SHARP AND HOWELLS

CONCRETE INVESTIGATION – XYPEX PANEL

INVESTIGATION REPORT

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1. INTRODUCTION

Australasian Corrosion Consultants were commissioned by Sharp and Howells to perform a survey on a concrete slab at Lascelles Wharf - Geelong Ports, Victoria. The wharf was constructed in 1995 and has given 19 years of service as a bulk chemical and grain dock. The diagnostic tests were completed with the intention of analysing a slab that has been treated with *a Xypex Admix – C Series*. The following report details the results and findings of this survey as performed on the 16/01/2014.

2. SCOPE OF INVESTIGATION WORKS

3.1 VISUAL CONDITION ASSESSMENT

This survey is carried out to ascertain the type and extent of visible defects to the concrete slab. A defects log is compiled. Photographic evidence can be used to confirm visual delamination data collected. From this information, areas are selected for detailed diagnostic testing. For the Lascelles Wharf investigation, a visual condition assessment will be performed before any other works are performed.

3.2 REINFORCING CONTINUITY TESTING

The electrical continuity of the slabs' embedded reinforcement is important for Electro-potential testing. The continuity is checked by measuring the resistance between reinforcing bars using a DC resistance meter in one direction and then reversing the test leads and repeating the measurement. For the case of the Xypex treated panel at Lascelles Wharf, an electrical resistance equal to or less than one ohm is considered acceptable.

3.3 CONCRETE COVER SURVEY

A concrete cover survey is performed via a cover meter to determine the thickness of the concrete overlying the reinforcement. The cover over reinforcement plays an important role in the corrosion stages, in particular the time to de-passivate the steel due to chloride ingress is a function of the cover. ACC has been requested by Sharp and Howells to provide a chloride assessment of the Xypex panel and therefore a concrete cover survey is required to achieve this.

3.4 EQUIPOTENTIAL MAPPING

Equipotential (or half-cell) mapping is a quick and reliable method of determining corrosion activity of reinforcing steel in atmospheric concrete, irrespective of the cause of the corrosion. Simply put, as reinforcing steel corrodes the potential (voltage) of the corroding areas is more negative, often to around -500mV (-0.5 V) The system works by measuring the voltage at the surface of the concrete, which approximates the voltage of the reinforcement at various points, allowing the potential gradients to be mapped.

For the purpose of this project Australasian Corrosion Consultants performed Equipotential Mapping on a 3 x 1 m section of the Xypex panel.

3.5 CHLORIDE CONTENT ASSESSMENT

Measurement of chloride levels is performed by laboratory testing. The critical level of chloride required to initiate corrosion is related to the hydroxide ion concentration in the concrete pore water. The chloride level likely to cause corrosion can only be estimated approximately and will vary according to environmental conditions, cement type and concrete cover.

In analysing the chloride levels, the following criteria as given in HB 84-2006 is applied:

Table 1 Chloride Criteria

Chloride W/W Cement	Corrosion Probability
<0.4%	Low
0.4% to 1.0%	Medium
>1.0%	High

ACC have been requested by Sharp and Howells to perform a chloride assessment on the Xypex panel in relation to its chloride ingress and effects on corrosion.

3. RESULTS OF TESTING

Detailed results of the testing that occurred on 16/01/2014 can be seen in appendix A attached.

4.1 VISUAL INSPECTION

Visual inspection of the Xypex slab indicated that there was very little delamination and surface damage. The concrete surface showed minor wear on the edges of the panel as well as small amounts of general wear. There were no visible cracks, spalling or other damage to the panel. Pictures from the Visual Inspection can be found in appendix B attached.

Visual inspection of the reinforcing steel showed a black colouration on the surface of the rebar. This can be seen in the figure 2 below. .The cause or nature of the discolouration was not investigated during this survey.

Figure 2 – Xypex Rebar

4.2 REINFORCEMENT CONTINUITY

Reinforcement continuity was tested for the slab. The results of this testing indicate that all reinforcing is electrically continuous. Results show that the resistance between the reinforcing on the Xypex slabs is less than 0.3 ohms. This indicates that equipotential testing can occur by making a connection to the reinforcing at any point and taking a potential reading to a reference electrode.

4.3 CONCRETE COVER SURVEY

The results of the covermeter survey can be used as a reference for assessment of the significance of the depth of penetration of chloride ions in the Xypex panel. The survey also provides a general indication of the distribution of reinforcing steel within the cover concrete. The following analysis indicates the typical reinforcing cover.

Table 2 - Concrete Cover Survey Results

Number of readings	Minimum Depth (mm)	Maximum Depth (mm)	Average Depth (mm)	Distribution (mm)
19	76	51	62	150 C-C

4.4 EQUIPOTENTIAL TESTING

Potential Mapping was undertaken on the Xypex slab. The criteria that is typically employed when performing a concrete potential mapping survey is the ASTM-C876-91 Standard. The ASTM-C876-91 Standard provides a very general guide for classification of half-cell potential values based upon probability for corrosion. This guideline is presented in table 1 below.

Table 3 – ASTM-C876-91 Standard Half-Cell potential value classification

Potential (ref CuCuSo4)	Probability of Corrosion
More positive than –200 mV	<5%
-200 to –350 mV	About 50%
More negative than –350 mV	>95%

The equipotential results for the slab as set out in Appendix A has been analysed and is shown in figures 3-4 below. The colour codes selected in the plots are set to the ASTM classifications contained in Table 1, above. The interpretation of these ranges (in millivolts (mV)) is described below.

(green)	**-50 to 100**	**Likely not corroding**
(yellow)	**-200 to -50**	**Possible chance of corrosion**
(blue)	**-350 to -200**	**Likely corroding**

The results of the equipotential mapping of the two slabs can be seen below.

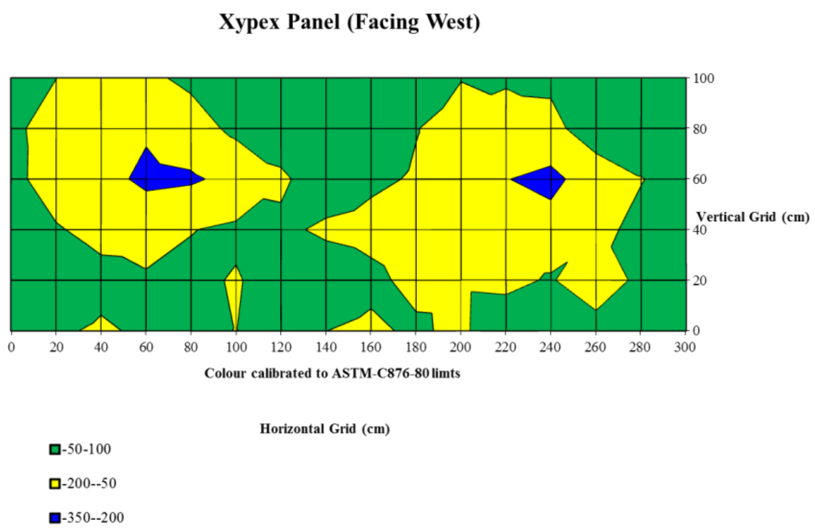


Figure 1 Xypex Panel

- Calculated Mean of the measured values: -51.6mV
- Range of measure values: -243mV to 52.9mV
- Calculated Standard Deviation of the measured values: 62.2

This analysis indicates that there are some sections of reinforcing that have a greater than 95% probability of corrosion (as identified by the blue areas (-200 to -350 mV)). These areas are at the location where the steel was exposed for the test connection. The wet nature of the exposed steel at these locations can distort the results, requiring careful interpretation.

For the purpose of this report ACC has removed the data surrounding the location of the exposed steel. After this is completed the plot is more homogenous, as can be seen below.

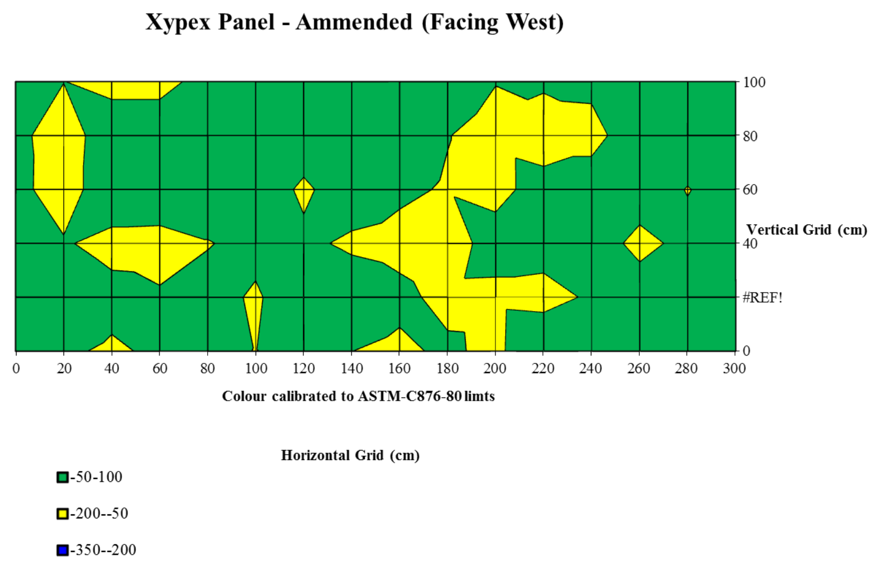


Figure 2 - Xypex Panel - Amended Values

- Calculated Mean of the amended values: -31.5mV
- Range of amended values: -105mV to 52.9mV
- Calculated Standard Deviation of the amended values:37.8

The amended plot indicates that the majority of the reinforcing in the Xypex panel has less than 5% probability of corrosion. There are however some sections that fall within a 50% probability of corrosion (-200 to -50 mV). After amending this data set, the calculated mean value can be seen to be more positive and there is a smaller standard deviation value than the measured values. This indicates that the amended sampling has a more evenly distributed potential range.

4.5 CHLORIDE CONTENT ASSESSMENT

ACC were provided with the percentage chloride content, weight/weight of concrete, of three different Xypex treated core samples by Sharp and Howells Laboratory. These results were given at three increment depths; 0-20mm, 20-40mm and 40-60mm. As chlorides are analysed to the requirements of HB 84-2006, ACC were required to determine the chloride content Weight/Weight of cement. For the purpose of this project a 15% cement content was assumed.

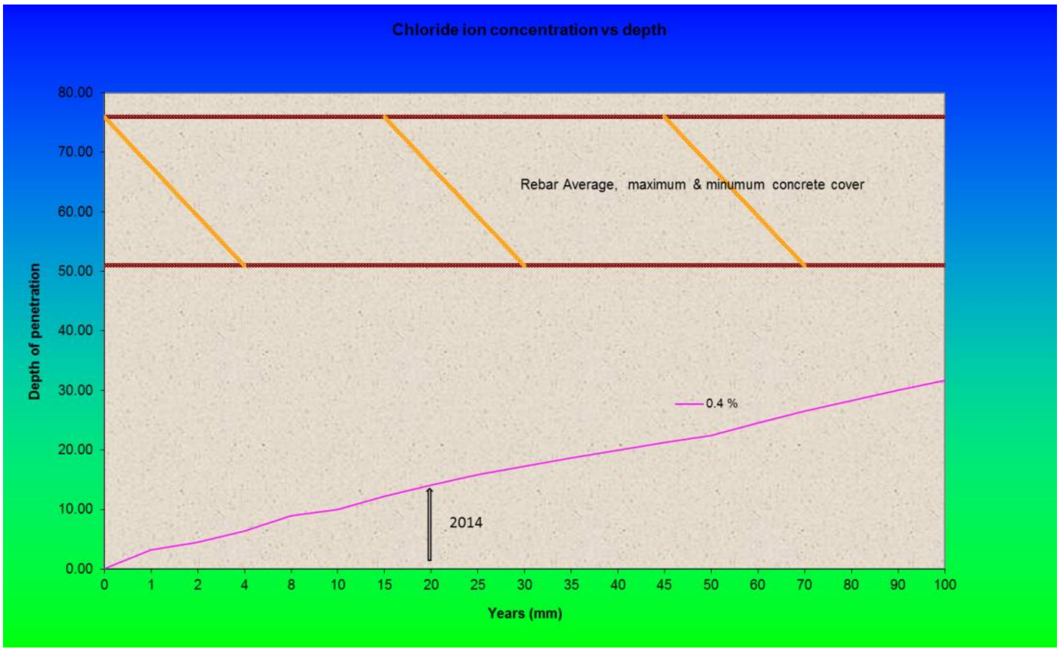
Using the chloride level provided for the 3 locations and at the 3 depths, ACC performed a chloride analysis using Fick's Second Law which predicts how diffusion causes the concentration to change with time.

A re-iterative plotting method is used to obtain a "best fit" curve, thus determining diffusion co-efficient (Dc) and chloride supply concentration (Co). These values are used to plot a graph showing penetration rate of the critical chloride level. Depth of reinforcement cover at the core location is plotted on the same graph.

The below graphs give an indication of the estimated future rate of penetration of the critical 0.4% w/w chloride concentration towards and beyond the level of the existing reinforcement thus permitting an assessment of present and future conditions.

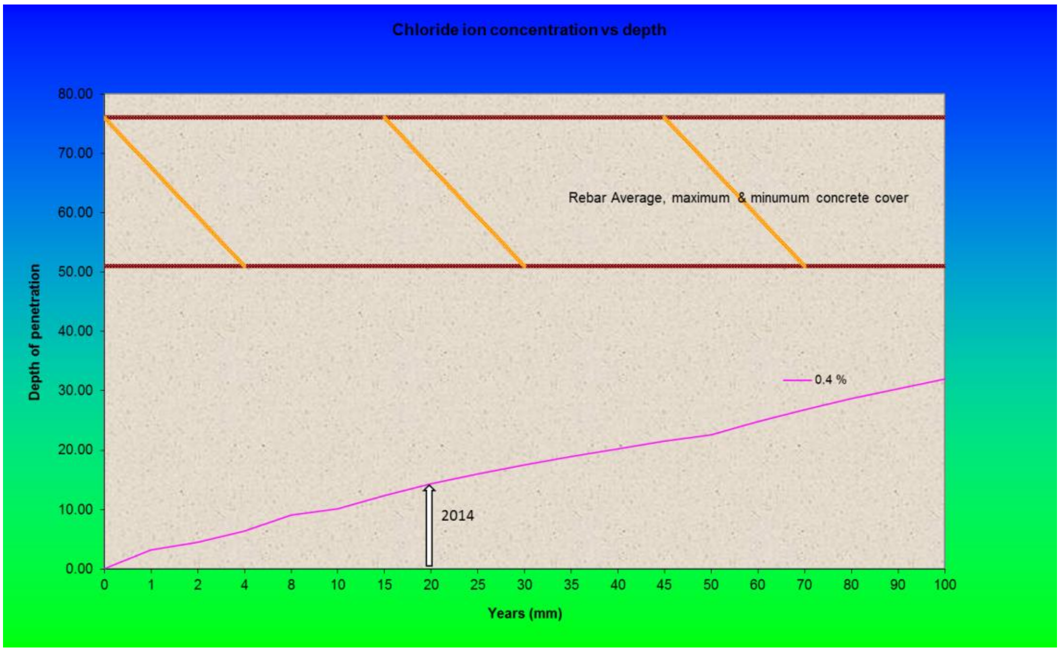
SAMPLE 1

The graph below gives an indication of the 0.4% w/w cement chloride level at concrete depth for the 1st location. The time required for the chloride levels to obtain the theoretical level of 0.4% w/w cement at reinforcement depth (51mm) as calculated by Fick's 2nd Law of diffusion, is 160 years for this location. As is shown in the graph, corrosive levels of chlorides will not be at rebar level for well over 100 years of service.



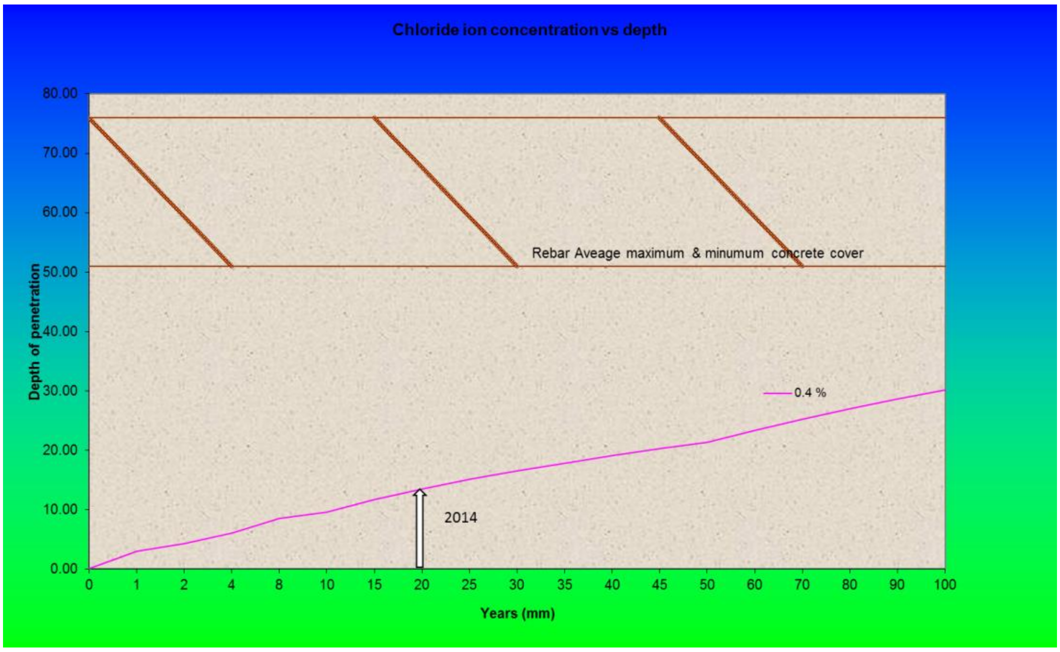
SAMPLE 3

The graph below gives an indication of the 0.4% w/w cement chloride level at concrete depth for the 3rd location. The time required for the chloride levels to obtain the theoretical level of 0.4% w/w cement at reinforcement depth (51mm) as calculated by Fick's 2nd Law of diffusion, is 156 years for this location. As is shown in the graph, corrosive levels of chlorides will not be at rebar level for well over 100 years of service.



SAMPLE 4

For the 4th location results are quite similar to location 1 and 3. The time required for the chloride levels to obtain the theoretical level of 0.4% w/w cement at reinforcement depth (51mm) as calculated by Fick's 2nd Law of diffusion, is 175 years for this location Corrosive levels of chlorides will not be at rebar depth for over 100 years.



4. CONCLUSIONS

Based on the results of the potential mapping and Chloride analysis, it is possible to conclude that the slabs appear to not be currently susceptible to corrosion. The results of the chloride analysis indicate that corrosion will not occur before well over 100 years.

APPENDIX A

SURVEY RESULTS

RR01	**ELECTRICAL CONTINUITY TESTING OF REBAR**		
Job No:		Date of Survey:	16/01/2014
Structure:	Lascelles Wharf, North Shore, Victoria	Reference:	TMS 1
Minimum No. of tests:	2 per test area or zone		

Structure Element	Location	Test number	From rebar	To rebar	Forward resistance (ohms)	Reversed resistance (ohms)	Result
Xypex Panel	Bore 1	1	North - South	East- West	0.1	0.2	OK
	Bore 1-2	2	North - South	East- West	0.2	0.1	OK

Potential Mapping Results

Xypex Facing West

	Measurement to Ag/AgCl (mV)															
Grid (cm)	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
0	-0.58	-40	-60	-38.3	-34	-51.5	-33	-49.6	-67.9	-33.6	-76.2	52.9	-13	39.5	13.8	30.1
20	23	1.2	-28	-43	-22	-60	4.4	0.07	-27.7	-77.1	-80.3	-91.3	-34.7	-186	2.8	39.6
40	-7.8	-44	-72	-75	-54	-28	-34	-64	-78	-105	-153	-142	-140	-77	-24	-23
60	-30	-85	-138	-240	-220	-160	-64	-4	-34	-58	-87	-196	-243	-115	-54	-7
80	-29	-92	-155	-178	-109	-20	-4	-7	-10	-47	-86	-118	-82	12	7	16
100	-16	-49	-75	-75	-23	4	29	1	22	3	-47	-32	-28	1	10	19

	Calibrated to $CuCuSo_4$ (mV)															
Grid (cm)	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
0	-0.58	-40	-60	-38.3	-34	-51.5	-33	-49.6	-67.9	-33.6	-76.2	52.9	-13	39.5	13.8	30.1
20	23	1.2	-28	-43	-22	-60	4.4	0.07	-27.7	-77.1	-80.3	-91.3	-34.7	-186	2.8	39.6
40	-7.8	-44	-72	-75	-54	-28	-34	-64	-78	-105	-153	-142	-140	-77	-24	-23
60	-30	-85	-138	-240	-220	-160	-64	-4	-34	-58	-87	-196	-243	-115	-54	-7
80	-29	-92	-155	-178	-109	-20	-4	-7	-10	-47	-86	-118	-82	12	7	16
100	-16	-49	-75	-75	-23	4	29	1	22	3	-47	-32	-28	1	10	19

RR05	**CONCRETE COVER METER SURVEY**		
Job No:	0	Date of Survey:	15/01/14
Structure:	0	Reference:	TMS 5

Structure Element	**Location**	**Test number**	**Specified Cover (mm)**	**Measurement (mm)**					
Xypex Slab	Lascelles Wharf	1	NA	70	72	70	68	64	
Xypex Slab	Lascelles Wharf	2	NA	68	64	73	76		
Xypex Slab	Lascelles Wharf	3	NA	53	62	66	53	53	53
Xypex Slab	Lascelles Wharf	4	NA	55	54				
Xypex Slab	Lascelles Wharf	5	NA	51	53				

CONCRETE CHLORIDE TESTING RESULTS

309 Date of Survey: 15/01/2014
0 Reference: TMS 9

Location	Test number	Type of sample	Depth, (mm)	Chloride, as Cl^- % w/w of cement	Average Depth	Years
Lascelles Wharf	1	0	0-20	0.540	10	19
Lascelles Wharf			20-40	0.130	30	19
Lascelles Wharf			40-60	0.050	50	19
						19
						19
						19
Lascelles Wharf	3	0	0-20	0.480	10	19
Lascelles Wharf			20-40	0.120	30	19
Lascelles Wharf			40-60	0.060	50	19
						19
						19
						19
Lascelles Wharf	4	0	0-20	0.470	10	19
Lascelles Wharf			20-40	0.180	30	19
Lascelles Wharf			40-60	0.060	50	19

APPENDIX B

PHOTOS OF SURVEY