on the slab top were found to have an average value of -370 mV. Although the measured potentials were relatively high negative values, the potentials were reasonably uniform over the slab surface as shown on the potential contour map. Two most negative potentials of -529 mV and -487 mV were measured at the two locations where the reading could have been influenced by the exposed fittings on the slab. Further analysis of the potential gradient based on the Potential Curvature method indicated only one locations with high potential curvature values that could relate to higher corrosion risks, and this was adjacent to one of the two fittings.

In conclusion, the slab concrete modified with Xypex admixture is in an excellent condition after nineteen years' exposure in a severe marine environment. This is indicated by its sound and defect-free condition, very low chloride diffusion coefficient and the absence of any significant half-cell potential gradients over the slab area.

KEY WORDS: concrete durability, chloride permeability, performance life

REVISION SHEET

Revision Number	Description of Revision	Prepared By	Checked/ Reviewed By	Approved	Issued to Client
	1st Draft	Z T Chang	M Marosszeky		
	Final Draft	Z T Chang	M Marosszeky		16 July 2013
	Final Issue	Z T Chang	M Marosszeky		22 July 2013

About the authors

Dr Zhen Tian Chang is a senior durability consultant with BCRC. He has researched and consulted in the areas of concrete durability and structural performance for over 20 years.

Marton Marosszeky is a Director of BCRC, he held the Multiplex Chair of Construction Innovation at UNSW. He was the Director of the Australian Centre for Construction Innovation at UNSW. He is widely published and has researched and consulted in the areas of infrastructure durability and performance for over 20 years.

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DURABILITY PERFORMANCE OF CRONULLA MARINA

A CONCRETE SLAB MODIFIED WITH XYPEX WATER-PROOFING ADMIXTURE

INTRODUCTION

Xypex Australia requested BCRC (Building & Construction Research & Consulting) Pty Ltd to assess the durability performance of a 19 year old Xypex modified precast concrete deck slab that has been in continuous service at the Cronulla Marina jetty since 1994.

When the precast jetty slabs were cast in October 1994 Xypex C-2000 admixture was added to the concrete mix to enhance the water-proof characteristics of the concrete. After construction the deck surface was treated with a "Faux Brick" application to form a pattern textured concrete surface for decorative purposes. The design details of the concrete mix and the slabs, the test results of compressive strength and chloride contents in the aggregates are attached in Appendix I. These jetty deck slabs have been exposed to a severe marine environment similar to a splash zone since the slab top surfaces are only around 350 mm above sea level.

During the investigation a visual inspection was carried out of the deck slabs and a detailed investigation was carried out on a deck slab at the outmost location of the jetty as denoted by a circle on the second drawing in Appendix I. A core sample was taken from the slab for analysis of the chloride contents at different depths from the top of the concrete slab and, a half cell corrosion potential survey was conducted on a 3m x 1.2m area on the slab. This report summarises the site observations, investigation results, analysis and conclusions regarding the durability performance of the concrete.

SITE INVESTIGATION

The site inspection was undertaken in June 2013. Overall, the jetty deck slabs were found to be in a good condition, there was no sign of any concrete spall or other defects (see **Photo 1**).

A detailed investigation was carried out on a deck slab 12 m long, 1.2 m wide and 100 mm thick at the outer end of the jetty. The slab was prestressed using longitudinal wire strands. During the visual inspection we looked for signs of corrosion induced damage and could find none, there were no rust stains or spalls (see **Photos 2 and 3**).

A concrete core was extracted within 1 m from the outer end (see **Photo 4**); at this location the structure is exposed to wind-swept waves and salt laden aerosols. The core was extracted between painted patches of the Faux Brick pattern in order to minimize any effect of the Faux Brick materials on the results. Two Faux Brick patches overlapped the edges of the core, these portions were sawn off (see **Photo 5**) before materials were sampled for the analysis of the chloride content in the core.

A 3m long slab area over the full width of the slab (1.2 m) was marked with a two directional 150 mm grid, starting from panel centre and carrying towards the outer end of the pier, a half-cell potential survey was conducted at each of the grid intersections. A copper & copper-sulphate electrode (CSE) was used for the half cell survey and a connection to the reinforcing steel was made to one of the exposed strands whose electrical continuity to the reinforcing steel in the slab had been verified.

TEST RESULTS AND DISCUSSIONS

Chloride Contents and Chloride Diffusion Coefficient

The report "Chloride Resistance of Concrete" by CCAA (Cement Concrete & Aggregates Australia, 2009) concludes that "The chloride diffusion coefficient, derived from the chloride profile after long-term exposure, is considered one of the best indicators of chloride resistance".

The concrete core sample extracted in this investigation was sent to a NATA accredited materials laboratory for analysis. The chloride content was measured at different depths from the top surface of the core. The concrete core was firstly saw cut into approximately 6mm thick slices parallel to the top surface and, each of these slices was crushed and ground into powder for analysis of the chloride content according to AS 1012, Part 20.

The results of the chloride content by weight of concrete are shown in Table-1 below and the laboratory report is attached in Appendix II. The chloride content by weight of cement can be obtained by multiplying the result by the ratio of the weight of concrete to the weight of cement in the concrete mix. The mix design information in Appendix I indicates that each cubic metre of concrete (2370 kg) contained 530 kg of cement, thus the concrete/cement ratio is 2370/530 = 4.471. The calculated chloride contents by weight of cement are shown in the last column in Table-1.

Table-1. Chloride Contents in the Concrete Slab Core

Range of Sample Depths (mm)	Average Sample Depth (mm)	Chloride Content by Weight of Concrete (%)	Chloride Content by Weight of Cement (%)
0 - 6	3	0.46	2.057
7 - 13	10	0.26	1.163
17 – 23	20	0.041	0.183
27 – 33	30	0.019	0.085
37 – 43	40	0.009	0.040

The results in Table-1 demonstrate that, after 19 years exposure in a severe marine environment, the chloride content in the concrete slab is only significant within the first approximate 15mm from the top surface, it then reduces rapidly to very low levels with depth. The dramatic drop in the chloride concentration with increased depth is a clear indication of a dense concrete with very low chloride permeability.

To further quantitatively evaluate the resistance of concrete against chloride penetration, the chloride diffusion coefficient in the core was calculated using Fick's second law of diffusion. In **Fig. 6** the measured chloride contents in the core are plotted as "diamonds", while the theoretical curve obtained from Fick’s law is displayed as the red line. This theoretical curve fits reasonably well with the measured chloride profile, and it yields an effective chloride diffusion coefficient of 0.08 $\times 10^{-12}$ (m^2/s). This diffusion coefficient is a very low value compared to those reported in the literature for normal concretes.

In typical concretes, chloride diffusion coefficients are found in the order of 10^{-12} m^2/s (John P. Broomfield, Corrosion of Steel in Concrete, 1997). A chloride diffusion coefficient of 0.94 x 10^{-12} m^2/s was considered as "typical" for the performance of a bridge pier exposed in "very severe" environments and designed in accordance with BS5400 (refer Taywood Engineering report "Guidance on the Selection of Measures for Minimising the Risk of Corrosion of Reinforcement in Concrete" for UK Concrete Society in 2004). The typical performance of such a bridge concrete designed with BS5400 was considered to have a predicted time to cracking (due to corrosion) of some 95 years.

The concrete cover depth to the main prestressing strands in the Cronulla Marina slab was measured with a Covermeter to be in the range of 40 to 45 mm. For a chloride diffusion coefficient of 0.080 x10^{-12} (m^2/s) for the Xypex modified concrete, an analysis was undertaken based on Fick's second law of diffusion to predict the time by which the chloride concentration would increase to the widely used critical threshold level of 0.4% by weight of cement at the level of the reinforcement.

The results of this analysis are plotted as the blue curve in **Fig. 7,** the predicted critical chloride concentration of 0.4% by weight of cement at 40 mm could be reached at an age of 129 years with the current exposure conditions. This is the time to the onset of corrosion and not to cracking resulting from corrosion as in the case referenced above.

Half-Cell Potential Survey

The half-cell potential technique has been widely used in corrosion condition surveys since the work on the evaluation of the condition of bridge decks by J R Van Daveer in 1975. This US Federal Highway Administration project compared the results of potential surveys to the physical manifestation of corrosion on reinforcing steel on 473 bridge decks. On the basis of this work Van Daveer and his team recommended guidelines for the probability of corrosion for varying potential readings as set out below.

- If a potential reading is more negative than -350 millivolt, then there is a 90% probability that the reinforcing steel is corroding.
- Between -200 and -350 millivolts, there is a 50% chance that the steel is corroding.
- If a potential reading is less negative than -200 millivolt then there is a 90% probability that the steel is not corroding.

This work became the basis of the ASTM C876-91 standard (Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete) and the above guidelines were also included in the appendix to ASTM C876 as guidance information.

However, these interpretation criteria were devised empirically based on bridge structures affected by deicing salts. It has been found by many investigators that, with different concretes and under different environmental conditions, the critical potential ranges can shift significantly ("Potential Mapping and Corrosion of Steel in Concrete", Proceedings of the Symposium on Corrosion Rates of Steel in Concrete, ASTM, 1990). In marine environments, very negative potential readings can be found in saturated conditions. However, the corrosion rates in these cases are often very slow due to lack of oxygen for the cathodic reaction of the corrosion process. Therefore, the location of steel corrosion in structures exposed to different environments may not be properly assessed with the guidelines from ASTM C876. The interpretation of the potential data, especially in marine structures, has to be based on the correlation with other factors and the experience in the investigation of similar corrosion problems.

An active corrosion "hot spot" is usually associated with not only more negative potentials but also high potential gradients. Based on the analysis of half-cell potential results and their gradients, a numerical method has been developed ("Potential Curvature Method – A new Approach for Corrosion Assessment in Concrete Structures", the 9th International Conference on Durability of Building Materials & Components, Brisbane, Australia, 2002), which identifies locations with higher active corrosion risks based on positive potential curvature values that correspond to potential gradients of 150 mV per meter or more.

In this investigation, a copper/copper-sulphate electrode (CSE) was used for the half cell potential survey. The potentials were measured on 150 mm x 150 mm square grid over an area of 3.6 square metres (**Photo 8**). The half-cell potential results are summarised in Table-2.

Table-2. Summary of Measured Half-Cell Potentials (CSE)

Time of Survey	**Max. Potential (mV)**	**Min. Potential (mV)**	**Average (mV)**
May 2013	**-290**	**-529**	**-370**
Total Points	**Points in the ASTM C876 Potential Ranges**		
	<-350mV	**-200 to –350mV**	**>-200mV**
189	**127**	**62**	**0**
100%	**67.2 %**	**32.8 %**	**0 %**

The measured potential values shown in Table-2 were very negative in a range of -290 mV to -529 mV with an average value of -370 mV. On the basis of the ASTM C876 guidelines, the potential values of 127 (67.2%) slab locations fall into the category having a 90% probability of active corrosion. Furthermore the remainder of the slab locations would have 50% chance of active corrosion. However, the slab as previously noted is in a very sound condition without any signs of deterioration or rust staining. The high negative potentials measured on the jetty slab in this case could be mainly related to the marine exposure environment rather than active corrosion.

The potential results were plotted as a potential contour map in **Fig. 9**, which shows equipotential lines with a 10 mV difference. In such a potential contour map denser equal-potential lines indicate higher potential gradients. In general, the equipotential lines are reasonably uniform and denser lines are found only at the two right corners (x = 3m), where the two most negative potentials of -529 mV and -487 mV were measured. It is considered that these readings were influenced by the two exposed fittings fixed in the slab at these corners.

To further analyse the half-cell potential readings on the basis of the local gradient of potential change, the Potential Curvature method of analysis was used. The half cell potential values over the measured area were numerically analysed for their potential curvature values based on the potential gradients in both directions.

Fig. 10 plots the half cell potential curvature contour map showing locations corresponding to the potential gradients of 150 mV per metre or higher. It shows there is only one location with high potential curvature values (x = 1.2m, y = 0.5m) where the risk would be only slightly higher because there are no multi and dense contour lines around the location.

CONCLUSION

Overall, the slab concrete modified with Xypex admixture is in an excellent condition after nineteen years' exposure in a severe marine environment. This is evidenced by its sound and defect-free condition, very low chloride diffusion coefficient and the absence of any significant half-cell potential gradients over the slab area.

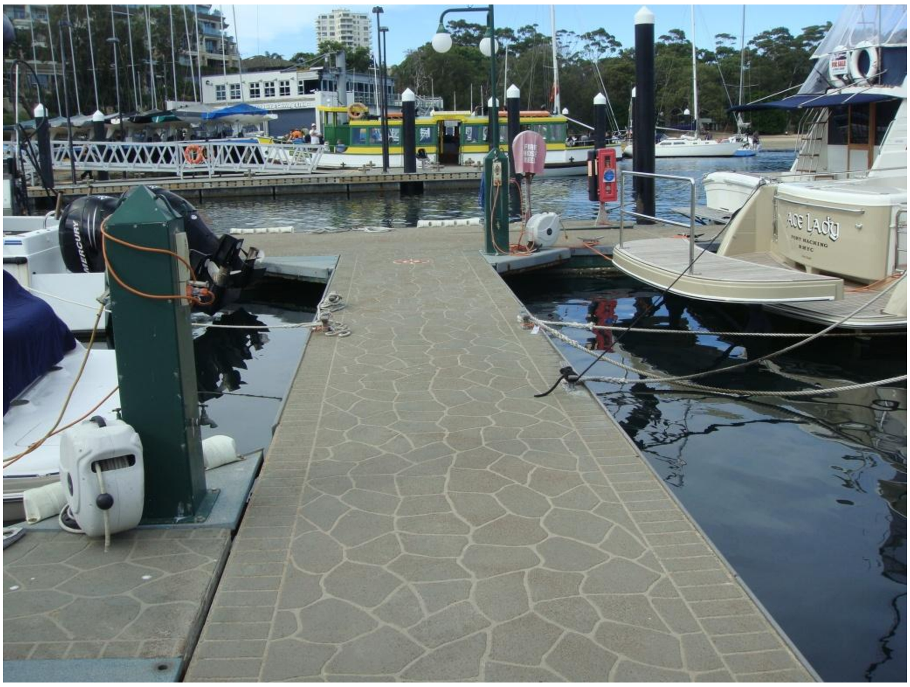


Photo 1: A view of part of the Cronulla Marina jetty

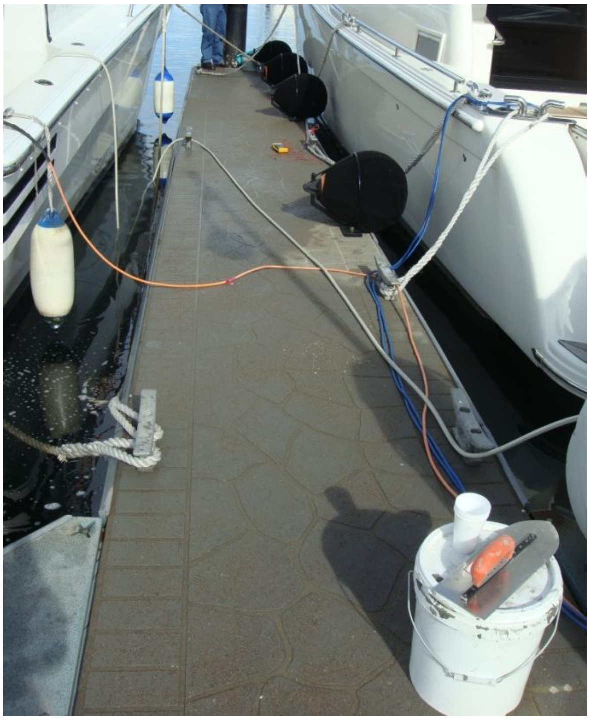


Photo 2: The 12m long jetty slab being investigated

Photo 3: A closer view of the jetty slab top surface condition

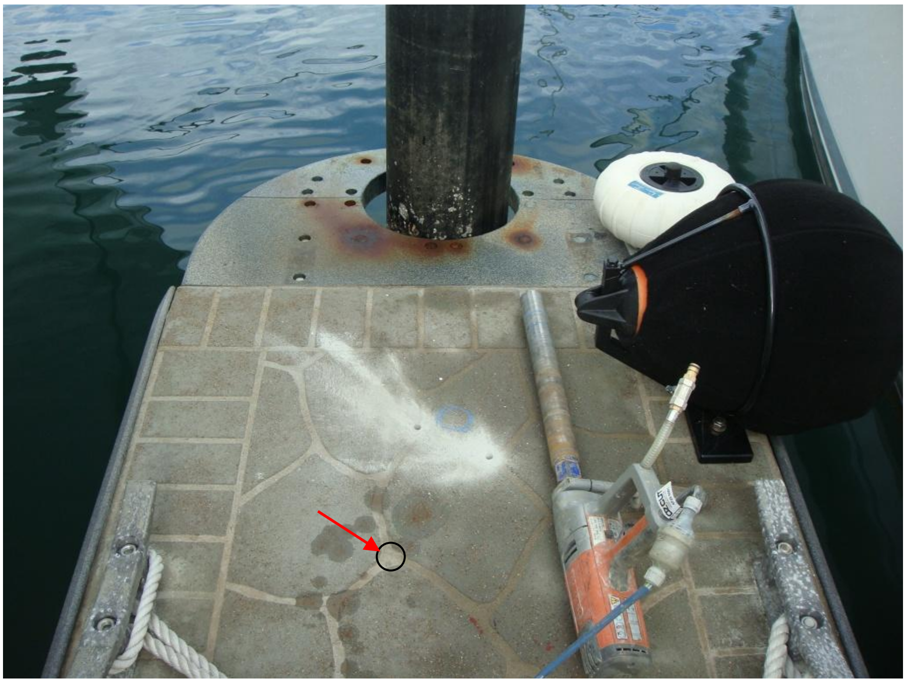


Photo 4: Core location between patterns near the slab seaside end

Photo 5: Core top surface after removing Faux Brick on two edges

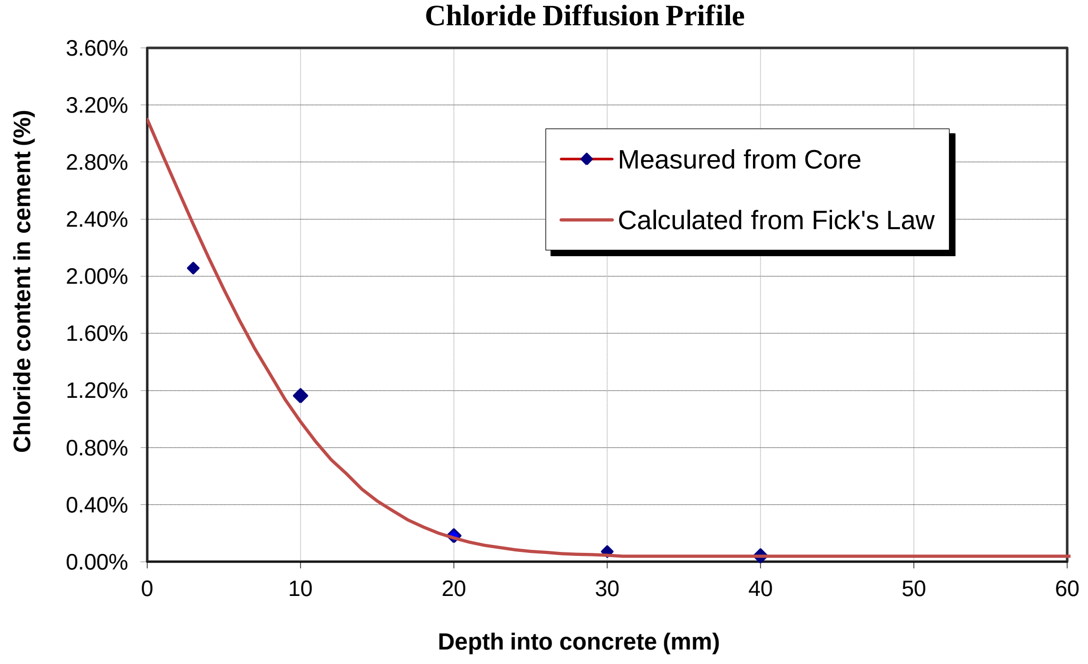


Fig.6 Measured and calculated Chloride diffusion profiles in the concrete core

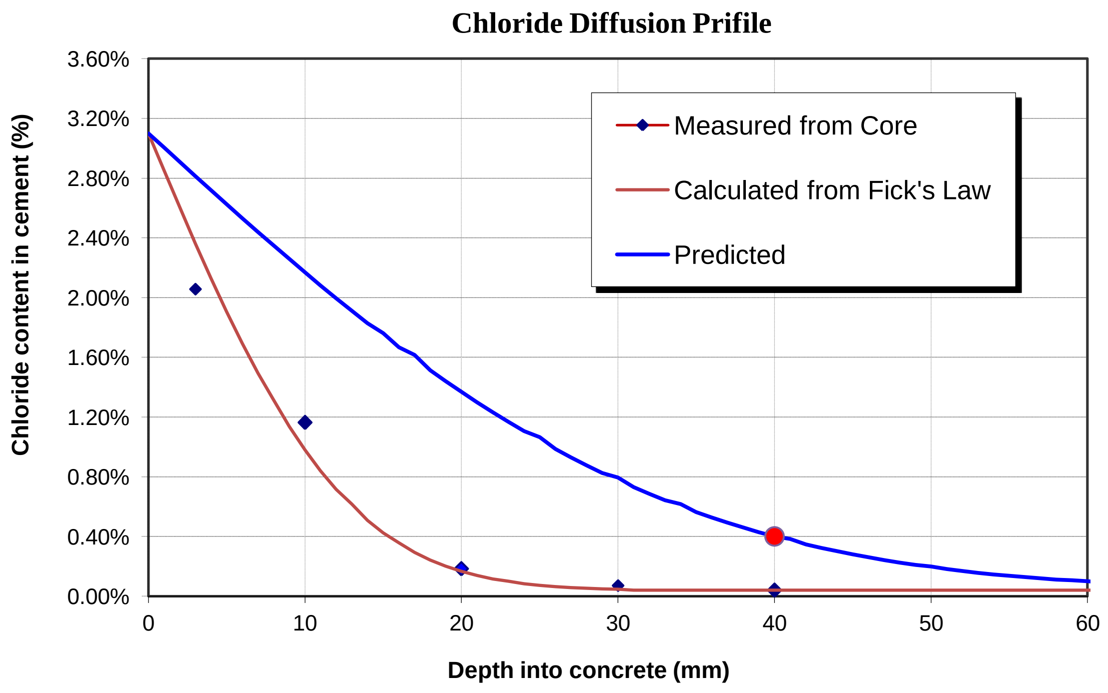


Fig.7 Predicted "Critical" chloride diffusion profile verses the measured profile

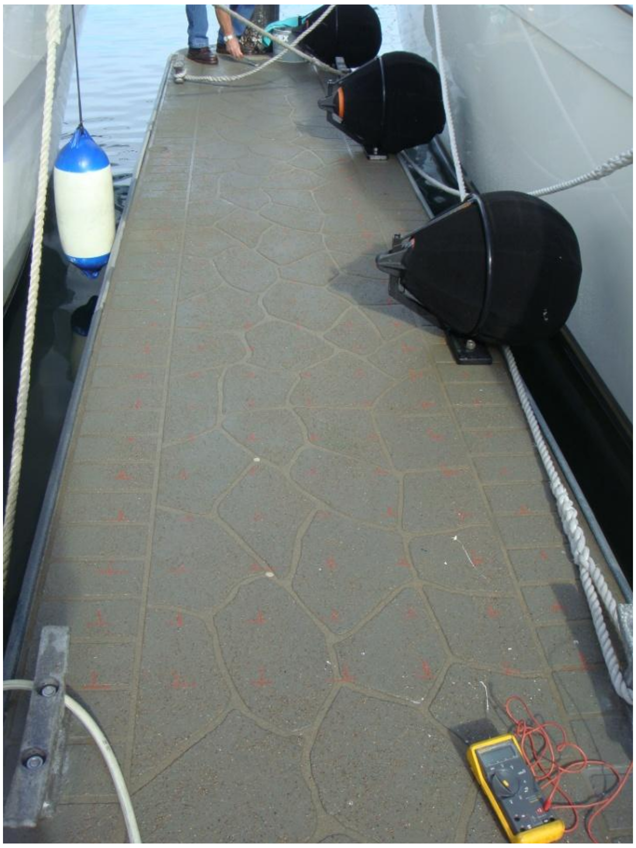


Photo 8: Grids marked on slab area for a half cell potential survey

Fig.9 Half Cell Potential Contour Map over Surveyed Concrete Slab Area

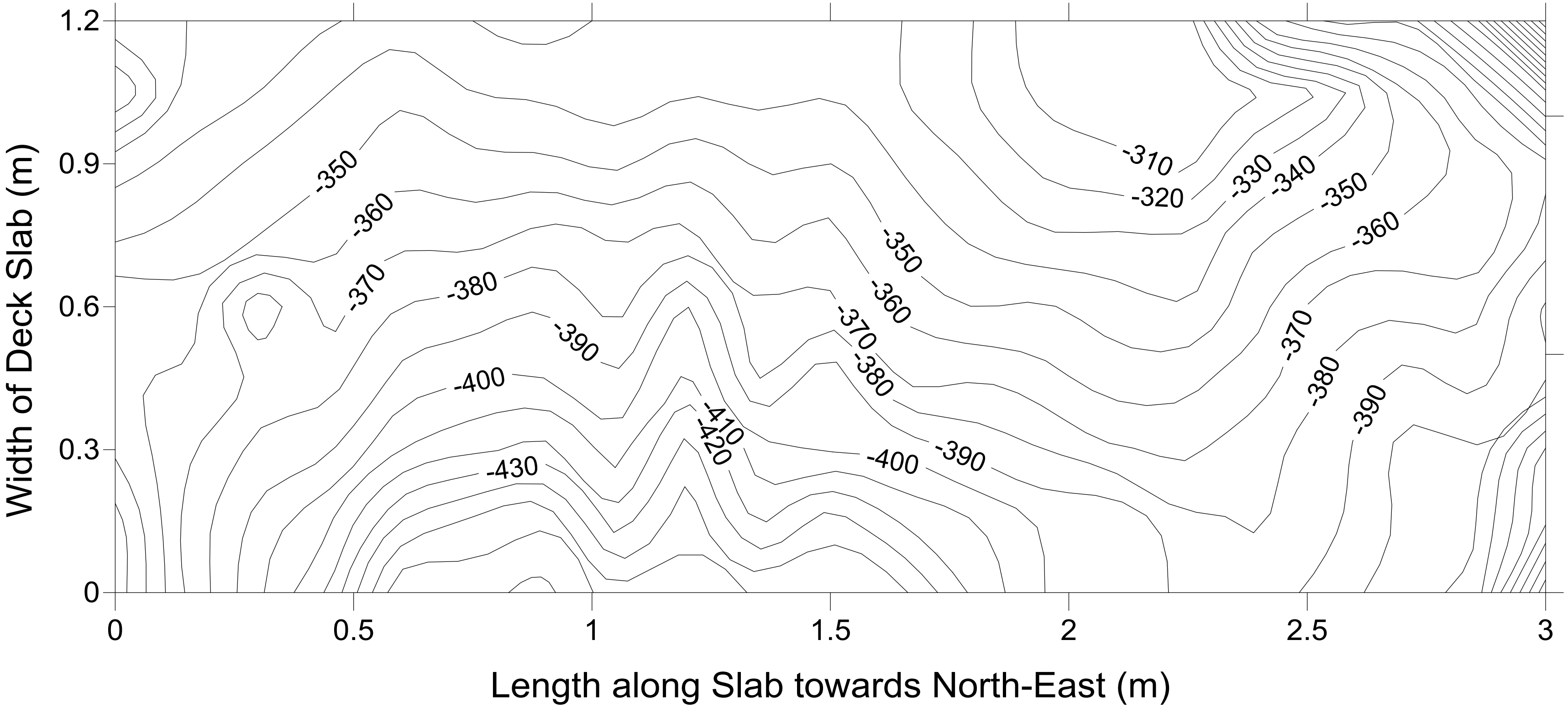
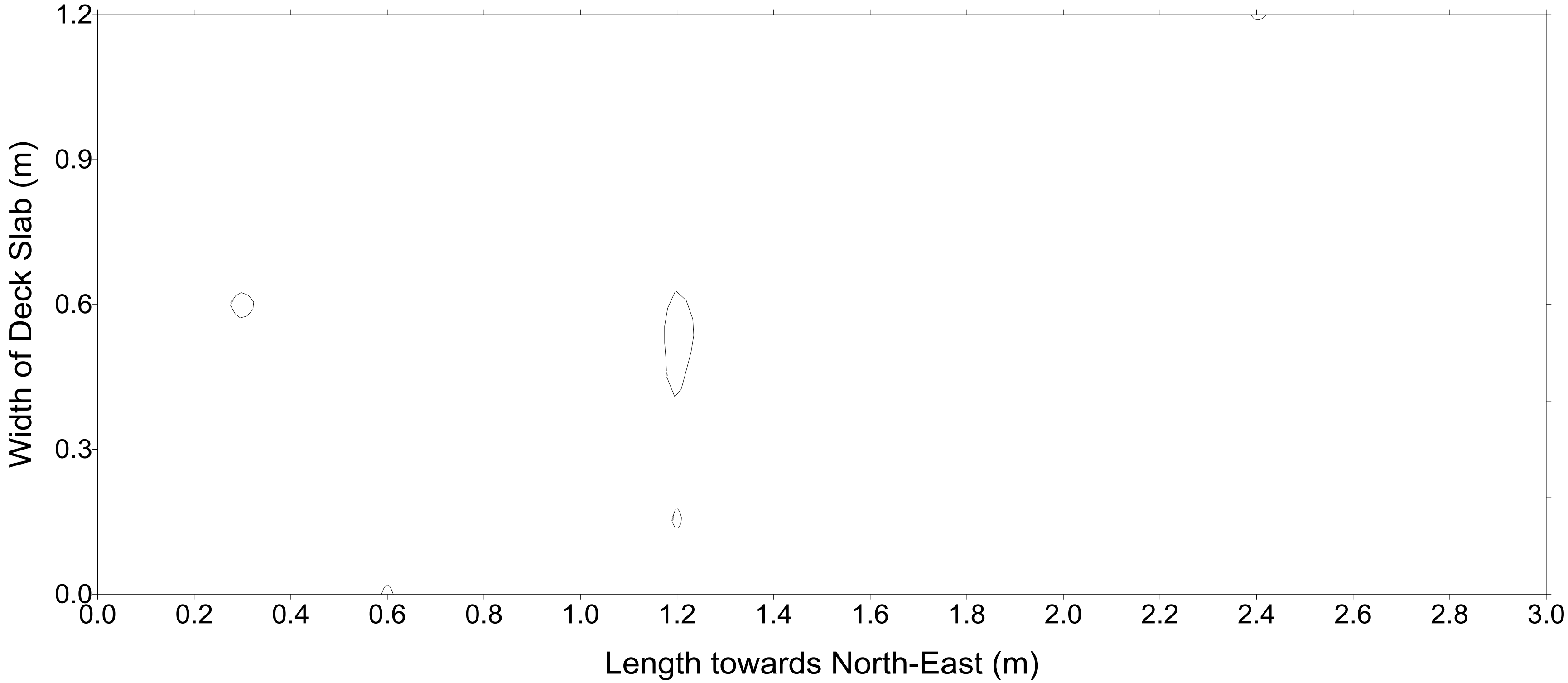


Fig.10 Half Cell Potential Curvature Contour Map over Surveyed Concrete Slab Area



Appendix I

Design Details of Concrete Mix and Slabs, Test Results of Compressive Strength of Concrete and Chloride Content in Aggregates and Sands

DATE: 16/11/98

TO: DON VENESS
XYPEX AUSTRALIA

FROM: Lyn Brighton

SUBJECT: CONCRETE MIX DESIGN used in our precast prestressed marine decks.

CONCRETE DESIGN MIX INCLUDING ADDITIVES

530 KG	G.P. CEMENT	
730 KG	20MM BASALT	(S.C. Latite)
340KG	10MM BASALT	(S.C. Latite)
480KG	COURSE SAND	(Nepean)
120KG	FINE SAND	(Kurnell)
170L	WATER	

SLUMP TO 85-90MM AT PLANT TO ACHIEVE SLUMP 80MM ON SITE FOR POURING

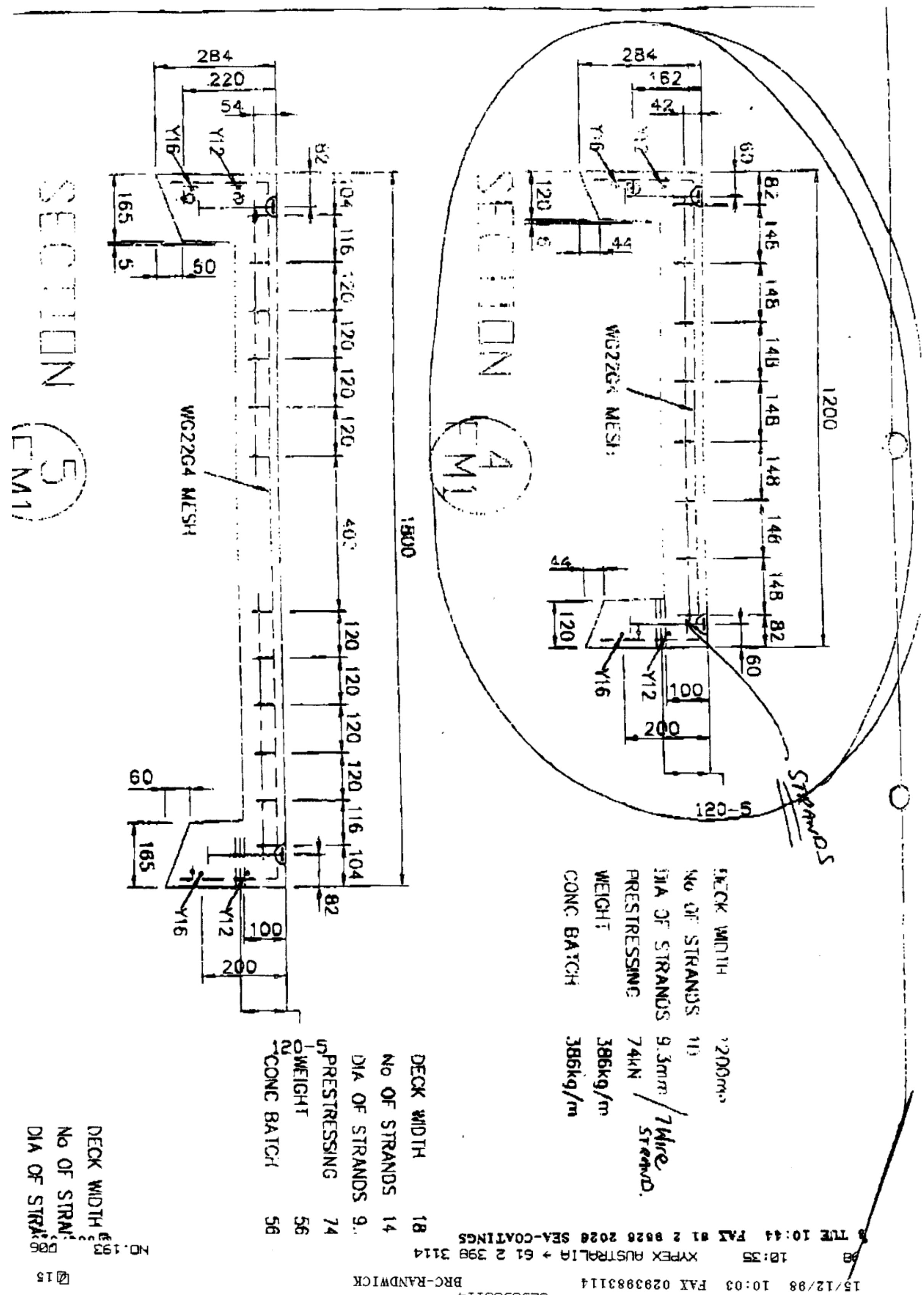
ADMIX – **XYPEX C 2000 4.2KG PER CUBIC METRE**

This batch has been designed to suit our needs to achieve the strength required ie 32 mpa for stripping at about 36-40 hrs. We do not have the steam curing facility. We have with the above batch achieved the required strength in the time, we reach approx. 50mpa in 7 days & around 70mpa in 28 days. We have been using this mix design successfully from the outset in October 1994.

Regards,

Lyn D. Brighton
For Sea-Slip Marinas Pty Ltd

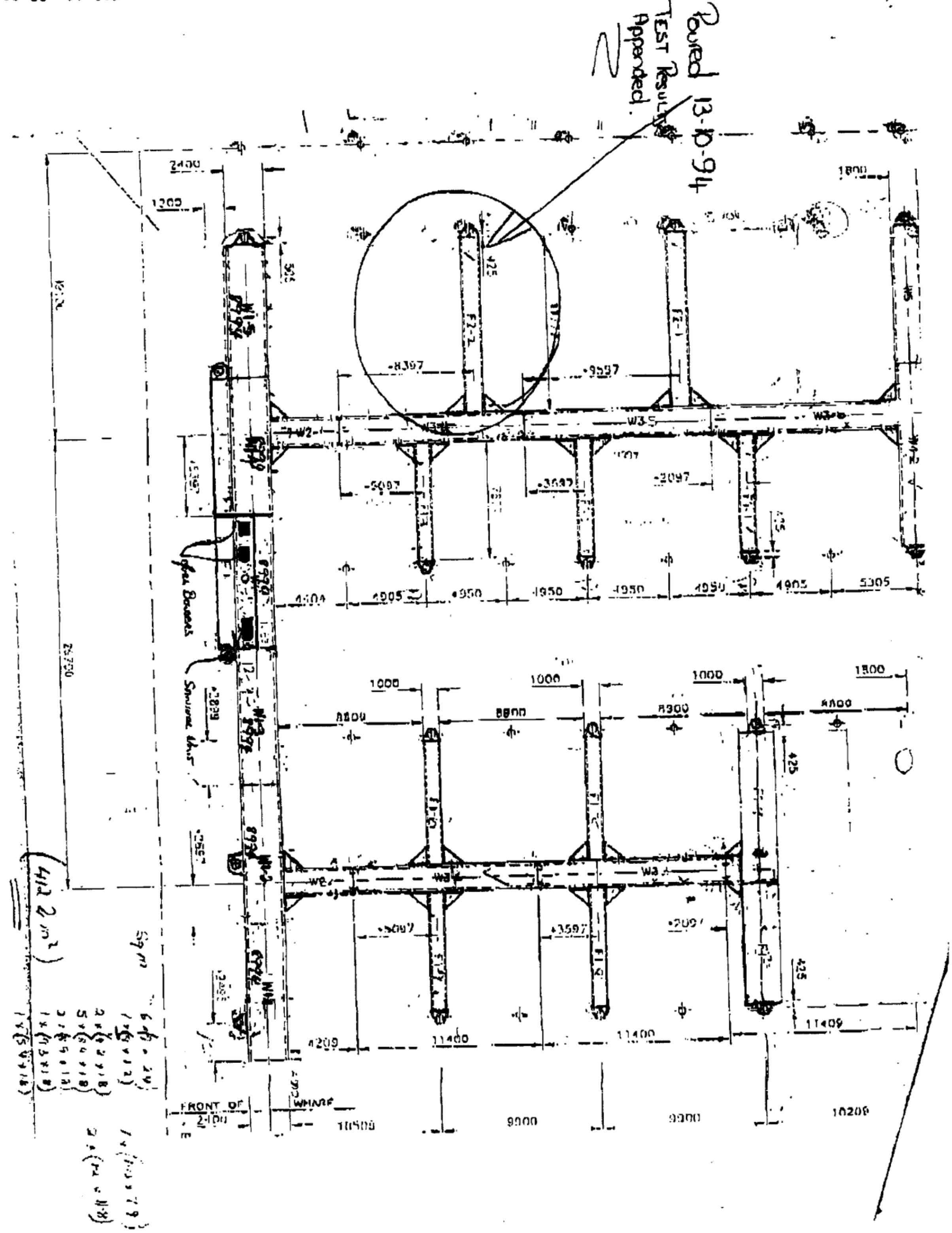
Lyn Brighton



SECTION 5 EM1
SECTION 4 EM1
WG22G4 MESH
STRANDS
DECK WIDTH
No OF STRANDS
DIA OF STRANDS
PRESTRESSING
WEIGHT
CONC BATCH

0293983114
15/12/98 10:03 FAX 0293983114 BRC-RANDWICK 016

04/11/98 10:35 XYPEX AUSTRALIA → 61 2 398 3114 NO.193 P05
03/11 '98 TUE 10:44 FAX 61 2 9526 2026 SEA-COATINGS 003/013



CONTEST CONCRETE TESTING PTY. LTD.
A.C.N. 001 871 067
Telephone: (02) 9601 3422
Fax: (02) 9601 8041
Correspondence: P.O. Box 523, Sutherland, 2232

CONTEST

17/12/98

Xypex Australia Pty Limited
P.O.Box 255
LAVINGTON NSW 2641

Attention: Mr Don Verness

re: Typical chloride content of aggregates.

The typical chloride content of aggregates used as raw materials for concrete supplied by Concrite Pty Limited to the Sea Coatings project at 58-64 Cook street, Kurnell, were as tabled below:

Material	Typical Chloride Content
Latite ex Bass Point	0.02%
Coarse River Sand ex Nepean	0.002%
Fine Dune Sand ex Kurnell	0.003%

Regards

S Pignat.

Stuart Pignat
Laboratory Manager

CONTEST CONCRETE TESTING PTY. LTD
A.C.N. 001 871 067
26 Seton Road, Moorebank.
Telephone: (02) 601 3547
Fax: (02) 601 8041
Correspondence: P.O. Box 126, Miranda. 2228

CONTEST

REPORT ON COMPRESSIVE STRENGTH TESTS OF CONCRETE CYLINDER SPECIMENS

Test Report No.: **940230**
Sydney Laboratory

This laboratory is registered by the National Association of Testing Authorities, Australia. The tests reported herein have been performed in accordance with its terms of registration.

CLIENT: **SEA COATINGS NSW**
P.O.BOX 233
CARINGBAH NSW 2229

PROJECT: 58-64 COOK STREET, KURNELL.

LOCATION OF POUR: SLAB

DATE OF SUPPLY: 13/10/94

Plant Docket No. Time Batched	Strength Grade Mix Identific. Ordered and Actual slump	Smpl.Loc. Smpl.Proc.	Time Sampled Conc.Temp.(°C) Init.Curing (hrs)	Specimen Ident.	Date of Test	Standard Moisture Curing (days)	Cap Type	aver. diam. x height	Mass per Unit Volume (kg/m^3)	Age at Test (days)	Compressive Strength (MPa)	Remarks
…ation of batch after placement (if avail.)												
CONCRITE-KIR	**50** F'c	6(b)	13:50	10874/A	14/10/94		R	100.0x199	2440	1	25.0	
449325	50 MPa	7.2.1	20	10874/B	15/10/94	1	R	99.8x200	2440	2	38.0	
12:50	80	75	24	10874/C	15/10/94	1	R	100.0x199	2460	2	40.0	
				10874/D	20/10/94	6	S	99.9x202	2480	7	56.0	
				10874/E	10/11/94	27	S	99.9x203	2460	28	68.5	
				10874/F	10/11/94	27	S	99.8x202	2500	28	69.5	
CONCRITE-KIR	**50** F'c	6(b)	13:50	10874/G	15/10/94	1	R	100.0x199	2420	2	35.0	water added on site
449325	50 MPa	7.2.1	20	10874/H	15/10/94	1	R	100.2x200	2420	2	35.5	
12:50	80	80	24	10874/I	20/10/94	6	R	100.4x198	2440	7	53.5	

Additional Information Relating to Tests

4 LITRES SUPERPLASTICIZER ADDED TO MIX.

SPECIMEN "A" CRUSHED AT 24 hours.
"B" CRUSHED AT 42 hours.
"C" CRUSHED AT 46 hours.

"G" CRUSHED AT 42 hours.
"H" CRUSHED AT 46 hours.

Note 1: Tests in accordance with AS 1012 Parts 1, 3 [Method 1], 8, 9 and 12 (Section 1) unless noted otherwise.
Note 2: Sampling location & procedure reference is to clauses in AS 1012 Part 1.
Note 3: All specimens compacted by rodding unless otherwise stated.
Note 4: Standard temperature zone.
Note 6: Cap Types : R = Rubber, S = Sulfur
Note 7: Unless otherwise noted, mass per unit volume of hardened concrete was determined in standard moisture condition, capped if sulfur cap used and uncapped if rubber cap used.

....
Approved Signatory
Date: 24/11/1994

Appendix II

Analytical Report of Chloride Contents in a Concrete Core

WATERTEST

Office:
PO BOX 591
SEVEN HILLS NSW 2147

Laboratory:
1/4 ABBOTT ROAD
SEVEN HILLS NSW 2147
Telephone: (02) 9838 8294
Fax: (02) 9838 8919
A.C.N. 098 982 140
A.B.N. 76 098 982 140
NATA No: 1884

ANALYTICAL REPORT for:

BCRC NSW PTY LTD

PO BOX 1989
GOSFORD NSW 2250

JOB NO:	WY0651
CLIENT ORDER:	20/06/13
DATE RECEIVED:	20/06/13
DATE COMPLETED:	28/06/13
TYPE OF SAMPLES:	CONCRETE
NO OF SAMPLES:	5

NATA Accredited for compliance with ISO/IEC 17025

....
Issued on 28/06/13
Sue Wyman
(Laboratory Supervisor)

ANALYTICAL REPORT

JOB NO: WY0651
CLIENT ORDER: 20/06/13

	SAMPLES	Cl- %
1	3mm	0.46
2	10mm	0.26
3	20mm	0.041
4	30mm	0.016
5	40mm	0.009
MDL		0.001
Method Code		10.13
Preparation		P1

WATERTEST

ANALYTICAL REPORT

JOB NO: WY0651
CLIENT ORDER: 20/06/13

METHODS OF PREPARATION AND ANALYSIS

The tests contained in this report have been carried out on the samples as received by the laboratory.

P1 Analysis performed on sample as received

10.13 Chloride in Concrete - AS1012.20