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Phoenix House
Valepits Road
Garretts Green
Birmingham
B33 0TD
0121 303 9300
www.birmingham.gov.uk/bcl

Robin Hood's Bay Seawall, North Yorkshire

CONCRETE CONDITION SURVEY

20H/01363

for Restek UK Ltd

Birmingham
City Council

Your Ref: Q19917/PO18121

Restek UK Ltd
Restek House
Booth Street
Derbyshire
DF5 3DNA

For the attention of Mr Timothy Knight

Contents **Pages**

Our Ref: 20H/01363

Date of Report: 16th November 2020

1.0 EXECUTIVE SUMMARY

The defect survey identified some 771 individual defects. The vast majority of which can be related to damage caused by corrosion of the underlying reinforcement. The panels and parapet walls show the high incidence of defects. Given the age and exposure of the structure, the columns appear to be preforming with a lower level of patent deterioration.

The chloride levels have been found to be extremely high and have penetrated to and beyond the outer reinforcement. The degree of contamination is in-keeping with long-term exposure to a tidal marine environment. It should however be noted, that chloride ingress and diffusion will take place from all faces of the elements and not just the exposed seaward face.

Half-cell potential readings are in-keeping with the level of chloride contamination and high moisture levels within the concrete. The very negative potentials indicate a high risk of active corrosion taking place, even where patent deterioration at the surface may not be evident.

Significant corrosion, loss of section and cracking is occurring before it can be identified by a typical hammer test delamination survey. The level of corrosion damage must be considered significantly greater, than that identified by the measured defect and delamination survey, undertaken as part of this investigation.

The columns would appear to have some form of post tensioning. There is evidence to suggest that the ducts are not grouted, and water has ingressed into the duct identified during this survey.

This structure is now exhibiting significant levels of both patent and latent deterioration related to corrosion of the embedded reinforcement. There are significant areas of concrete which have spalled and a greater area of concrete which has been identified as delaminated or in the process of delamination; due to the formation of sub-surface parallel cracking at the depth of reinforcement.

This structure should now be monitored, and repairs / intervention undertaken to maintain the safety of the structure and the public. If full repairs (including corrosion control) are not undertaken, we would recommend that regular inspections are conducted to maintain the safety of the structure. These inspections should include structural assessment and make safe surveys to remove sections of concrete at risk of becoming detached.

CONCRETE CONDITION SURVEY

ROBIN HOOD'S BAY SEAWALL

2.0 INTRODUCTION

As requested, we have undertaken a concrete condition survey to Robin Hood's Bay Seawall. We understand the seawall was constructed in 1975.

The seawall structure consists of a series fifty-two reinforced concrete columns, infilled with pre-cast reinforced concrete panels. To the South end of the wall two panels atop each other to form the infill, with the centre and North end of the wall being infilled with three panels. To both the North and South flanks of the wall, the cliff face has been stabilised with a cast in-situ concrete wall. At the foot of the sea wall are a series of curved pre-cast reinforced base units. At the head of the sea wall a reinforced concrete parapet is present, this parapet runs the full length of the structure. Details of the structure are provided in the appended drawings AQI-JBAU-00-00-DR-C-0001 and AQI-JBAU-00-00-DR-C-0002, kindly supplied by the client.

These concrete testing works were conducted in order to provide technical information relating to the current condition and mechanisms for deterioration of the seawall and to assist the client in specifying suitable repair methodology.

The BCL site investigative works were conducted 31st August to 12th September 2020, the weather conditions were predominately dry and sunny, with temperatures between 17 to 21 degree centigrade.

3.0 OBJECTIVES

The objectives of the survey, as instructed by the client, are as follows.

- Undertake a full measured defect and delamination survey to the exposed reinforced concrete elements forming the sea wall; to include columns, panels, base units, parapet wall and concrete flank walls.
- Remove incremental samples from a selection of concrete elements to establish the chloride profile.
- At each chloride sampling location undertake site determinations of concrete cover to reinforcement and carbonation depths.
- Undertake half-cell potential measurements to column and panel sections.
- Remove concrete core samples from selective columns and panels for petrographic examination and to determine free lime content of the concrete using scanning electron microscopy (SEM).
- Determine pertinent dimensions at a typical column / panel junction
- Conduct a photographic log throughout the investigative works

4.0 METHODOLOGY

A full methodology of the techniques used for surveying, testing and the corrosion mechanisms related to reinforced concrete are present in the addendum of this report. The addendum is located after the appended results.

5.0 MEASURED DEFECT SURVEY RESULTS

The results of the abseil defect survey are attached as follows:

- Sketch 20H/01363-1 details the abseil drop location references and panel lines, which have been used to reference each individual defect location and number.
- Appendices 1 to 31 present the defects results in tabular format.
- Appendices 42 to 46 are photographs of examples of salient defects, all photographs are available at:

  https://drive.google.com/drive/folders/1Fx9NkQ-kLTKhz61r6N7yDQZ63u1uQvjl?usp=sharing

A total of 771 defects were noted across the area of exposed concrete surveyed and are summarised/categorised in the following table. The Excel spreadsheet of the data has been made available to the client.

Element	Total No. Defects	Spall / Delam.	Cracking	Previous Repair Good Condition	Previous Repair Failing	Rust Stain / Calcite deposit	Other
Parapet Walls	264	98	85	9	0	72	0
Panels (including flanks)	336	164	101	11	9	47	4
Columns	167	26	126	1	1	11	2
Base Units	4	3	0	0	0	1	0

Table 1: Summary of defects

6.0 CONCRETE COVER, CARBONATION & CHLORIDE ANALYSIS RESULTS

A total of 36 positions were investigated comprising; 2 parapets, 1 flank panel, 10 columns, 20 panels and 3 base unit locations. The investigation locations are shown in sketch 20H/01363-1 attached.

The chloride content of the incremental samples has been used with the determinations of concrete cover and carbonation to provide a corrosion risk assessment for each sample location, in accordance with BRE Digest 444. The chlorides have been assessed as ingressing from an external source, due to the marine environment to with the structure is exposed.

6.0 CONCRETE COVER, CARBONATION & CHLORIDE ANALYSIS RESULTS

The site test and analysis results are presented in appendices 32 to 41. A summary of concrete cover to reinforcement, carbonation depths and chloride results are presented below in Table 1.

Element	Concrete Cover (mm)			Carbonation (mm)			Chloride Levels (all increments)		
	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
Parapet	14	60	40	4	5	4.5	2.79%	3.71%	3.18%
	Areas where concrete cover is less than 20mm = 1 (50%)			Areas where reinforcement is located within carbonated concrete = 0 (0%)			2 extremely high corrosion risk areas		
Flank Wall	64	78	72	1	1	1	1.71%	2.29%	1.95%
	Areas where concrete cover is less than 20mm = 5 (83%)			Areas where reinforcement is located within carbonated concrete = 0			1 extremely high corrosion risk area		
Columns (Upper)	41	68	51	1	3	2	0.36%	1.36%	0.76%
	Areas where concrete cover is less than 20mm = 0 (0%)			Areas where reinforcement is located within carbonated concrete = 0 (0%)			2 high, 2 moderate and 1 low corrosion risk area		
Columns (Lower)	38	62	49	1	20	8	0.36%	4.21%	1.45%
	Areas where concrete cover is less than 20mm = 0 (0%)			Areas where reinforcement is located within carbonated concrete = 0 (0%)			2 extremely high, 2 high and 1 moderate corrosion risk area		
Panels (level 3)	50	79	67	1	4	2	0.71%	2.36%	1.49%
	Areas where concrete cover is less than 20mm = 0 (0%)			Areas where reinforcement is located within carbonated concrete = 0 (0%)			2 extremely high and 2 high corrosion risk areas		
Panels (level 2)	37	85	67	1	3	2	0.86%	2.14%	1.08%
	Areas where concrete cover is less than 20mm = 0 (0%)			Areas where reinforcement is located within carbonated concrete = 0 (0%)			8 high corrosion risk areas		
Panels (level 1)	43	79	68	1	3	2	0.93%	4.29%	2.66%
	Areas where concrete cover is less than 20mm = 0 (0%)			Areas where reinforcement is located within carbonated concrete = 0 (0%)			5 extremely high and 3 high corrosion risk areas		
Base Units	51	67	57	1	1	1	1.43%	5.71%	2.70%
	Areas where concrete cover is less than 20mm = 0			Areas where reinforcement is located within carbonated concrete = 0 (0%)			1 extremely high & 2 high corrosion risk areas		

Table 2: Summary of concrete cover to reinforcement, carbonation depths, and chloride results

7.0 HALF CELL POTENTIAL SURVEY RESULTS

As shown in sketch 20H/01363-2, four column and four panel areas were subjected to half-cell potential surveying. The results of the half-cell potential survey are presented in sketches 20H/01363-3 to 6. Also attached is the electronic Profometer Link ".pqm" half-cell potential scan file titled "20H_01362_HC".

7.0 HALF CELL POTENTIAL SURVEY RESULTS (CONTINUED)

The Windows based Proceq software will need to be downloaded in order to open, edit and analyse the half-cell potential results. Software can be download from the following web site:

http://www.proceq.com/en/site/downloads/

From the attached results, the following overall summary is obtained.

Element	Sketch	Least Negative	Mean	Most Negative
Column 10 (level 1)	20H/01363 - 3	21	-245	-1000 Note 1
Panel 11 (level 1)	20H/01363 - 3	189	-450	-1000 Note 1
Panel 28 (level 2)	20H/01363 - 4	-492	-550	-629
Column 28 (level 2)	20H/01363 - 4	-199	-439	-518
Panel 36 (level 2)	20H/01363 - 5	-442	-561	-666
Column 36 (level 2)	20H/01363 - 5	-489	-547	-670
Column 49 (level 1)	20H/01363 - 6	-412	-518	-634
Column 50 (level 1)	20H/01363 - 6	-566	-645	-723

Table 3: Half-cell survey results summary

Note 1: the potential records of -1000mV appear to be very localised interference or an equipment signal issue

From the Profometer software, the results obtained can be transposed into the percentage of each area affected by different levels of likely corrosion, refer to Table 4 below.

7.0 HALF CELL POTENTIAL SURVEY RESULTS (CONTINUED)

Corrosion Risk Expressed as Percentage of Scan Area				
Element	**Sketch/Plot**	**More Positive than -200 mV Low Corrosion Risk**	**-200 to -350 mV Uncertain Corrosion Risk**	**More Negative than -350 mV High Corrosion Risk**
Column 10 (level 1)	20H/01363 - 3	60%	11%	29%
Panel 11 (level 1)	20H/01363 - 3	17%	12%	71%
Panel 28 (level 2)	20H/01363 - 4	0	0	100%
Column 28 (level 2)	20H/01363 - 4	0	0	100%
Panel 36 (level 2)	20H/01363 - 5	0	0	100%
Column 36 (level 2)	20H/01363 - 5	0	0	100%
Column 49 (level 1)	20H/01332 - 6	0	0	100%
Column 50 (level 1)	20H/01363 - 6	0	0	100%

Table 4: Differing corrosion risks affecting each area

8.0 PETROGRAPHIC EXAMINATION RESULTS

Five cores where removed from the reinforced concrete elements; two cores from panels, two cores from columns and one core from the parapet. The cores were petrographically examined to determine the general quality of the concrete, stability of the aggregates and to identify any latent mechanisms for deterioration. At the request of the client, samples from the cores have also been examined using scanning electron microscopy to determine the extent of free lime remaining in the concrete binder. Core locations are shown on the appended sketch 20H/01363-1.

The full results of the petrographic examination and testing to demine free lime are presented in the appended report, Reference 68316/K.

8.0 PETROGRAPHIC EXAMINATION RESULTS (CONTINUED)

Details of the cores examined are as follows:

GMRS Ref.	Client / site reference	Core diameter / length
K16151/1	**Core 1**, Column 17 - full thickness of front "flange" (high level)	70mm / 311-325mm
K16151/2	**Core 2**, Column 16 - part thickness (tidal zone)	70mm / 149-159mm
K16151/3	**Core 3**, Panel 21 - full thickness (high level)	70mm / 294-211mm
K16151/4	**Core 4**, Panel 11 - full thickness (tidal zone)	70mm / 278-291mm
K16151/5	**Core 5**, Parapet 11 - full thickness with concrete infill behind (base of seaward face 150mm above joint with top panel)	70mm / 206-210mm

A summary of the findings are as follows:

I. The coarse aggregate in the column cores is composed of flint gravel, with the fine aggregate been a mixture of siliceous medium sand and crushed flint.

II. The coarse aggregates in the panel and parapet samples consist entirely of crushed basalt. The fine aggrege consists of a mixture of siliceous fine to medium sand mainly of quartz and crushed basalt. The sand contains a wide range of rock types including shells, which suggests a marine origin, such marine sourced aggregates can be a potential source of chloride contamination.

III. The aggregates in all samples are potentially reactive with alkalis in the cement paste, however there is no evidence in the cores of alkali aggregate reaction (AAR).

IV. The binder in all samples is based on Ordinary Portland Cement (OPC). The water: cement ratio of all samples was found to be in the range of 0.45 to 0.50.

V. There is little evidence that the samples have been altered or weekend by moisture movement and the alteration of the paste is low.

VI. Four of the core (2, 3, 4, & 5) contained reinforcement. None of the cores were taken from areas which showed patent evidence of deterioration or delamination.
   a) Core 2, from a column within the tidal zone showed a bar a 50mm depth which had severely corroded. At bar depth, there are an abundance of sub-surface parallel cracks.
   b) Core 3, from a panel at high level showed a bar present at a depth of 81mm which showed surface corrosion and minimal loss of section.
   c) Core 4, removed from a panel within the tidal zone, shows reinforcement at 97mm depth, which has suffered severe corrosion and loss of section. There are sub-surface parallel cracks at the bar depth, filled with corrosion product.

8.0 PETROGRAPHIC EXAMINATION RESULTS (CONTINUED)

d) Core 5, removed from the parapet wall, showed reinforcement at 80mm, 134mm and 150mm. There is no evidence of significant corrosion of the bar at 80mm from outer surface, however the bars located to the rear of the wall have undergone moderate corrosion and loss of section. The rear of the parapet wall, at the location cored, abuts loose infill concrete beneath the mosaic walkway. High chloride levels could be expected to exist within the infill material.

e) The binder around of the corroding reinforcement showed elevated chloride levels when analysed using the SEM. This concurs with the results of the samples removed for analysis which showed high levels of chlorides have penetrated deeply into the concrete.

f) No free lime was detected in the cover concrete of three samples analysed by SEM.

GMRS Ref.	Client sample reference	Level of deterioration
K16151/1	Core 1, Column - High level	Level 2
K16151/2	Core 2, Column - Tidal zone	Level 4 Note 1
K16151/3	Core 3, Panel - High level	Level 2
K16151/4	Core 4, Panel - Tidal zone	Level 4 Note 1
K16151/5	Core 5, Parapet - Base of seaward face	Level 2

Note 1: The deterioration is localised to the corroded reinforcement where localised cracking has developed as a result of reinforcement corrosion. It should however be noted that the concrete distant from the corroded reinforcement is at Level 2.

9.0 PANEL / COLUMN DIMENSIONS

The typical dimensions and details of the column sections are shown on the appended sketch 20H/01363-7.

During our survey it was noted that where one of the columns, adjacent to where the South end of the seawall is exposed, there appears to be a grouted socket in the top of the column, reminiscent of a post tensioning anchorage point. Also, whilst performing a breakout to inspect reinforcement within one of the columns, a metal sleeve / duct was encountered. This duct was locally penetrated and was found to be filled with water, which was expelled under pressure through the hole formed. The duct / sleeve was found to contain a tendon. Given the marine environment and the fact that the ducts are not grouted, but full of water, the condition of the possible post tensioning system installed in the columns should be fully investigated.

10.0 CONCLUSIONS

I. The concrete used in the construction of the seawall is of good quality, with both the aggregates and binder showing no signs of significant deterioration or alteration. The columns have been manufactured from a different concrete from the panels and parapet wall. The fine aggregate within the panel and parapet concretes was found to be potentially from a marine source and hence may have been contaminated with chlorides. The column concrete shows a lower level of porosity and would be expected to be the more robust of the two concretes.

II. The defect survey identified some 771 individual defects. The vast majority of which can be related to damage caused by corrosion of the underlying reinforcement. The panels and parapet walls show the highest incidence of defects. Given the age and exposure of the structure, the columns appear to be preforming well, with a lower level of patent deterioration. There are many instances of calcite staining and build-up of drip stone, this suggests that water is moving through the concrete structure from behind or above the wall.

III. The concrete columns and panels have been well manufactured with reinforcement provided with very good concrete cover. The design of the columns and panels has taken into consideration the exposure conditions. The parapet wall does show concrete cover as low as 14mm at the areas surveyed, however the mean cover was found to be circa 40mm at the locations surveyed.

IV. Carbonation of the concrete was found to be very low and at no position has the carbonation depth reached the depth of reinforcement and cause de-passivation of the steel. The low carbonation depths are a result of both the quality of the concrete and more so the high moisture levels to which the structure is consistently exposed. The petrographic examination of the samples also indicated that the binder around embedded bars to be un-carbonated; hence corrosion of the bars is related to elevated chloride levels.

V. The chloride levels have been found to be extremely high and have penetrated to and beyond the outer reinforcement. The degree of contamination is in-keeping with long-term exposure to a tidal marine environment. It should be noted, that chloride ingress and diffusion will take place from all faces of the elements and not just the exposed seaward face. The Northern end of the structure would appear to be subject to the greatest tidal range.

VI. Half-cell potential readings are in-keeping with the level of chloride contamination and high moisture levels within the concrete. The very negative potentials indicate a high risk of active corrosion taking place, even where patent deterioration at the surface may not be evident. Where very high moisture levels persist towards the base of the wall, corrosion is likely to be somewhat restrained due to low oxygen levels. Areas of the wall which show significant chloride contamination, cyclic wetting and drying and lower concrete cover to reinforcement are at most risk of damage related to chloride induced corrosion.

10.0 CONCLUSIONS (CONTINUED)

VII. Cores removed from the columns, panels and parapet wall show that corrosion, loss of section and sub-surface parallel cracking is occurring at reinforcement located deep within the sections. The locations cored showed no patent evidence of delamination or spalling. It must therefore be considered that significant corrosion, loss of section and cracking is occurring before it can be identified by a typical hammer test delamination survey. The level of corrosion damage must be considered as significantly greater than identified by the measured defect and delamination survey undertaken as part of this investigation.

VIII. The columns would appear to have some form of post tensioning. There is evidence to suggest that the ducts are not grouted, and water has ingressed into the duct identified during this survey.

11.0 RECOMMENDATIONS

Protection or repair of reinforced concrete elements should be designed and undertaken in accordance with BS EN 1504, Products and systems for the protection and repair of concrete structures.

This structure is now exhibiting significant levels of both patent and latent deterioration related to corrosion of the embedded reinforcement. There are significant areas of concrete which have spalled and a greater area of concrete which has been identified as delaminated or in the process of delamination due to the formation of sub-surface parallel cracking at the depth of reinforcement. We would recommend additional testing to more fully understand the extent of the sub-surface parallel cracking.

As such, this structure should now be monitored, and repairs / intervention undertaken to maintain the safety of the structure and the public. If full repairs (including corrosion control) are not undertaken, we would recommend that regular inspections are conducted to maintain the safety of the structure. These inspections should include structural assessment and make safe surveys to remove sections of concrete at risk of becoming detached.

Although not directly part of this survey, it has been identified that the columns could well be post-tensioned. We would recommend that this confirmed, the condition of post-tensioning assessed and understood as part of any remedial works.

The repair of this structure will very much depend on the service life extension which is required by the client. Given the levels of chlorides identified, the only long-term option to afford corrosion control, would be the installation of a fully impressed cathodic protection system. Even with the installation of such a system, there will be the necessity to undertake substantial repair / replacement of areas which currently show significant damage.

11.0 RECOMMENDATIONS (CONTINUED)

The design of the electrochemical protection system should be undertaken by a Corrosion Engineer holding Level 4 cathodic protection certification (steel in concrete) and professional membership of the Institute of Corrosion (MICorr / FICorr). Cathodic protection systems (fully impressed and galvanic) should be designed, installed and monitored in accordance with BS EN ISO 15257:2017.

If a short-term service life is required (5 to 10 years) repairs could be limited to palliative making safe repairs. Such repairs should follow the following principals of BS EN 1504.

Where repairs are required to re-establish cover or repair sections of failed concrete, patch repairs can be undertaken in accordance with Principal 7 of BS EN 1504: Preserving or Restoring Passivity. These repairs should be undertaken using a proprietary R4 repair mortar.

To curtail further chloride ingress (where appropriate) consideration could be given to Principal 6 of BS EN 1504 – Increasing Resistance to Chemicals. This can be achieved by the application of a suitable coating. The application of such a coating could also be used to increase resistivity of the concrete above the tidal zone in accordance with Principal 8 of BS EN 1504. However, if should be noted that moisture and chloride ingress will be occurring from behind the wall as well as the seaward face. This will have to be considered as part of any repair design.

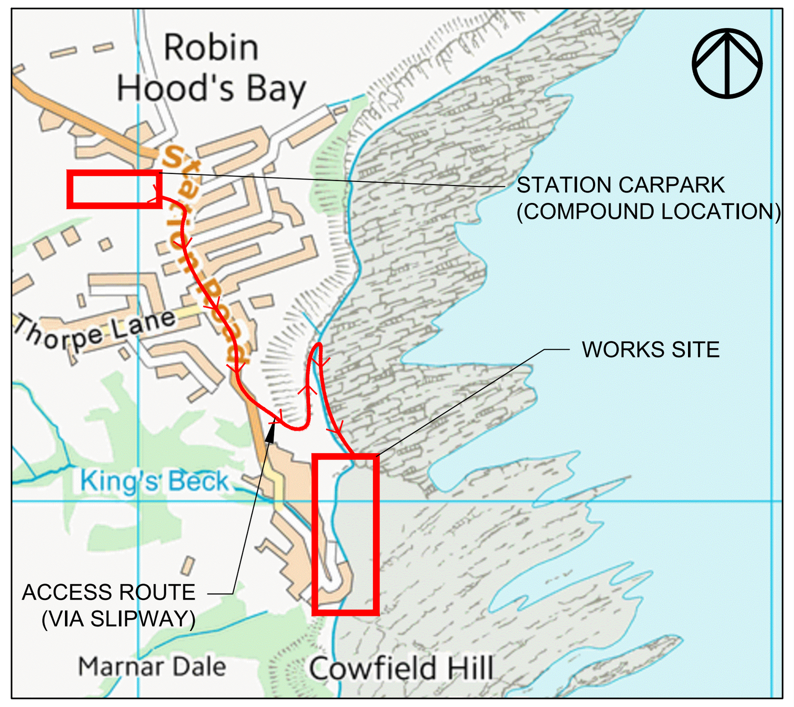
Significant chloride levels have been found to have penetrated deeply into the structure. As such, consideration will have to be given to localised corrosion control around any patch repairs undertaken to prevent incipient anode formation. This protection should be considered in accordance with Principal 10; Cathodic protection (Galvanic or Impressed Current). Galvanic systems are normally most appropriate to officer protection to localised repairs. However, given the levels of chlorides identified and environment; the service life of the installed galvanic anodes may be limited and should be considered as part of the repair design.

Where corrosion damage is extensive, it may prove to be more cost effective to replace or recast sections of certain elements, this may be appropriate for sections of the parapet wall and certain severely damaged panels.

We trust this report is to your satisfaction. If you require any further assistance, please do not hesitate to make further contact.

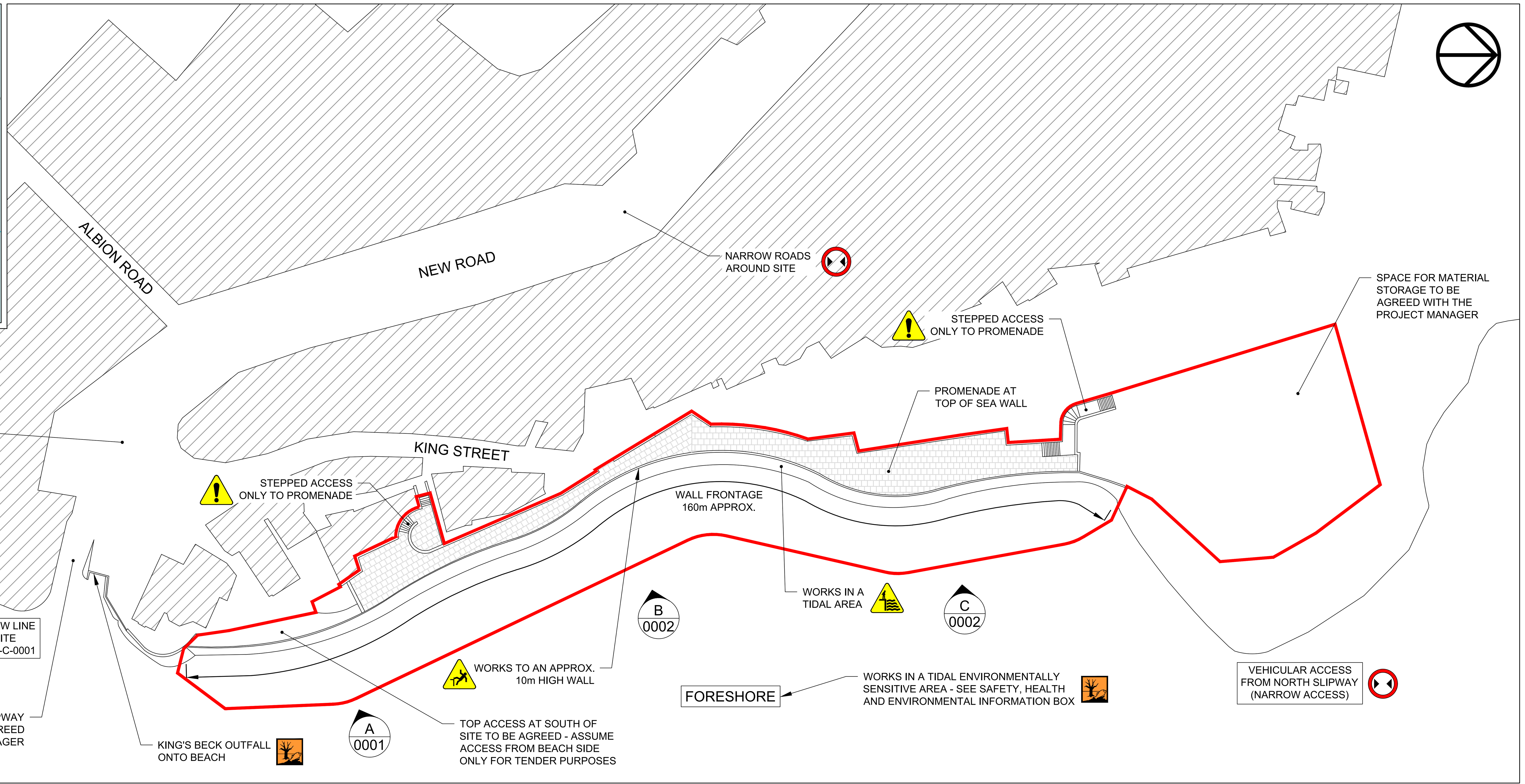
On behalf of:
BIRMINGHAM CITY LABORATORIES

Prepared by:	**Verified by:**
JP Walsh	
JOHN WALSH **Senior Engineer**	**TREVOR BOX** **Principal Engineer**



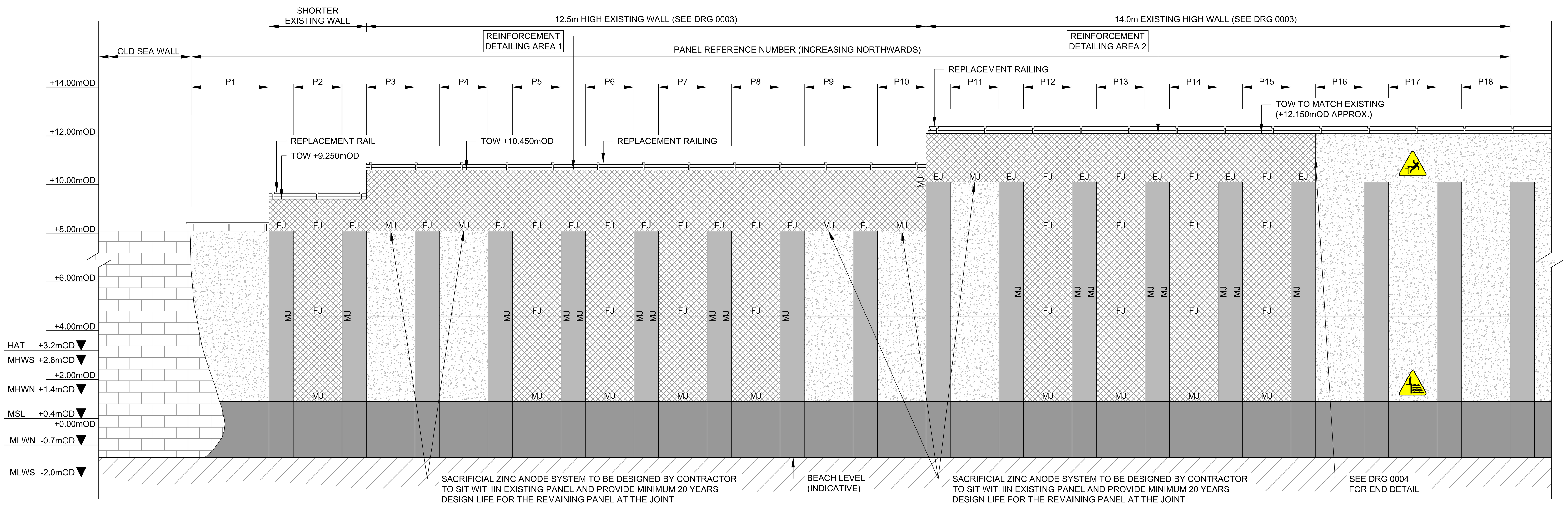
LOCATION PLAN

scale 1:10 000



SITE PLAN AND CONSTRAINTS

scale 1:500 (approx.)



REPLACEMENT LOCATIONS
LONG ELEVATION A

scale 1:100 (approx.)

Construction Risks	Public Risks	Environmental Risks
• Working at height • Working in a tidal environment • Plant / people interface • Access with limited width • Services in locality	• Site in the public realm • Public beach	• Works above / in a tidal environment • Works within a SSSI (Maw Wyke to Beast Cliff)

In addition to the hazards/risks normally associated with the types of work detailed on this drawing take note of the above.
It is assumed that all works detailed on this drawing will be carried out by a competent contractor working, where appropriate, to an appropriate method statement.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

Drawing Notes

1. All dimensions are shown in millimetres unless otherwise stated and levels are in metres to Ordnance Datum
2. Do not scale from the drawings. Dimensions require checking / verification on site.
3. Location of repairs to be confirmed on site by supervisor.
4. Information on existing arrangement taken from record drawings produced by John H. Haiste & Partners.
5. Existing level information taken from point cloud survey undertaken by Academy Geomatics - BIM reference AQI-AG-00-00-SU-C-0001.
6. No services identified within site boundary from desktop utility search (BIM reference AQI-CBS-00-00-SU-C-0001). However, the Contractor shall fully satisfy himself of the location of all relevant services prior to undertaking the Works and take suitable action for their protection, including along access routes.
7. Contains Ordnance Survey data © Crown copyright and database right 2019.
8. Tide levels shown from Whitby secondary port tide information.

Legend

- Site boundary (plan view)
- Access route (location plan)
- Buildings (plan view)
- Promenade (plan view)
- Reinforced panel or parapet to be retained
- Reinforced panel or parapet included in works (see drawings 0003 & 0004 for details)
- Precast concrete columns (to be retained)
- Curved reinforced concrete base units (to be retained)
- TOW Top of wall
- FJ False joint (see drawing 0004)
- EJ Expansion joint (see drawing 0004)
- MJ Movement joint (see drawing 0004)

Rev.	Comments	Date	Drawn	Designed	Checked	Approved
P02	Minor revisions for tender issue	05.07.19	DP	DP	AT	GK

Client Approval
A - Approved
B - Approved with Revisions
C - Do Not Use

Purpose of Issue: For tender
Status: D2

JBA consulting
35 Perrymount Road
HAYWARDS HEATH
West Sussex
RH16 3BW
United Kingdom
www.jbaconsulting.com
t +44 (0)1444 473652
f +44 (0)845 8627772
e info@jbaconsulting.com
Offices at Coleshill, Doncaster, Dublin, Edinburgh, Exeter, Haywards Heath, Limerick, Newcastle upon Tyne, Newport, Saltaire, Skipton, Tadcaster, Thirsk, Wallingford and Warrington

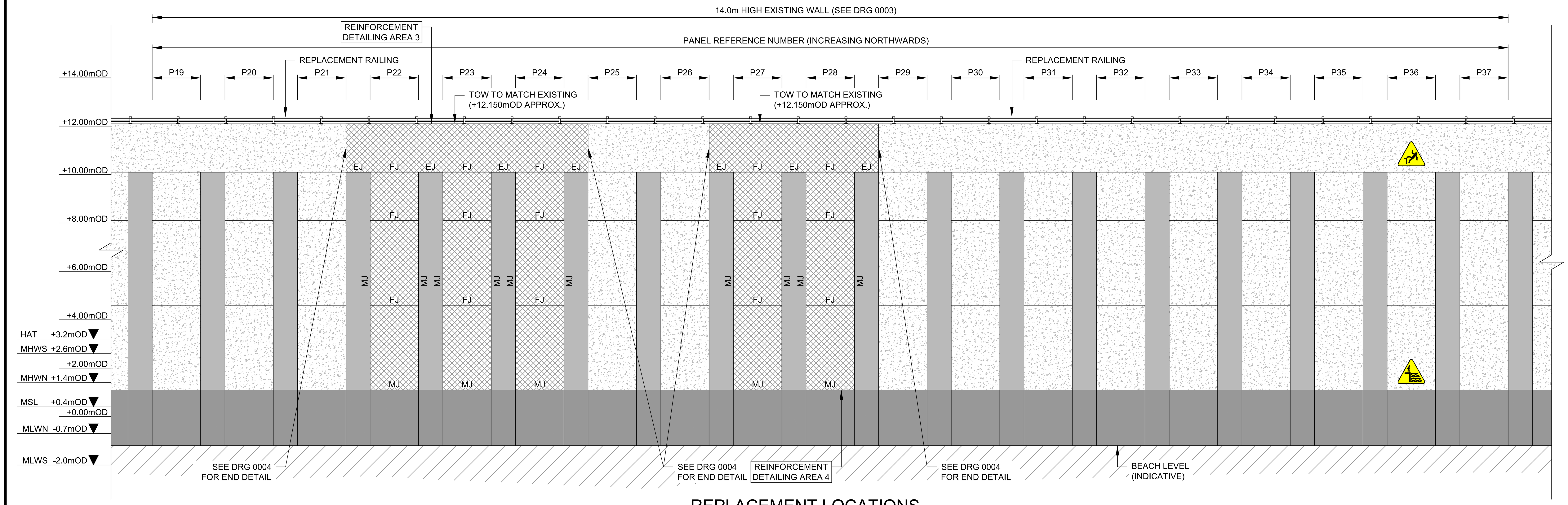
ROBIN HOOD'S BAY SEAWALL MAINTENANCE WORKS

SITE PLAN AND
WALL PANEL & PARAPET
REPAIR LOCATIONS (SHEET 1 OF 2)
for
Whitby Scarborough Borough of Scarborough

Scale:		
AS SHOWN AT A1	Drawn: G. West	12.04.19
	Designed: D. Potts	12.04.19
	Checked: A. Tyndel	12.04.19
	Approved: G. Kenn	12.04.19

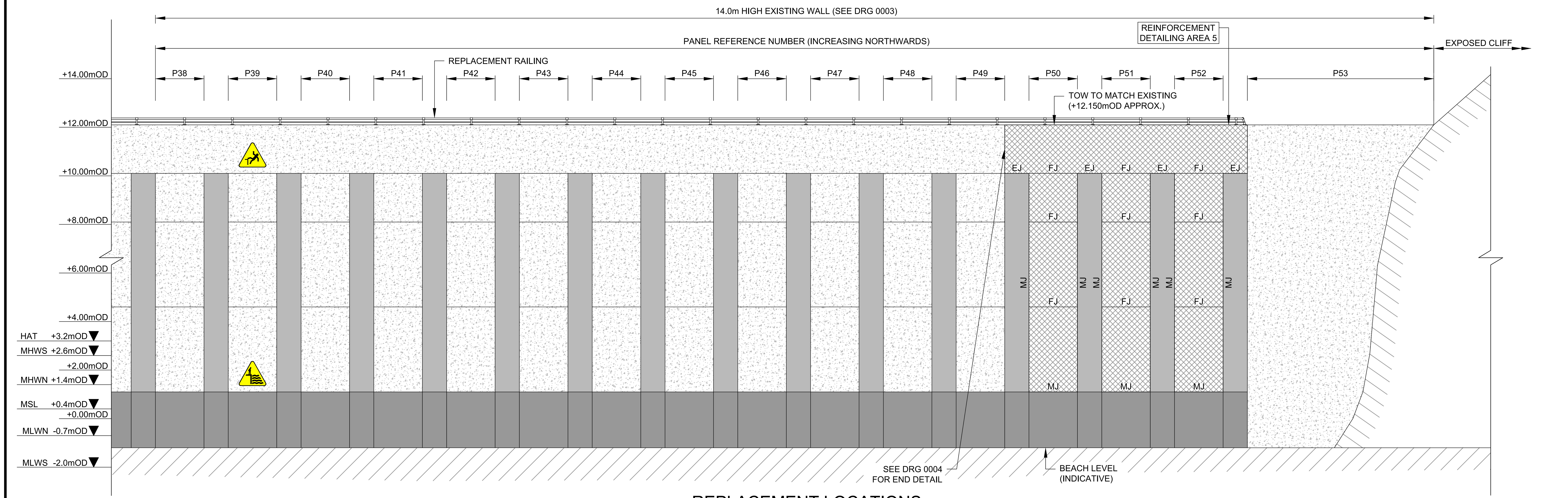
Digital File Name: aqi-jbau-00-00-dr-c.dwg

Drawing Number: AQI-JBAU-00-00-DR-C-0001
Revision: P02



REPLACEMENT LOCATIONS
LONG ELEVATION B

scale 1:100 (approx.)



REPLACEMENT LOCATIONS
LONG ELEVATION C

scale 1:100 (approx.)

Construction Risks	Public Risks	Environmental Risks
• Working at height • Working in a tidal environment • Services in locality	• Public beach	• Works above / in a tidal environment • Works within a SSSI (Maw Wyke to Beast Cliff)

In addition to the hazards/risks normally associated with the types of work detailed on this drawing take note of the above.
It is assumed that all works detailed on this drawing will be carried out by a competent contractor working, where appropriate, to an appropriate method statement.

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

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7. Tide levels shown from Whitby secondary port tide information.

Legend

- Reinforced panel or parapet to be retained
- Reinforced panel or parapet included in works (see drawings 0003 & 0004 for details)
- Precast concrete columns (to be retained)
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- FJ False joint (see drawing 0004)
- EJ Expansion joint (see drawing 0004)
- MJ Movement joint (see drawing 0004)

Rev.:	Comments									
Rev.:	Date		Drawn		Designed		Checked		Approved	
Rev.:	Date		Drawn		Designed		Checked		Approved	
Rev.:	Date		Drawn		Designed		Checked		Approved	
Rev.:	Date		Drawn		Designed		Checked		Approved	
P02	Minor updates for tender issue									
Rev.:	Date	05.07.19	Drawn	DP	Designed	DP	Checked	AT	Approved	GK

Client Approval
- A - Approved
- B - Approved with Revisions
- C - Do Not Use

Purpose of Issue	Status
For tender	D2

JBA consulting
35 Perrymount Road
HAYWARDS HEATH
West Sussex
RH16 3BW
United Kingdom
www.jbaconsulting.com
t +44 (0)1444 473652
f +44 (0)845 8627772
e info@jbaconsulting.com
Offices at Coleshill, Doncaster, Dublin, Edinburgh, Exeter, Haywards Heath, Limerick, Newcastle upon Tyne, Newport, Saltaire, Skipton, Tadcaster, Thirsk, Wallingford and Warrington

ROBIN HOOD'S BAY SEAWALL MAINTENANCE WORKS

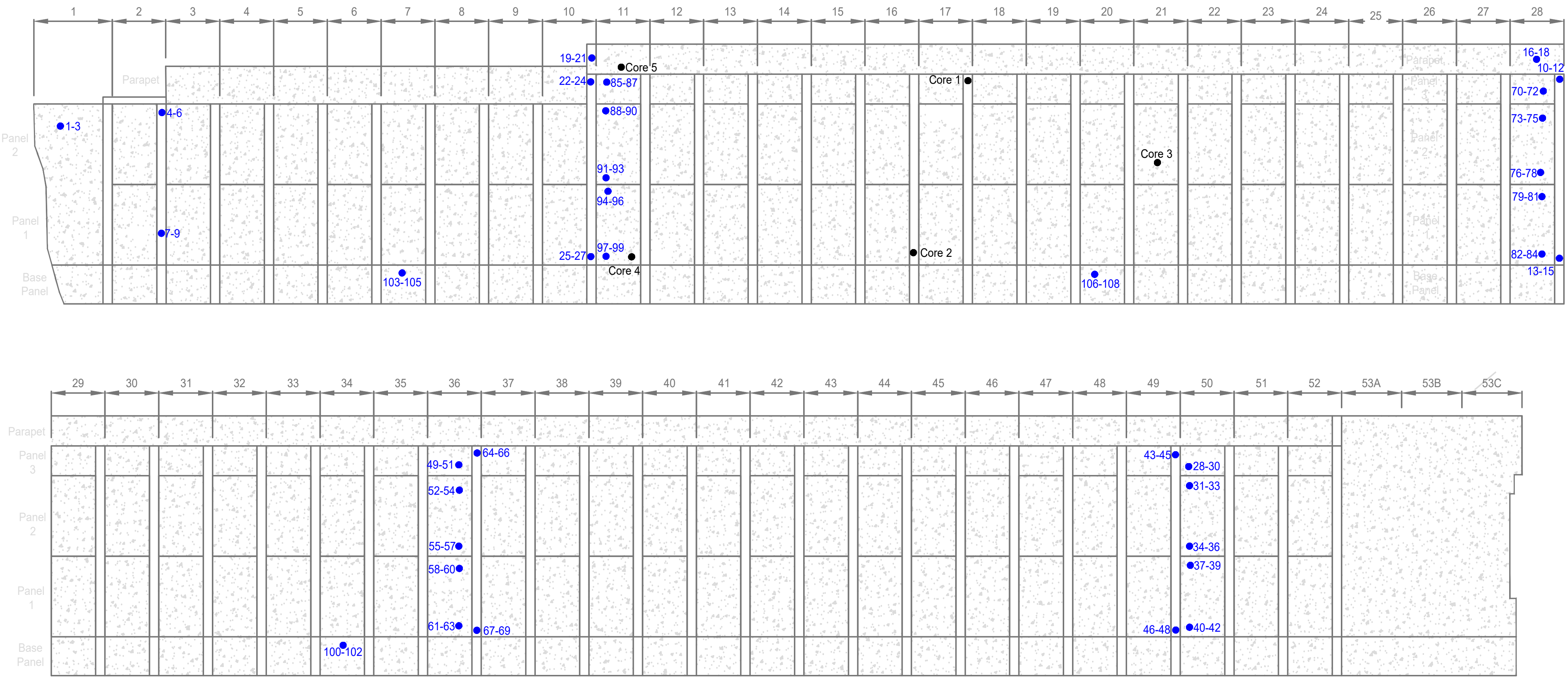
WALL PANEL
& PARAPET REPAIR
LOCATIONS (SHEET 2 OF 2)
for

Scale:			
AS SHOWN AT A1	Drawn:	G. West	12.04.19
	Designed:	D. Potts	12.04.19
	Checked:	A. Tyndel	12.04.19
	Approved:	G. Kenn	12.04.19

Digital File Name: aqi-jbau-00-00-dr-c.dwg

Drawing Number: AQI-JBAU-00-00-DR-C-0002

Revision: P02



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Project: **ROBIN HOODS BAY DEFENCE WALL**
Defect And Structural Survey
Sample Positions

Birmingham City Laboratories
Since 1910

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Job No:	20H/01363
Drawing No:	20H/01363 - 1
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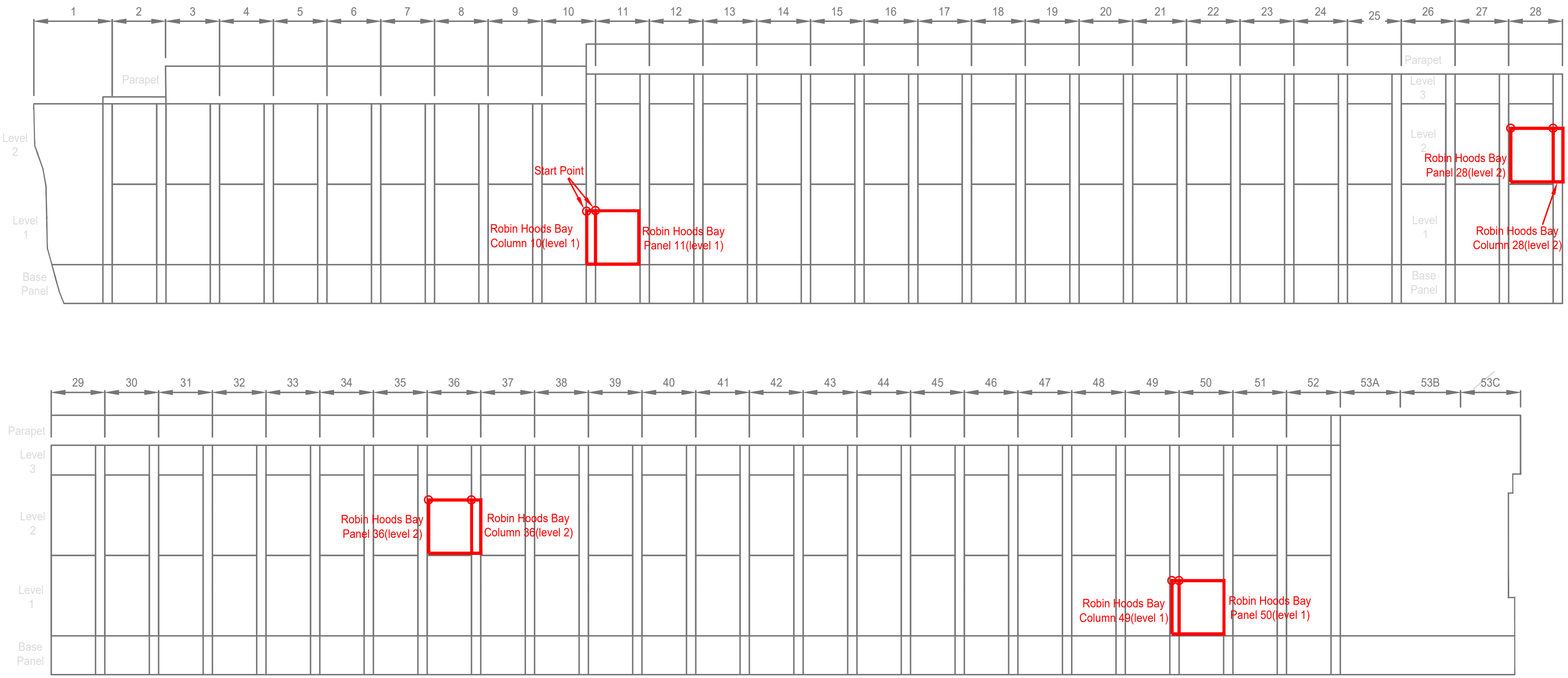

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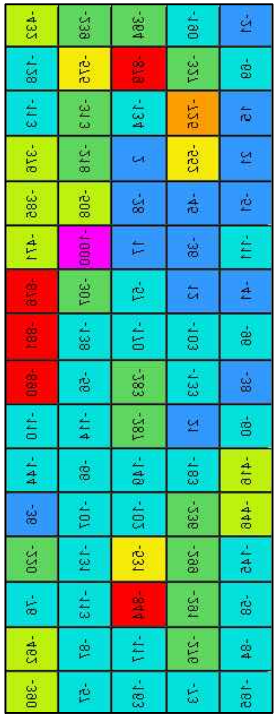
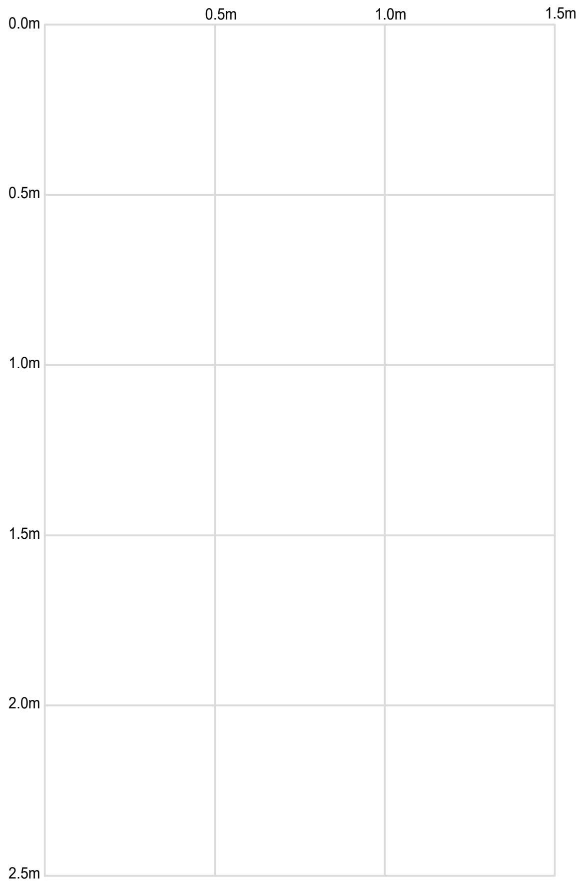
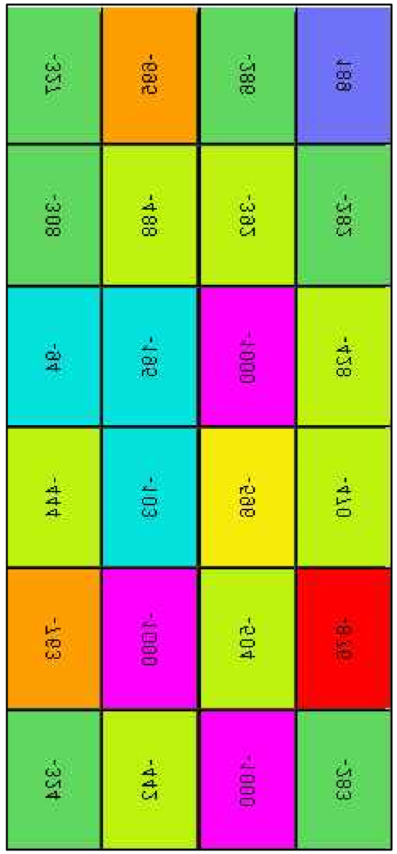
Robin Hoods Bay
Column 10 (level 1)



Robin Hoods Bay
Column 10(level 1)



Robin Hoods Bay
Panel 11(level 1)



Robin Hoods Bay
Panel 11(level 1)

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Project: ROBIN HOODS BAY DEFENCE WALL
Defect And Structural Survey
Half-Cell Plots

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Drawing No:	20H/01363 - 3
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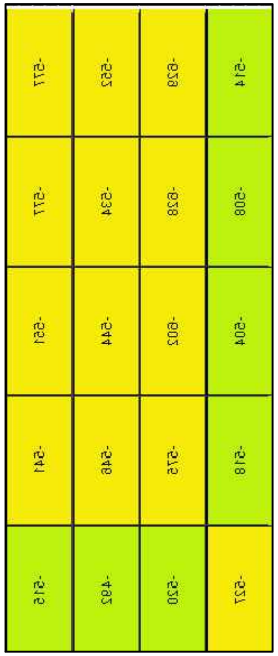
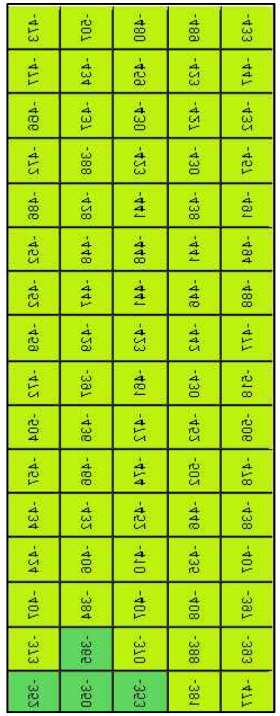
Robin Hoods Bay
Panel 28(level 2)



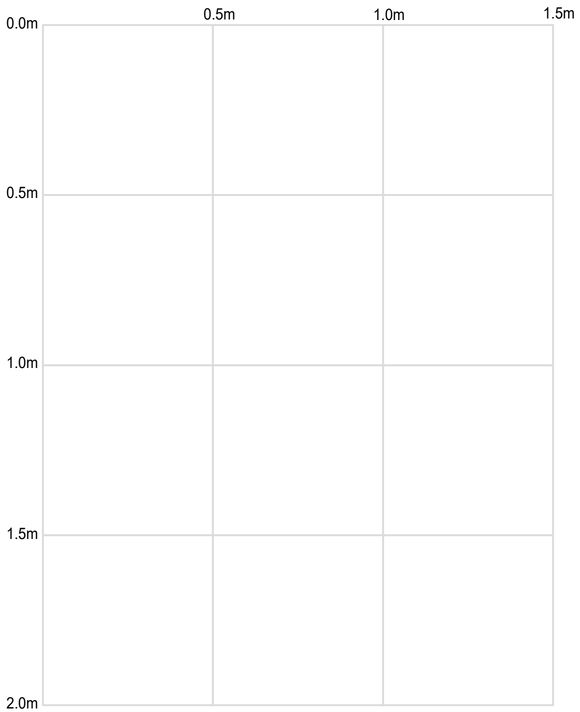
Robin Hoods Bay
Panel 28(level 2)

Robin Hoods Bay
Column 28(level 2)

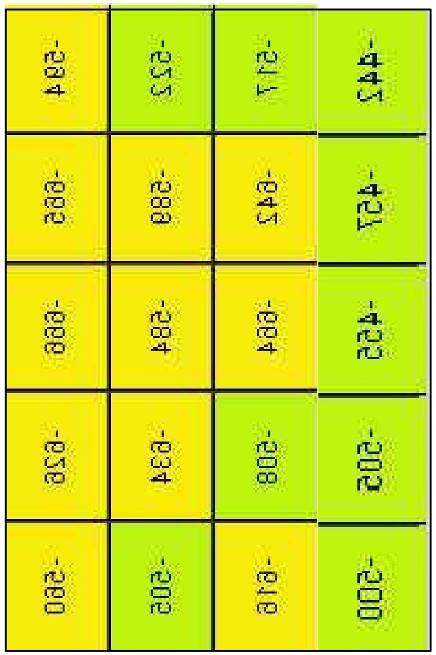


Robin Hoods Bay
Column 28(level 2)

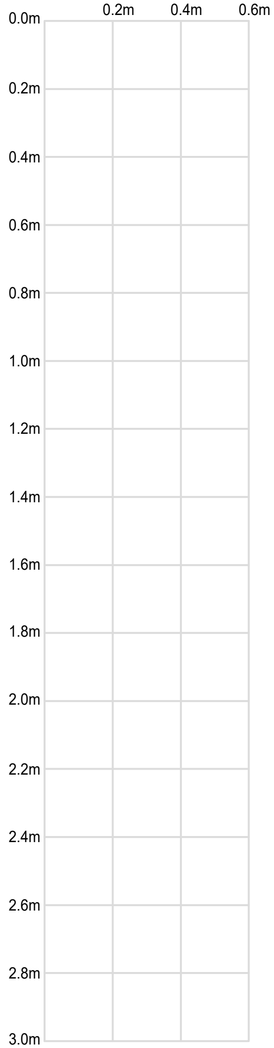
BIRMINGHAM CITY LABORATORIES Valepits Road Garretts Green B33 0TD Telephone: 0121 303 9300 Facsimile: 0121 303 9301 http://www.bcl-testing.co.uk	**Project:** ROBIN HOODS BAY DEFENCE WALL Defect And Structural Survey Half-Cell Plots Birmingham City Laboratories Since 1910	**RESTEK** RESTEK UK Ltd Restek House Booth Street Ripley Derbyshire. DE5 3DN.	Drawn by: MC Job No: 20H/01363 Drawing No: 20H/01363 - 4 NOT DRAWN TO SCALE



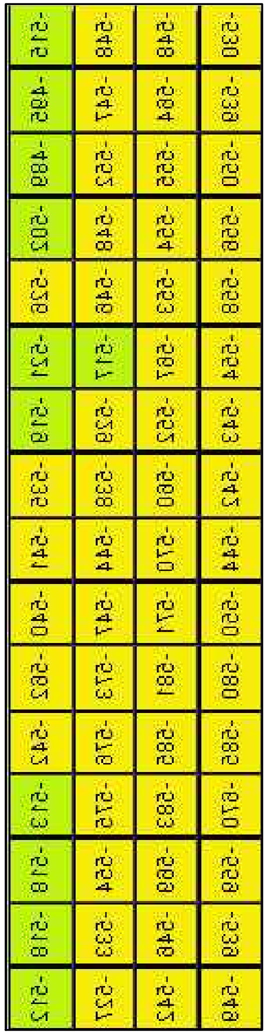
Robin Hoods Bay
Panel 36(level 2)



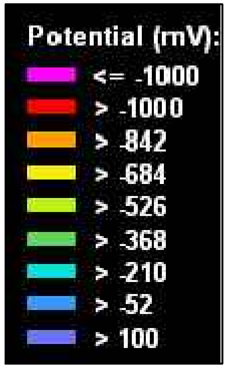
Robin Hoods Bay
Panel 36(level 2)



Robin Hoods Bay
Column 36(level 2)



Robin Hoods Bay
Column 36(level 2)



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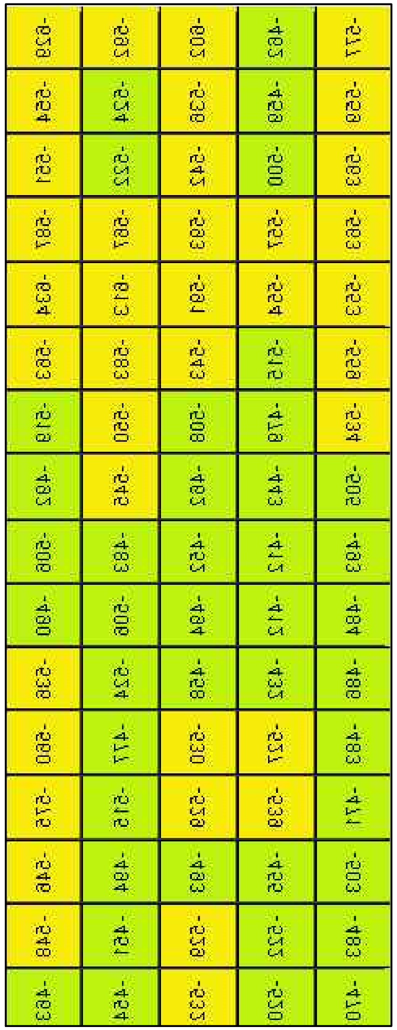
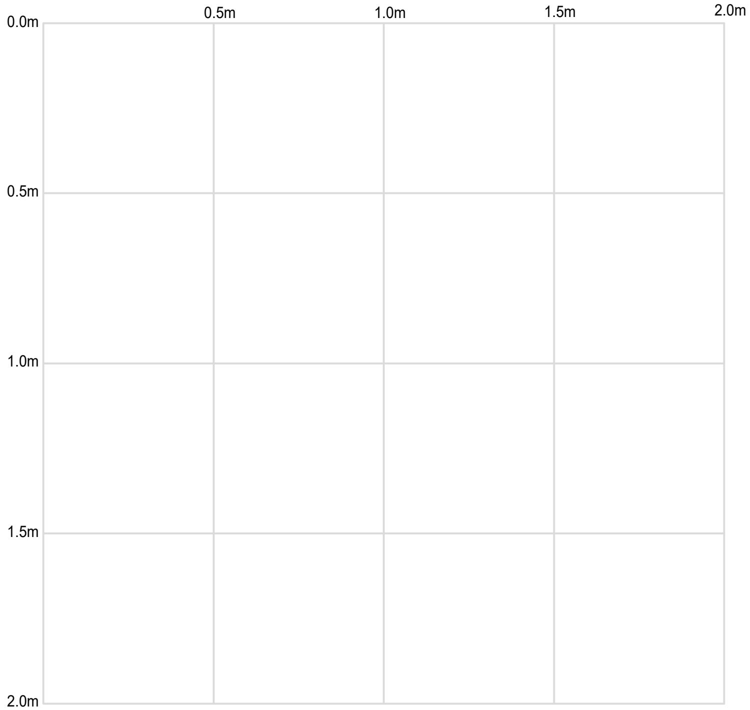
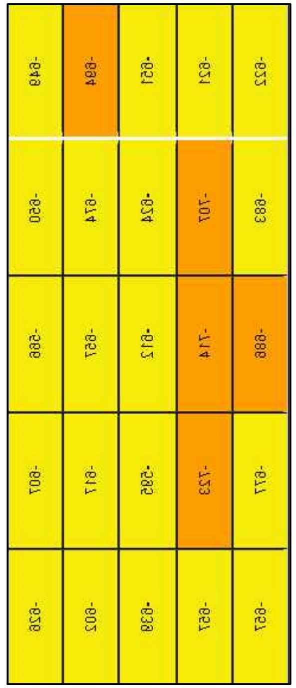
Robin Hoods Bay
Column 49(level 1)



Robin Hoods Bay
Column 49(level 1)



Robin Hoods Bay
Panel 50(level 1)



Robin Hoods Bay
Panel 50(level 1)

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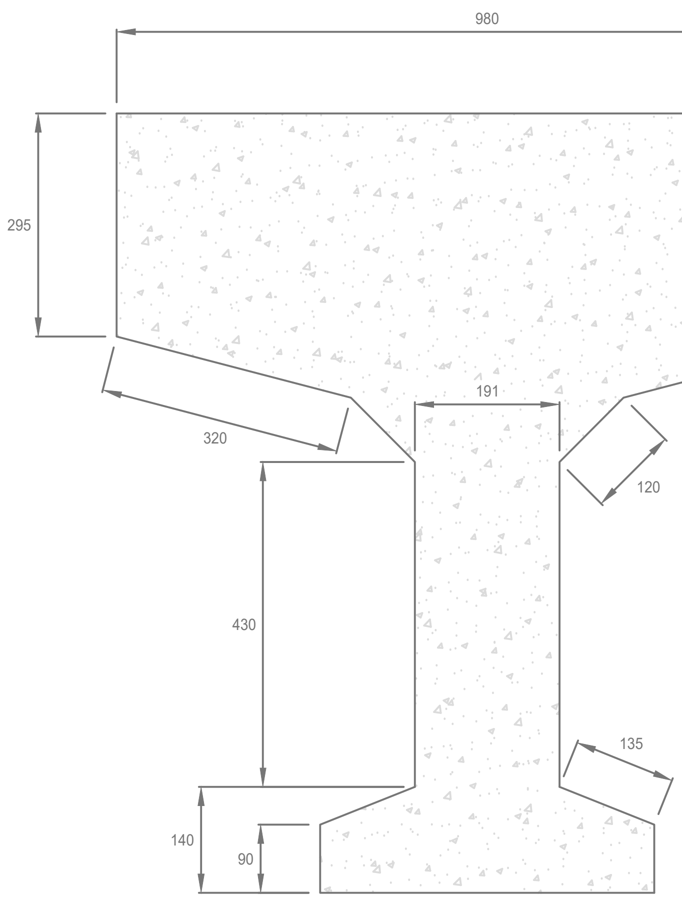
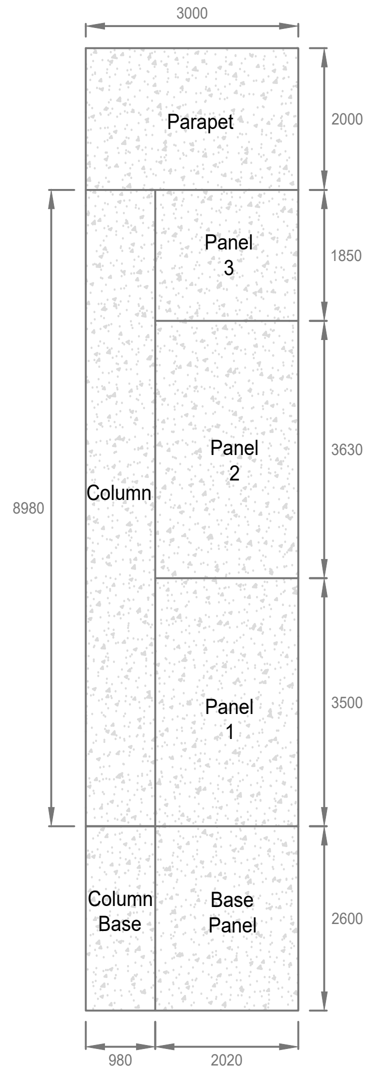


COLUMN DETAIL



WALL PANEL DETAIL

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Project: **ROBIN HOODS BAY DEFENCE WALL**
Defect And Structural Survey
Column And Wall Panel Detail

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APPENDIX 1 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
1-1	Parapet	Top Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2450	3			
1-2	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack With Rust Stain			650	1			
1-3	Parapet	Top Right Hand Side	Parapet	Concrete	Multi Directional Cracking			350	400		1	
1-4	2	Centre	Column	Concrete	Multi Directional Cracking			1000	1500		1	
1-5	2	Bottom Left Hand Corner	Column	Concrete	Delamination		Yes	400	500	30	30	
1-6	2	Bottom Centre	Column	Concrete	Horizontal Crack			1000	1			
1-7	1	Centre	Panel	Concrete	Multi Directional Cracking With Rust Stain			2200	150		1	
1-8	1	Top Centre	Column	Concrete	Horizontal Crack			1000	1			
1-9	1	Centre	Column	Concrete	Horizontal Crack			1000	1			
1-10	1	Bottom Centre	Column	Concrete	Delamination			500	400			
1-11	1	Bottom Centre	Column	Concrete	Multi Directional Cracking			1000	500		1	
1-12	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
1-13	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Spall			90	80	10		
1-14	Parapet Inner	Top Left-Right Hand Side	Parapet Inner	Concrete	Spalling With Exposed Reinforcement Corroding			60	50	30		20
Parapet-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
2-1	Parapet	Left Hand Side	Parapet	Concrete	Spall			1070	350	40		
2-2	2	Left Hand Side	Panel	Concrete	Spall			120	120	10		
2-3	2	Left Hand Side	Panel	Concrete	Spall		Yes	300	80	20	20	
2-4	2	Left-Right Hand Side	Column	Concrete	Multi Directional Cracking			7000	970			
2-5	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
2-6	2	Centre	Panel	Concrete	Spall			330	240	20		
2-7	2	Left Hand Side	Column	Concrete	Spall		Yes	1040	690	70	70	
2-8	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
2-9	Parapet Inner	Bottom Centre	Parapet Inner	Concrete	Spall			300	200	15		
Parapet-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	6						
3-1	Parapet	Top Left Hand Corner	Parapet	Concrete	Delamination With Spalling			750	700	50		

KEY
HL = Hairline crack

APPENDIX 2 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
3-2	Parapet	Top Centre	Parapet	Concrete	Delamination With Spalling			450	500	40		
3-3	Parapet	Bottom Left Hand Corner	Parapet	Concrete	Delamination With Spalling			550	360	35		
3-4	Parapet	Centre	Parapet	Concrete	Delamination With Spalling			500	450	50		
3-5	Parapet	Centre	Parapet	Concrete	Vertical Crack			1800	2			
3-6	Parapet	Top Right Hand Corner	Parapet	Concrete	Horizontal Crack			1000	1			
3-7	Parapet	Right Hand Side	Parapet	Concrete	Delamination			300	300			
3-8	Parapet	Bottom Right Hand Corner	Parapet	Concrete	Horizontal Crack			1000	1			
3-9	2	Top Left-Right Hand Side	Parapet	Concrete	Horizontal Crack With Calcite	2		1300	1			
3-10	2	Centre Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1750	1			
3-11	2	Centre Left-Right Hand Side	Column	Concrete	Horizontal Crack	2		1000	1			
3-12	2	Right Hand Side	Panel	Concrete	Spall		Yes	70	90	30	30	
3-13	2	Left Hand Side	Panel	Concrete	Spall		Yes	80	120	40	40	
3-14	2	Bottom Centre	Panel	Concrete	Delamination		Yes	800	330	30	30	
3-15	1	Top Centre	Column	Concrete	Horizontal Crack			1000	1			
3-16	1	Left Hand Side	Panel	Concrete	Spall		Yes	1700	50	30	30	
3-17	1	Right Hand Side	Panel	Concrete	Spall		Yes	200	100	30	30	
3-18	1	Centre Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1950	0.5			
3-19	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
3-20	Parapet Inner	Top Centre	Parapet Inner	Concrete	Spall			300	240	40		
3-21	Parapet Inner	Bottom Centre	Parapet Inner	Concrete	Spall			300	200	15		
Parapet-3	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	18						
4-1	Parapet	Right Hand Side	Parapet	Concrete	Spall			220	60	20		
4-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Multi Directional Cracking			2000	2300		0.5	
4-3	Parapet	Bottom Centre	Parapet	Concrete	Previous Repair			660	500			
4-4	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2000	2			
4-5	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack	2		970	0.5			

KEY
HL = Hairline crack

APPENDIX 3 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
4-6	2	Centre	Panel	Concrete	Previous Repair Failing		Yes	1200	720	60	60	
4-7	1	Left Hand Side	Panel	Concrete	Spall		Yes	900	130	20	20	
4-8	1	Left Hand Side	Column	Concrete	Spall		Yes	130	100	10	10	
4-9	1	Right Hand Side	Panel	Concrete	Vertical Crack			1100	30			
4-10	1	Left Hand Side	Column	Concrete	Spall			300	60	15		
4-11	1	Bottom Right Hand Corner	Panel	Concrete	Spall		Yes	230	90	20	20	
4-12	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
4-13	Parapet Inner	Bottom Left-Right Hand Side	Parapet Inner	Concrete	Spall			2000	500	20		
Parapet-4	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	15						
5-1	Parapet	Top to Bottom	Parapet	Concrete	Vertical Crack			2300	4			
5-2	Parapet	Right Hand Side	Parapet	Concrete	Multi Directional Cracking			800	1200			
5-3	Parapet	Top Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2000	3			
5-4	Parapet	Top Centre	Parapet	Concrete	Delamination With Spalling			450	600	30		
5-5	Parapet	Top Centre	Parapet	Concrete	Delamination With Spalling			260	300	25		
5-6	Parapet	Bottom Centre	Parapet	Concrete	Horizontal Crack With Rust Stain			800	2			
5-7	2	Top Left Hand Corner	Panel	Concrete	Spall			100	140	25		
5-8	2	Top Right Hand Corner	Panel	Concrete	Spall		Yes	70	90	20	20	
5-9	2	Left Hand Side	Panel	Concrete	Multi Directional Cracking			200	1200		1	
5-10	2	Right Hand Side	Panel	Concrete	Previous Repair			150	300			
5-11	2	Top Centre	Column	Concrete	Delamination With Horizontal Crack & Calcite		Yes	680	260	10	10	
5-12	2	Bottom Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
5-13	2	Right Hand Side	Panel	Concrete	Previous Repair			180	160			
5-14	2	Bottom Centre	Panel	Concrete	Spall		Yes	100	200	30	30	
5-15	2	Bottom Centre	Panel	Concrete	Previous Repair			280	240			
5-16	1	Top Centre	Column	Concrete	Horizontal Crack			1000	0.5			
5-17	1	Top Right Hand Corner	Panel	Concrete	Calcite Deposit			340	600			

KEY
HL = Hairline crack

APPENDIX 4 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
5-18	1	Bottom Centre	Column	Concrete	Multi Directional Cracking With Delamination			1850	1000		1	
5-19	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
Parapet-5	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	15						
6-1	Parapet	Top Left-Right Hand Side	Parapet	Concrete	Multi Directional Cracking			2000	1300		40	
6-2	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1200	0.5			
6-3	2	Left Hand Side	Panel	Concrete	Spall		Yes	360	80	20	20	
6-4	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack	3		970	0.5			
6-5	2	Right Hand Side	Panel	Concrete	Delamination			1300	570			
6-6	2	Left Hand Side	Column	Concrete	Horizontal Crack	3		600	0.5			
6-7	1	Top Left Hand Corner	Panel	Concrete	Previous Repair			200	150			
6-8	1	Right Hand Side	Column	Concrete	Spall		Yes	1000	230	30	30	
6-9	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack	2		970	0.5			
6-10	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
6-11	Parapet Inner	Centre	Parapet Inner	Concrete	Spall			900	250	20		
6-12	Parapet Inner	Top Centre	Parapet Inner	Concrete	Spall			300	190	20		
6-13	Parapet Inner	Bottom Right Hand Corner	Parapet Inner	Concrete	Spalling With Exposed Reinforcement Corroding			1270	80	60		50
Parapet-6	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	9						
7-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Multi Directional Cracking With Rust Stain			3000	2000		2	
7-2	Parapet	6 RHS + 7 LHS	Parapet	Concrete	Spalling With Exposed Reinforcement Corroding			600	950	55		
7-3	2	Top Left Hand Side	Panel	Concrete	Spall		Yes	230	70	40	40	
7-4	2	Top Centre	Panel	Concrete	Spall		Yes	270	110	40	40	
7-5	2	Top Right Hand Corner	Panel	Concrete	Spall		Yes	350	110	40	40	
7-6	2	Top Centre	Column	Concrete	Spall		Yes	250	80	30	30	
7-7	2	Centre	Panel	Concrete	Delamination			700	670			
7-8	2	Bottom Left Hand Corner	Panel	Concrete	Delamination			500	1500	30		
7-9	2	Bottom Centre	Panel	Concrete	Delamination			870	640	30		

KEY
HL = Hairline crack

APPENDIX 5 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
7-10	1	Top Centre	Column	Concrete	Horizontal Crack With Rust Stain& Calcite			1000	1			
7-11	1	Top Right Hand Side	Panel	Concrete	Spall			260	1400	50		
7-12	1	Bottom Left Hand Corner	Panel	Concrete	Previous Repair			430	180			
7-13	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
7-14	Parapet Inner	Top Centre	Parapet Inner	Concrete	Spall			1220	480	30		
7-15	Parapet Inner	Centre	Parapet Inner	Concrete	Spall			300	270	40		
Parapet-7	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	15						
8-1	Parapet	Right Hand Side	Parapet	Concrete	Spall			600	260	60		
8-2	Parapet	Centre	Parapet	Concrete	Previous Repair			1200	800			
8-3	Parapet	Left-Right Hand Side	Parapet	Concrete	Multi Directional Cracking			2000	2300		10	
8-4	Parapet	Bottom Left Hand Corner	Parapet	Concrete	Spall			640	200	45		
8-5	Parapet	Bottom Right Hand Corner	Parapet	Concrete	Spall		Yes	280	160	35	35	
8-6	3	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
8-7	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
8-8	2	Bottom Left Hand Corner	Panel	Concrete	Spall			660	440	40		
8-9	2	Bottom Left Hand Corner	Panel	Concrete	Spall		Yes	470	100	40	40	
8-10	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
8-11	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
8-12	1	Top Left Hand Side	Panel	Concrete	Spall		Yes	190	50	40	40	
8-13	1	Right Hand Side	Column	Concrete	Multi Directional Cracking			980	690		10	
8-14	1	Bottom Left Hand Side	Panel	Concrete	Spall		Yes	270	250	30	30	
8-15	1	Top Left-Right Hand Side	Panel	Concrete	Spall			560	80	40		
8-16	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
8-17	Parapet Inner	Centre	Parapet Inner	Concrete	Previous Repair			1880	1500			
Parapet-8	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots		8					
9-1	Parapet	Top Centre	Parapet	Concrete	Delamination			500	440			

KEY
HL = Hairline crack

APPENDIX 6 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
9-2	Parapet	Left Hand side	Parapet	Concrete	Multi Directional Cracking With Rust Stain			170	180		1	
9-3	2	Top Left Hand Corner	Panel	Concrete	Spall		Yes	90	210	40	40	
9-4	2	Top Left Hand Corner	Panel	Concrete	Spall		Yes	60	200	20	20	
9-5	2	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking			380	300		0.5	
9-6	2	Top Right Hand Corner	Panel	Concrete	Spall			80	110	30		
9-7	2	Bottom Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
9-8	2	Bottom Centre	Panel	Concrete	Delamination			300	340			
9-9	2	Bottom Right Hand Corner	Panel	Concrete	Delamination			550	440			
9-10	1	Centre	Column	Concrete	Delamination			450	350			
9-11	1	Bottom Centre	Column	Concrete	Delamination			260	460			
9-12	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
9-13	Parapet Inner	Centre	Parapet Inner	Concrete	Spall			790	320	20		
9-14	Parapet Inner	Right Hand side	Parapet Inner	Concrete	Spalling With Exposed Reinforcement Corroding			440	120	20		20
Parapet-9	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	15						
10-1	Parapet	Left Hand Side	Parapet	Concrete	Previous Repair			580	580			
10-2	Parapet	Right Hand Side	Parapet	Concrete	Spalling With Exposed Reinforcement Corroding		Yes	200	130	20	20	20
10-3	Parapet	Bottom Right Hand Corner	Parapet	Concrete	Spall		Yes	390	210	20	20	
10-4	3	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
10-5	2	Left Hand Side	Panel	Concrete	Spall		Yes	200	50	15	15	
10-6	2	Left-Right Hand Side	Panel	Concrete	Multi Directional Cracking			2000	300		0.5	
10-7	2	Left Hand Side	Panel	Concrete	Spall			400	120	10		
10-8	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	10			
10-9	1	Bottom Right Hand Corner	Panel	Concrete	Spall		Yes	110	100	20	20	
10-10	Parapet Inner	Left-Right Hand Side	Parapet Inner	Concrete	Multi Directional Cracking			1260	3000		0.5	
10-11	Parapet Inner	Top Centre	Parapet Inner	Concrete	Spall			350	150	20		
10-12	Parapet Inner	Bottom Right Hand Corner	Parapet Inner	Concrete	Spall			250	120	20		

KEY
HL = Hairline crack

APPENDIX 7 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
Parapet-10	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	6						
11-1	Parapet	Top Centre	Parapet	Concrete	Spall With Exposed Corroding Reinforcement			400	600	40		30
11-2	Parapet	Bottom Left To Top Right	Parapet	Concrete	Diagonal Crack With Calcite			1900	1			
11-3	Parapet	Top Left Hand Corner	Parapet	Concrete	Spall			150	200	30		
11-4	Parapet	Top Right Hand Corner	Parapet	Concrete	Spall			130	80	30		
11-5	3	Top Left-Right Hand Side	Panel/ Column	Concrete	Calcite Deposit			3000	500			
11-6	3	Top Centre	Panel	Concrete	Horizontal Crack With Calcite			1600	2			
11-7	2	Top Centre	Panel	Concrete	Drill Hole			15	15			
11-8	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
11-9	2	Bottom Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
11-10	2	Bottom Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
11-11	1	Top Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			470	560		1	
Parapet-11	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	5						
12-1	Parapet	Right Hand Side	Parapet	Concrete	Spall			340	100	20		
12-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2000	0.5			
12-3	3	Top Right Hand Corner	Panel	Concrete	Calcite Deposit							
12-4	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack	2		970	0.5			
12-5	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
12-6	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
12-7	1	Left-Right Hand Side	Panel	Concrete	Multi Directional Cracking			1000	1000		0.5	
12-8	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
12-9	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
12-10	1	Left Hand Side	Panel	Concrete	Spall		Yes	600	150	20	20	
12-11	1	Left Hand Side	Panel	Concrete	Spall			500	150	20		
12-12	Parapet Inner	Left Hand Side	Parapet Inner	Render	Spall			940	160	10		
Parapet-12	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	7						

KEY
HL = Hairline crack

APPENDIX 8 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
13-1	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack With Rust Stain			1100	2			
13-2	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack With Rust Stain			150	1			
13-3	2	Top Left Hand Corner	Panel	Concrete	Spall With Rust Stain And Wood Behind		Yes	200	400	60	60	
13-4	2	Top Right Hand Corner	Panel	Concrete	Spall With Wood Behind		Yes	220	80	25	25	
13-5	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
13-6	2	Left Hand Side	Panel	Concrete	Delamination			1850	300			
13-7	2	Bottom Centre	Panel	Concrete	Delamination			300	200			
13-8	2	Bottom Centre	Panel	Concrete	Delamination			570	370	15		
13-9	2	Bottom Centre	Panel	Concrete	Delamination			400	170	10		
13-10	2	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			400	330		1	
13-11	2	Bottom Right Hand Corner	Panel	Concrete	Delamination			450	500			
13-12	1	Top Centre	Column	Concrete	Horizontal Crack With Calcite			1000	2			
13-13	1	Top Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			260	340	1		
13-14	1	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Delamination & Calcite			260	640		2	
13-15	1	Bottom Right Hand Corner	Panel	Concrete	Spall		Yes	210	100	40	40	
Parapet-13	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	6						
14-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2000	0.5			
14-2	3	Top Left-Right Hand Side	Panel	Concrete	Calcite Deposit							
14-3	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
14-4	2	Left-Right Hand Side	Panel	Concrete	Previous Repair Failing		Yes	2000	600	35	35	
14-5	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
14-6	Parapet Inner	Top Left Hand Side	Parapet Inner	Render	Spall			320	60	20		
Parapet-14	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	4						
15-1	Parapet	Top Right Hand Corner	Parapet	Concrete	Spall		Yes	190	60	30	30	
15-2	Parapet	Bottom Centre	Parapet	Concrete	Horizontal Crack With Calcite			1400	0.5			
15-3	3	Top Left-Right Hand Side	Panel/ Column	Concrete	Calcite Deposit			3000	500			

KEY
HL = Hairline crack

APPENDIX 9 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
15-4	2	Top Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			760	260		1	
15-5	2	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			200	670		1	
15-6	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite			1000	0.5			
15-7	2	Top Right Hand Corner	Panel	Concrete	Spall			120	60	30		
15-8	2	Bottom Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			1000	540		1	
15-9	1	Top Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			500	300		0.5	
15-10	1	Top Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
15-11	1	Right Hand Side	Column	Concrete	Vertical Crack With Rust Stain			500	2			
15-12	1	Bottom Left Hand Corner	Panel	Concrete	Delamination With Multi Directional Cracking			520	270		10	
15-13	1	Bottom Right Hand Corner	Column	Concrete	Spall		Yes	100	340	40	40	
Parapet-5	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
16-1	Parapet	Right Hand Side	Parapet	Concrete	Spall			540	230	20		
16-2	Parapet	Left Hand Side	Parapet	Concrete	Horizontal Crack			1560	0.5			
16-3	3	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
16-4	3	Right Hand Side	Panel	Concrete	Spall		Yes	600	400	40	40	
16-5	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	20			
16-6	2	Centre	Column	Concrete	Spall			900	220	35		
16-7	2	Right Hand Side	Panel	Concrete	Spall			380	60	10		
16-8	2	Left Hand Side	Panel	Concrete	Spall			260	220	25		
16-9	2	Left-Right Hand Side	Column	Concrete	Multi Directional Cracking			1700	970		0.5	
16-10	2	Bottom Right Hand Corner	Panel	Concrete	Spall		Yes	840	520	20	20	
16-11	1	Left-Right Hand Side	Column	Concrete	Multi Directional Cracking With Delamination			970	3600		0.5	
16-12	1	Left Hand Side	Panel	Concrete	Spall			250	150	15		
16-13	1	Bottom Right Hand Corner	Column	Concrete	Spall		Yes	280	80	40	40	
16-14	Base	Top Right Hand Corner	Base	Concrete	Spall		Yes	300	100	20	20	
Parapet-16	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	4						

KEY
HL = Hairline crack

APPENDIX 10 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
17-1	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack With Rust Stain	2		1000	1			
17-2	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack	2		700	0.5			
17-3	3	Top Left-Right Hand Side	Column	Concrete	Calcite Deposit			3000	50			
17-4	2	Top Centre	Column	Concrete	Horizontal Crack			1000	1			
17-5	2	Centre	Column	Concrete	Horizontal Crack			1000	1			
17-6	2	Bottom Centre	Column	Concrete	Horizontal Crack			1000	1			
17-7	1	Top Centre	Column	Concrete	Horizontal Crack With Wood Behind			1000	1			
17-8	2	Bottom Left Hand Corner	Panel	Concrete	Delamination With Spalling			780	630	20		
17-9	2	Bottom Centre	Panel	Concrete	Delamination With Spalling			650	40	10		
17-10	2	Bottom Right Hand Corner	Panel	Concrete	Delamination With Spalling			430	860	10		
17-11	1	Top Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1850	0.5			
17-12	1	Bottom Right Hand Corner	Panel	Concrete	Spall With Exposed Corroding Reinforcement			300	710	50		40
Parapet-17	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	5						
18-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Multi Directional Cracking			1900	2000		0.5	
18-2	3	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
18-3	2	Centre	Column	Concrete	Vertical Crack			3700	0.5			
18-4	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack	3		970	0.5			
18-5	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
18-6	2	Centre	Column	Concrete	Diagonal Crack			500	0.5			
18-7	Parapet Inner	Right Hand side	Parapet Inner	Render	Delamination			1090	1040			
18-8	Parapet Inner	Top Right Hand Side	Parapet Inner	Render	Spall			400	100	20		
Parapet-18	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	9						
19-1	Parapet	Top Centre	Parapet	Concrete	Spall			130	230			
19-2	Parapet	Top Centre	Parapet	Concrete	Delamination With Horizontal Crack			460	340	1		
19-3	Parapet	Bottom Centre	Parapet	Concrete	Vertical Crack			900	0.5			
19-4	3	Top Right Hand Corner	Panel	Concrete	Diagonal Crack With Calcite			680	1			

KEY
HL = Hairline crack

APPENDIX 11 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
19-5	2	Top Right Hand Corner	Panel	Concrete	Horizontal Crack With Calcite			540	1			
19-6	2	Bottom Left Hand Corner	Panel	Concrete	Delamination			870	630			
19-7	2	Bottom Right Hand Corner	Panel	Concrete	Delamination			800	290			
19-8	1	Top Centre	Column	Concrete	Delamination With Horizontal Crack			1000	20			
19-9	1	Top Right Hand Corner	Panel	Concrete	Horizontal Crack	2		400	0.5			
19-10	1	Left Hand Side	Panel	Concrete	Multi Directional Cracking			280	1560		1	
Parapet-19	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots							
20-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Multi Directional Cracking			2000	400		0.5	
20-2	3	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
20-3	3	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
20-4	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
20-5	2	Bottom Centre	Panel	Concrete	Spall			200	100	30		
20-6	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
20-7	1	Right Hand Side	Panel	Concrete	Spall			400	60	20		
20-8	1	Right Hand Side	Panel	Concrete	Multi Directional Cracking			900	400		0.5	
20-9	1	Bottom Left Hand Side	Panel	Concrete	Spall		Yes	250	140	35	35	
Parapet-20	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	4						
21-1	Parapet	Top Centre	Parapet	Concrete	Multi Directional Cracking			1200	600		0.5	
21-2	Parapet	Right Hand Side	Parapet	Concrete	Vertical Crack With Calcite	2		1800	1			
21-3	Parapet	Right Hand Side	Parapet	Concrete	Vertical Crack With Rust Stain			1800	1			
21-4	2	Top Right Hand Corner	Panel	Concrete	Delamination			260	300			
21-5	2	Top Centre	Column	Concrete	Horizontal Crack			1000	0.5			
21-6	2	Top Left Hand Corner	Panel	Concrete	Delamination			200	500			
21-7	2	Centre	Panel	Concrete	Previous Repair			120	120			
21-8	2	Bottom Centre	Panel	Concrete	Previous Repair With Delamination & Spalling		Yes	1600	640	50	50	
21-9	2	Bottom Centre	Column	Concrete	Horizontal Crack			1000	0.5			

KEY
HL = Hairline crack

APPENDIX 12 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
21-10	1	Left Hand Side	Panel	Concrete	Delamination			360	500			
21-11	1	Bottom Left Hand Corner	Panel	Concrete	Delamination			250	260			
21-12	1	Bottom Right Hand Corner	Panel	Concrete	Spall			70	450	35		
21-13	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Delamination			640	130			
21-14	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Spall			300	200	20		
Parapet-21	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	2						
22-1	Parapet	Centre	Parapet	Concrete	Spall			470	240	20		
22-2	Parapet	Right Hand Side	Parapet	Concrete	Vertical Crack			2000	0.5			
22-3	3	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
22-4	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			950	0.5			
22-5	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
22-6	2	Left Hand Side	Column	Concrete	Horizontal Crack			730	0.5			
22-7	2	Bottom Right Hand Corner	Panel	Concrete	Multi Directional Cracking			700	600		0.5	
22-8	2	Bottom Centre	Panel	Concrete	Spall			230	150	10		
22-9	2	Bottom Left Hand Side	Panel	Concrete	Spall		Yes	500	400	10	10	
22-10	1	Left-Right Hand Side	Column	Concrete	Multi Directional Cracking			970	1100		30	
22-11	1	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	1			
22-12	1	Right Hand Side	Panel	Concrete	Spall			200	50	10		
22-13	Parapet Inner	Top Left Hand Side	Parapet Inner	Render	Delamination			260	130			
Parapet-22	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	22						
23-1	Parapet/ 3	Bottom Left-Right Hand Side	Parapet/ Panel	Concrete	Horizontal Crack With Calcite			1950	1			
23-2	3	Top Centre	Panel	Concrete	Horizontal Crack			1900	1			
23-3	3	Top Left Hand Corner	Panel	Concrete	Spall With Rust Stain			160	110	30		
23-4	3	Bottom Left Hand Corner	Panel	Concrete	Delamination			500	200			
23-5	3	Bottom Right Hand Corner	Panel	Concrete	Spall			530	440	50		
23-6	3	Bottom Centre	Column	Concrete	Delamination With Spalling			320	400	20		

KEY
HL = Hairline crack

APPENDIX 13 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
23-7	2	Top Right Hand Corner	Column	Concrete	Delamination With Spalling			480	460	30		
23-8	2	Top Left Hand Corner	Panel	Concrete	Delamination			360	1350			
23-9	2	Bottom Centre	Panel	Concrete	Previous Repair Failing			1650	2200			
23-10	2	Bottom Right Hand Corner	Column	Concrete	Previous Repair Failing			400	300			
23-11	2	Bottom Centre	Column	Concrete	Delamination With Horizontal Crack & Calcite			1000	250	1		
23-12	2	Bottom Right Hand Corner	Panel	Concrete	Delamination			700	240			
23-13	2 / 1	Bottom Left Hand Corner	Panel	Concrete	Spall		Yes	260	460	50	50	
23-14	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Spall			740	170	20		
23-15	Parapet Inner	Left Hand Side	Parapet Inner	Render	Spall			960	780	20		
Parapet-23	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	23						
24-1	3	Top Centre	Column	Concrete	Spall			400	130	40		
24-2	2	Top Right Hand Side	Panel	Concrete	Multi Directional Cracking			400	230		0.5	
24-3	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
24-4	2	Right Hand Side	Panel	Concrete	Multi Directional Cracking			500	170		0.5	
24-5	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
24-6	2	Left Hand Side	Panel	Concrete	Previous Repair Failing			1300	660			
24-7	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	30			
24-8	1	Left Hand Side	Panel	Concrete	Spall		Yes	320	200	20	20	
24-9	Parapet Inner	Top Right Hand Side	Parapet Inner	Render	Spall			160	160	20		
24-10	Parapet Inner	Top Left-Right Hand Side	Parapet Inner	Render	Previous Repair			1460	260			
Parapet-24	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	2						
25-1	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack			1230	1			
25-2	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack With Rust Stain			3000	1			
25-3	Parapet	Left Hand Side	Parapet	Concrete	Vertical Crack With Rust Stain			1500	1			
25-4	3	Top Left Hand Corner	Panel	Concrete	Horizontal Crack With Rust Stain& Calcite			1300	1			
25-5	3	Top Left Hand Corner	Column	Concrete	Horizontal Crack			500	0.5			

KEY
HL = Hairline crack

APPENDIX 14 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
25-6	3	Bottom Left Hand Corner	Panel	Concrete	Spall			150	60	10		
25-7	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite			500	0.5			
25-8	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite			500	0.5			
25-9	2	Top Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			270	360		0.5	
25-10	2	Top Right Hand Corner	Panel	Concrete	Delamination			180	330			
25-11	2	Centre	Column	Concrete	Delamination With Spalling		Yes	900	1800	50	50	
25-12	2	Bottom Left Hand Corner	Panel	Concrete	Previous Repair			330	330			
25-13	2	Bottom Centre	Panel	Concrete	Previous Repair			300	350			
25-14	2	Bottom Right Hand Corner	Panel	Concrete	Multi Directional Cracking			1000	700		0.5	
25-15	1	Top Centre	Column	Concrete	Horizontal Crack With Calcite			800	0.5			
25-16	1	Right Hand Side	Panel	Concrete	Spall With Exposed Corroding Reinforcement			130	220	15		15
25-17	1	Top Centre	Column	Concrete	Spall With Calcite			130	250	10		
25-18	1	Bottom Left Hand Corner	Column	Concrete	Spall			400	170			
25-19	1	Bottom Right Hand Corner	Panel	Concrete	Spall With Calcite			130	400	15		
25-20	Parapet Inner	Top Centre	Parapet Inner	Render	Spall			1000	220	20		
25-21	Parapet Inner	Right Hand Side	Parapet Inner	Render	Spall			550	160	20		
25-22	Parapet Inner	Top Right Hand Corner	Parapet Inner	Render	Previous Repair			370	170			
Parapet-25	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	6						
26-1	Parapet	Left Hand Side	Parapet	Concrete	Spall			200	100	20		
26-2	Parapet	Left Hand Side	Parapet	Concrete	Multi Directional Cracking			1100	330		0.5	
26-3	Parapet	Left Hand Side	Parapet	Concrete	Spall			300	120	120		
26-4	3	Left Hand Side	Panel	Concrete	Multi Directional Cracking			400	130		0.5	
26-5	3	Right Hand Side	Panel	Concrete	Multi Directional Cracking			470	250		0.5	
26-6	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
26-7	2	Bottom Right Hand Corner	Panel	Concrete	Delamination			1200	670			
26-8	1	Top Right Hand Side	Panel	Concrete	Spall			360	60	10		

KEY
HL = Hairline crack

APPENDIX 15 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
26-9	1	Top Right Hand Side	Panel	Concrete	Spall		Yes	490	150	20	20	
26-10	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	20			
26-11	Parapet Inner	Top Right Hand Side	Parapet Inner	Render	Previous Repair			220	120			
Parapet-26	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
27-1	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack			1900	0.5			
27-2	3	Top Right Hand Corner	Panel	Concrete	Delamination With Spalling			280	120	30		
27-3	3	Top Left Hand Corner	Panel	Concrete	Calcite Deposit			1000	1000			
27-4	2	Top	Panel	Concrete	Multi Directional Cracking With Calcite			1950	500		0.5	
27-5	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite	3		1000	0.5			
27-6	2	Centre Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1950	2			
27-7	2	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			500	0.5			
27-8	2	All	Panel	Concrete	Delamination			1950	1850			
27-9	2	Bottom Centre	Column	Concrete	Horizontal Crack With Calcite			1000	0.5			
27-10	1	Bottom Left Hand Corner	Panel	Concrete	Spall		Yes	140	340	40	40	
Parapet-27	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
28-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2000	0.5			
28-2	3	Left-Right Hand Side	Panel	Concrete	Calcite Deposit							
28-3	3	Right Hand Side	Panel	Concrete	Spall			470	240	20		
28-4	3	Left Hand Side	Panel	Concrete	Spall			200	170	10		
28-5	3	Centre	Panel	Concrete	Multi Directional Cracking			1000	200		0.5	
28-6	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
28-7	2	Centre	Panel	Concrete	Spall			230	130	16		
28-8	2	Left Hand Side	Panel	Concrete	Spall			820	420			
28-9	1	Right Hand Side	Panel	Concrete	Vertical Crack			2600	20			
28-10	1	Bottom Left Hand Side	Panel	Concrete	Spall			270	140	20		
28-11	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack	2		970	40			

KEY
HL = Hairline crack

APPENDIX 16 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
28-12	1	Right Hand Side	Column	Concrete	Horizontal Crack			700	0.5			
28-13	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack			970	20			
28-14	Parapet Inner	Top Right Hand Corner	Parapet Inner	Render	Spall			190	80	20		
Parapet-28	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
29-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2000	0.5			
29-2	Parapet	Right Hand Side	Parapet	Concrete	Horizontal Crack			1100	0.f			
29-3	3	Right Hand Side	Panel	Concrete	Horizontal Crack			640	0.5			
29-4	3	Right Hand Side	Panel	Concrete	Multi Directional Cracking			2000	400		0.5	
29-5	2	Left-Right Hand Side	Panel	Concrete	Calcite Deposit							
29-6	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			960	0.5			
29-7	2	Left Hand Side	Panel	Concrete	Delamination Removed - Spall		Yes	700	560	40	40	
29-8	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack			750	40			
29-9	2	Left Hand Side	Column	Concrete	Horizontal Crack			300	20			
29-10	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack			640	0.5			
29-11	1	Right Hand Side	Column	Concrete	Horizontal Crack			550	0.5			
29-12	Parapet Inner	Top Centre	Parapet Inner	Render	Previous Repair			490	140			
Parapet-29	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	5						
30-1	Parapet	Top Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2700	1			
30-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							
30-3	Parapet	Left Hand Side	Parapet	Concrete	Horizontal Crack	3		1070	0.5			
30-4	3	Top	Column	Concrete	Calcite Deposit			1200	1600			
30-5	2	Top	Column	Concrete	Horizontal Crack			960	0.5			
30-6	2	Top Left Hand Side	Panel	Concrete	Delamination			280	100			
30-7	2	Top Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1960	0.5			
30-8	2	Right Hand Side	Panel	Concrete	Delamination			700	1100			

KEY
HL = Hairline crack

APPENDIX 17 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
30-9	2	Bottom Left Hand Corner	Column	Concrete	Horizontal Crack With Calcite			960	0.5			
30-10	2	Bottom Left Hand Corner	Panel	Concrete	Delamination			670	430			
30-11	1	Top Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1380	0.5			
30-12	Parapet Inner	Top Left Hand Side	Parapet Inner	Render	Spall			860	130	20		
30-13	Parapet Inner	Top Centre	Parapet Inner	Render	Previous Repair			1300	260			
Parapet-30	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	9						
31-1	Parapet	Top Right Hand Corner	Parapet	Concrete	Horizontal Crack With Rust Stain			1500	1			
31-2	Parapet	Top Left Hand Corner	Parapet	Concrete	Horizontal Crack With Rust Stain			1800	1			
31-3	Parapet	Bottom Left Hand Corner	Parapet	Concrete	Horizontal Crack With Rust Stain			800	1			
31-4	Parapet	Bottom Right Hand Corner	Parapet	Concrete	Horizontal Crack With Rust Stain			900	1			
31-5	3	Left Hand Side	Panel	Concrete	Calcite Deposit			3000	50			
31-6	3	Top Right Hand Corner	Panel	Concrete	Horizontal Crack With Calcite			420	0.5			
31-7	3	Bottom Right Hand Side	Panel	Concrete	Multi Directional Cracking			1100	450		1	
31-8	2	Bottom Centre	Panel	Concrete	Horizontal Crack			1950	1			
31-9	2	Bottom Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Rust Stain			300	750		0.5	
31-10	2	Bottom Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	1			
31-11	2	Bottom Right Hand Corner	Panel	Concrete	Delamination			400	500			
31-12	2	Bottom Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Delamination			600	500		0.5	
31-13	1	Top Centre	Panel	Concrete	Horizontal Crack			1950	1			
31-14	1	Top Centre	Column	Concrete	Horizontal Crack With Calcite	2		1000	1			
31-15	1	Bottom Right Hand Corner	Panel	Concrete	Spall With Exposed Corroding Reinforcement		Yes	380	500	50	50	40
31-16	1	Bottom Left-Right Hand Side	Panel	Concrete	Multi Directional Cracking			1700	200		0.5	
Parapet-31	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	11						
32-1	Parapet	Top Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			3000	1			
32-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							

KEY
HL = Hairline crack

APPENDIX 18 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
32-3	Parapet	Bottom Left Hand Corner	Parapet	Concrete	Rust Stain			480	280			
32-4	3	Top	Column	Concrete	Calcite Deposit			1400	2300			
32-5	3	Top Left Hand Corner	Panel	Concrete	Horizontal Crack With Calcite			530	0.5			
32-6	2	Top Right Hand Corner	Panel	Concrete	Previous Repair With Delamination		Yes	450	160	40	40	
32-7	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1960	0.5			
32-8	2	Top	Column	Concrete	Horizontal Crack With Calcite			960	0.5			
32-9	2	Right Hand Side	Panel	Concrete	Multi Directional Cracking With Calcite And Rust Stain			1800	760		0.5	
32-10	2	Left Hand Side	Panel	Concrete	Spall With Rust Stain		Yes	160	450	25	25	
32-11	1	Top Right Hand Corner	Panel	Concrete	Delamination With Spalling			330	960	90		
32-12	2	Bottom	Column	Concrete	Horizontal Crack			960	0.5			
32-13	1	Top	Column	Concrete	Horizontal Crack			960	0.5			
32-14	1	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1960	1			
32-15	1	Left Hand Side	Panel	Concrete	Delamination			360	240			
32-16	1	Bottom	Column	Concrete	Delamination With Spalling			2350	670	40		
32-17	1	Bottom Left Hand Side	Panel	Concrete	Delamination With Spalling			350	1840	30		
32-18	Parapet Inner	Right Hand Side	Parapet Inner	Render	Delamination			1000	930			
Parapet-32	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	8						
33-1	Parapet	Centre	Parapet	Concrete	Delamination Removed - Spall			130	130	20		
33-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			1900	0.5			
33-3	Parapet	Left Hand Side	Parapet	Concrete	Horizontal Crack			1000	0.5			
33-4	3	Top Right Hand Corner	Panel	Concrete	Calcite Deposit							
33-5	3	Right Hand Side	Panel	Concrete	Delamination Removed - Spall			200	120	20		
33-6	3	Bottom Centre	Panel	Concrete	Delamination Removed - Spall			170	100	20		
33-7	2	Top Left Hand Side	Panel	Concrete	Delamination Removed - Spall		Yes	300	120	25	25	
33-8	2	Right Hand Side	Column	Concrete	Horizontal Crack	3		960	0.5			

KEY
HL = Hairline crack

APPENDIX 19 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
33-9	2	Left Hand Side	Column	Concrete	Delamination Removed - Spall			330	110	20		
33-10	2	Left-Right Hand Side	Column	Concrete	Horizontal Crack	2		950	0.5			
33-11	2	Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1950	0.5			
Parapet-33	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
34-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							
34-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			3000	1			
34-3	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			1400	1			
34-4	Parapet	Centre	Parapet	Concrete	Spall			240	180	20		
34-5	3	Top	Column	Concrete	Calcite Deposit			2000	1600			
34-6	2	Top	Column	Concrete	Horizontal Crack With Calcite			1000	1			
34-7	2	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			900	1000		0.5	
34-8	2	Top Centre	Panel	Concrete	Previous Repair+ Calcite			140	220			
34-9	2	Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
34-10	2	Centre	Panel	Concrete	Delamination			800	400			
34-11	2	Centre Right Hand Side	Panel	Concrete	Multi Directional Cracking With Rust Stain			570	500		0.5	
34-12	2	Bottom	Column	Concrete	Horizontal Crack With Calcite			1000	1			
34-13	2	Bottom Centre	Panel	Concrete	Vertical Crack			1500	0.5			
34-14	1	Top Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2000	0.5			
34-15	1	Right Hand Side	Panel	Concrete	Delamination With Spalling			900	450	35		
34-16	1	Left Hand Side	Panel	Concrete	Spall			1560	150	50		
34-17	1	Bottom Left Hand Corner	Panel	Concrete	Delamination			860	840			
34-18	1	Bottom Right Hand Corner	Panel	Concrete	Spall			120	130	35		
Parapet-34	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	8						
35-1	Parapet	Left Hand Side	Parapet	Concrete	Rust Stain							
35-2	3	Right Hand Side	Column	Concrete	Calcite Deposit							

KEY
HL = Hairline crack

APPENDIX 20 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
35-3	3	Left-Right Hand Side	Panel	Concrete	Multi Directional Cracking			2000	360		0.5	
35-4	2	Right Hand Side	Column	Concrete	Horizontal Crack	5		980	0.5			
35-5	1	Top Right Hand Corner	Panel	Concrete	Delamination Removed - Spall			100	50	10		
35-6	1	Top Left Hand Corner	Panel	Concrete	Spall			550	200	10		
35-7	1	Left Hand Side	Panel	Concrete	Vertical Crack			3400	5			
35-8	Parapet Inner	Top Left-Right Hand Side	Parapet Inner	Render	Spall			1360	210			
Parapet-35	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
36-1	Parapet	Top Left-Right Hand Side	Parapet	Concrete	Horizontal Crack With Rust Stain			3000	1			
36-2	Parapet	Top Left Hand Corner	Parapet	Concrete	Delamination With Spalling			290	930	25		
36-3	3	Top to Bottom	Column	Concrete	Calcite Deposit			1000	3000			
36-4	3	Bottom Left Hand Side	Panel	Concrete	Vertical Crack			750	1			
36-5	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
36-6	2	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			500	370		1	
36-7	2	Top Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
36-8	2	Top Left Hand Corner	Panel	Concrete	Spall		Yes	160	470	30	30	
36-9	2	Bottom Centre	Column	Concrete	Horizontal Crack With Calcite	3		1000	1			
36-10	2	Bottom Left Hand Corner	Panel	Concrete	Spall			100	700	25		
36-11	2	Bottom Left Hand Corner	Panel	Concrete	Delamination			400	580	30		
36-12	1	Top Right Hand Corner	Panel	Concrete	Delamination			680	2000			
36-13	1	Top Right To Bottom Left Hand Corner	Panel	Concrete	Delamination With Spalling			400	450	15		
36-14	1	Bottom Left Hand Corner	Panel	Concrete	Spall With Exposed Corroding Reinforcement		Yes	470	570	50	50	40
36-15	Parapet Inner	Top Right Hand Corner	Parapet Inner	Render	Spall			670	230	20		
Parapet-36	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	6						
37-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							
37-2	3	Top Right Hand Corner	Column	Concrete	Drill Hole			30	30			

KEY
HL = Hairline crack

APPENDIX 21 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
37-3	2	Right Hand Side	Column	Concrete	Horizontal Crack	2		960	0.5			
37-4	2	Right Hand Side	Column	Concrete	Horizontal Crack			960	0.5			
37-5	1	Left Hand Side	Panel	Concrete	Rust Stain							
37-6	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Spall			340	120	20		
Parapet-37	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	2						
38-1	Parapet	Top Centre	Parapet	Concrete	Vertical Crack			1000	1			
38-2	3	Top Left Hand Corner	Panel	Concrete	Delamination			550	450			
38-3	3 to Base	Top Left to Bottom Right Hand Corner	Panel	Concrete	Calcite Deposit			10000	500			
38-4	3 to Base	Top Left to Bottom Right Hand Corner	Column	Concrete	Calcite Deposit			10000	1000			
38-5	2	Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
38-6	2	Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
38-7	2	Bottom Left-Right Hand Side	Panel	Concrete	Horizontal Crack With Calcite			1950	1			
38-8	2	Bottom Left-Right Hand Side	Column	Concrete	Horizontal Crack With Calcite			1000	1			
38-9	1	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			900	600		1	
Parapet-38	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	2						
39-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							
39-2	3	Right Hand Side	Panel	Concrete	Calcite Deposit							
39-3	2	Left Hand Side	Panel	Concrete	Horizontal Crack			1300	0.5			
39-4	2	Right Hand Side	Column	Concrete	Horizontal Crack			770	0.5			
39-5	2	Centre	Panel	Concrete	Delamination Removed - Spall			380	200	35		
39-6	2	Left Hand Side	Panel	Concrete	Horizontal Crack			670	0.5			
39-7	2	Right Hand Side	Panel	Concrete	Horizontal Crack			770	0.5			
39-8	Parapet Inner	Top Right Hand Side	Parapet Inner	Render	Delamination			490	130			
Parapet-39	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	3						
40-1	Parapet	Top Right Hand Corner	Parapet	Concrete	Horizontal Crack With Rust Stain	2		800	0.5			

KEY
HL = Hairline crack

APPENDIX 22 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
40-2	Parapet	Top Left Hand Corner	Parapet	Concrete	Horizontal Crack With Rust Stain			500	1			
40-3	Parapet	Top Centre	Parapet	Concrete	Delamination			150	130	10		
40-4	3 to Base	Left Hand Side	Panel/ Column	Concrete	Calcite Deposit			8000	50			
40-5	3	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	1			
40-6	2	Bottom Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	1			
40-7	2	Bottom Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	1			
40-8	1	Bottom Left-Right Hand Side	Panel	Concrete	Spacers Exposed	3						
Parapet-40	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	5						
41-1	Parapet	Right Hand Side	Parapet	Concrete	Staining							
41-2	3	Top Right Hand Corner	Panel	Concrete	Rust Stain With Calcite							
41-3	3	Left Hand Side	Panel	Concrete	Delamination Removed - Spall		Yes	770	280	20	20	
41-4	2	Right Hand Side	Panel	Concrete	Multi Directional Cracking			1600	450		0.5	
41-5	2	Right Hand Side	Column	Concrete	Horizontal Crack With Calcite	2		990	0.5			
41-6	2	Left Hand Side	Panel	Concrete	Rust Stain							
41-7	1	Top Centre	Panel	Concrete	Delamination Removed - Spall			240	60	20		
41-8	Parapet Inner	Top Left-Right Hand Side	Parapet Inner	Render	Spall			2300	130	20		
Parapet-41	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	11						
42-1	Parapet	Top Right Hand Corner	Parapet	Concrete	Delamination With Spalling			280	260	30		
42-2	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack	2		1000	1			
42-3	Parapet	Top Centre	Parapet	Concrete	Rust Stain			3000	2000			
42-4	3	Top Right Hand Corner	Panel	Concrete	Previous Repair			110	200			
42-5	3	Centre Left-Right Hand Side	Panel	Concrete	Delamination With Spalling			1340	400	20		
42-6	3	Top Left Hand Corner	Column	Concrete	Previous Repair			190	150			
42-7	3	Centre Right Hand Side	Panel	Concrete	Calcite Deposit			400	1400			
42-8	3	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	0.5			

KEY
HL = Hairline crack

APPENDIX 23 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
42-9	3	Top Right Hand Corner	Panel	Concrete	Previous Repair			160	160			
42-10	2	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	0.5			
42-11	2	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	0.5			
42-12	2	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			1200	1250		0.5	
42-13	1	Top Left Hand Corner	Panel	Concrete	Rust Stain			300	2000			
42-14	1	Centre	Panel	Concrete	Delamination & Spall With Exposed Corroding Reinforcement		Yes	370	600	20	20	20
Parapet-42	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	9						
43-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							
43-2	Parapet	Centre	Parapet	Concrete	Spall			130	210	35		
43-3	Parapet	Left Hand Side	Parapet	Concrete	Horizontal Crack			1820	1			
43-4	Parapet	Right Hand Side	Parapet	Concrete	Spall			2000	90	30		
43-5	3	Bottom Left-Right Hand Side	Panel	Concrete	Delamination With Multi Directional Cracking			490	1960		0.5	
43-6	2	Top Left Hand Corner	Panel	Concrete	Delamination			450	500			
43-7	2	Top Right Hand Corner	Panel	Concrete	Multi Directional Cracking			570	550		0.5	
43-8	2	Centre	Panel	Concrete	Horizontal Crack			1970	0.5			
43-9	2	Centre	Column	Concrete	Horizontal Crack With Calcite			1000	1			
43-10	2	Centre	Panel	Concrete	Delamination			460	320			
43-11	2	Left-Right Hand Side	Column	Concrete	Multi Directional Cracking With Calcite			960	500		0.5	
43-12	2	Bottom Left Hand Corner	Panel	Concrete	Multi Directional Cracking			480	600		0.5	
43-13	2	Bottom Right Hand Corner	Panel	Concrete	Delamination			1200	880			
43-14	1	Top Left + Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	1			
43-15	1	Left-Right Hand Side	Column	Concrete	Horizontal Crack With Calcite			1000	1			
43-16	1	Right Hand Side	Panel	Concrete	Delamination With Multi Directional Cracking			1000	400		0.5	
Parapet-43	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	10						
44-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							

KEY
HL = Hairline crack

APPENDIX 24 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
44-2	3	Top Left Hand Side	Panel	Concrete	Delamination Removed - Spall			310	240	40		
44-3	2	Centre	Panel	Concrete	Horizontal Crack			1100	0.5			
44-4	2	Right Hand Side	Panel	Concrete	Horizontal Crack			950	0.5			
44-5	2	Right Hand Side	Panel	Concrete	Horizontal Crack	5		970	0.5			
44-6	2	Centre	Panel	Concrete	Horizontal Crack			1200	0.5			
44-7	1	Top Left Hand Corner	Panel	Concrete	Delamination Removed - Spall			280	200	20		
44-8	1	Left Hand side	Panel	Concrete	Spall			2300	210	20		
44-9	1	Bottom Right Hand Corner	Panel	Concrete	Rust Stain							
44-10	Parapet Inner	Bottom Left-Right Hand Side	Parapet Inner	Render	Delamination			1900	470			
44-11	Base	Right Hand Side	Base	Concrete	Spall			190	100	100		
Parapet-44	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	10						
45-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							
45-2	3	Top Right Hand Side	Panel	Concrete	Rust Stain							
45-3	3 to 2	Right Hand Side	Panel	Concrete	Calcite Deposit							
45-4	2	Top Right Hand Side	Panel	Concrete	Rust Stain							
45-5	2	Right Hand Side	Column	Concrete	Horizontal Crack			950	0.5			
45-6	1	Right Hand Side	Panel	Concrete	Rust Stain							
45-7	Base	Right Hand Side	Base	Concrete	Rust Stain							
45-8	2	Left Hand side	Panel	Concrete	Delamination Removed - Spall			230	180	40		
45-9	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Delamination			390	130			
45-10	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Delamination			480	130			
45-11	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Spall			390	50	20		
45-12	Parapet Inner	Top Centre	Parapet Inner	Render	Delamination			1000	120			
Parapet-45	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	8						
46-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain			2000	2000			

KEY
HL = Hairline crack

APPENDIX 25 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
46-2	3	Top Left-Right Hand Side	Panel	Concrete	Calcite Deposit			2950	50			
46-3	2	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite	2		1000	0.5			
46-4	2	Top Right Hand Corner	Panel	Concrete	Delamination With Spalling			250	600	30		
46-5	2	Right Hand Side	Column	Concrete	Horizontal Crack With Calcite			800	0.5			
46-6	2	Bottom Right Hand Corner	Panel	Concrete	Previous Repair Spalling			230	460	35		
46-7	2	Bottom Left Hand Corner	Panel	Concrete	Delamination			380	400			
46-8	1	Top Right Hand Corner	Column	Concrete	Horizontal Crack			820	0.5			
46-9	1	Bottom Right Hand Corner	Column	Concrete	Delamination			180	740			
46-10	2	Bottom Right Hand Corner	Panel	Concrete	Poor Finish			340	110			
46-11	Parapet Inner	Top Centre	Parapet Inner	Render	Spall			330	80	15		
46-12	Parapet Inner	Bottom Right Hand Side	Parapet Inner	Render	Spall			630	190	20		
46-13	Parapet Inner	Bottom Right Hand Side	Parapet Inner	Render	Delamination			400	330			
46-14	Parapet Inner	Right Hand Side	Parapet Inner	Render	Spall			420	120	120		
Parapet-46	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	9						
47-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain							
47-2	Parapet	Right Hand Side	Parapet	Concrete	Horizontal Crack			2700	1			
47-3	Parapet	Centre	Parapet	Concrete	Spall			240	130	20		
47-4	Parapet	Centre	Parapet	Concrete	Horizontal Crack			1110	0.5			
47-5	3	Top	Column	Concrete	Calcite Deposit			1300	1000			
47-6	2	Top Left-Right Hand Side	Panel	Concrete	Multi Directional Cracking			1900	300		0.5	
47-7	2	Top Left-Right Hand Side	Column	Concrete	Horizontal Crack With Calcite			990	1			
47-8	2	Centre Left-Right Hand Side	Panel	Concrete	Horizontal Crack			2010	1			
47-9	2	Bottom Left-Right Hand Side	Column	Concrete	Horizontal Crack With Calcite			1000	1			
47-10	1	Top Left Hand Side	Panel	Concrete	Multi Directional Cracking			1020	600		0.5	
47-11	1	Top Right Hand Side	Panel	Concrete	Multi Directional Cracking			640	1500		1	

KEY
HL = Hairline crack

APPENDIX 26 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
47-12	1	Bottom Centre	Column	Concrete	Spall			140	180	15		
47-13	1	Bottom Left + Right Hand Side	Panel	Concrete	Rust Stain	2		60	60			
47-14	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Spall			170	160	20		
47-15	Parapet Inner	Top Left Hand Corner	Parapet Inner	Render	Delamination			300	130			
Parapet-47	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	9						
48-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain			3000	200			
48-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			300	2			
48-3	3	Left-Right Hand Side	Column	Concrete	Calcite Deposit			3000	50			
48-4	Parapet	Bottom Left Hand Corner	Parapet	Concrete	Spall			140	360	30		
48-5	2	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	1			
48-6	2	Left Hand Side	Panel	Concrete	Spall			120	990	40		
48-7	2	Left Hand Side	Panel	Concrete	Calcite Deposit			1850	1850			
48-8	2	Left Hand Side	Panel	Concrete	Spall			70	330			
48-9	1	Top Right Hand Corner	Panel	Concrete	Spall			100	600	40		
48-10	1	Top Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			1000	0.5			
48-11	1	Left Hand Side	Panel	Concrete	Spall			140	2600	40		
48-12	Parapet Inner	Left-Right Hand Side	Parapet Inner	Render	Delamination			1700	1150			
Parapet-48	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	11						
49-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain			3000	2000			
49-2	Parapet	Top Right Hand Side	Parapet	Concrete	Horizontal Crack With Rust Stain			1450	1			
49-3	Parapet	Right Hand Side	Parapet	Concrete	Horizontal Crack With Rust Stain			2650	1			
49-4	Parapet	Centre	Parapet	Concrete	Delamination			790	280			
49-5	3	Bottom Right Hand Corner	Column	Concrete	Horizontal Crack With Calcite			970	1			
49-6	2	Centre	Column	Concrete	Horizontal Crack With Calcite			540	1			
49-7	2	Bottom Right Hand Corner	Panel	Concrete	Delamination With Multi Directional Cracking - Spall			740	1140	15		

KEY
HL = Hairline crack

APPENDIX 27 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
49-8	1	Bottom Right Hand Corner	Panel	Concrete	Multi Directional Cracking			960	210		0.5	
49-9	1	Bottom Left Hand Corner	Panel	Concrete	Delamination With Multi Directional Cracking - Spall			860	290	35		
49-10	3 to 1	Right Hand Side	Column	Concrete	Calcite Deposit			1400	3500			
49-11	Parapet Inner	Bottom Left Hand Corner	Parapet Inner	Render	Delamination			600	180			
49-12	Parapet Inner	Top Left Hand Side	Parapet Inner	Render	Spall			340	130	20		
49-13	Parapet Inner	Centre	Parapet Inner	Render	Delamination			550	450			
Parapet-49	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	9						
50-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			2900	10			
50-2	Parapet	Right Hand Side	Parapet	Concrete	Delamination Removed - Spall			770	130	30		
50-3	Parapet	Top Centre	Parapet	Concrete	Delamination Removed - Spall			860	180			
50-4	Parapet	Top Centre	Parapet	Concrete	Rust Stain							
50-5	3	Right Hand Side	Panel	Concrete	Calcite Deposit							
50-6	2	Left-Right Hand Side	Panel	Concrete	Rust Stain With Calcite							
50-7	1	Top Left-Right Hand Side	Panel	Concrete	Spall			1000	500	60		
50-8	1	Top Left Hand Side	Panel	Concrete	Spall		Yes	800	280	60	60	
50-9	Parapet Inner	Top Right Hand Corner	Panel	Render	Spall		Yes	450	150	20	20	
Parapet-50	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	8						
51-1	Parapet	Top Centre	Parapet	Concrete	Delamination			410	410			
51-2	Parapet	Centre	Parapet	Concrete	Horizontal Crack			2580	3			
51-3	Parapet	Left-Right Hand Side	Parapet	Concrete	Staining							
51-4	3	Top Left-Right Hand Side	Panel	Concrete	Calcite Deposit							
51-5	3	Top Right Hand Side	Column	Concrete	Horizontal Crack			970	0.5			
51-6	3	Right Hand Side	Column	Concrete	Horizontal Crack			990	50			
51-7	3	Right Hand Side	Column	Concrete	Horizontal Crack			490	0.5			
51-8	3	Right Hand Side	Column	Concrete	Horizontal Crack			980	0.5			

KEY
HL = Hairline crack

APPENDIX 28 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
51-9	2	Bottom Right Hand Side	Panel	Concrete	Delamination Removed - Spall			190	130	10		
51-10	2	Right Hand Side	Column	Concrete	Horizontal Crack			950	0.5			
51-11	1	Bottom Centre	Panel	Concrete	Delamination			430	380			
51-12	1	Top Left-Right Hand Side	Panel	Concrete	Rust Stain							
51-13	Parapet Inner	Bottom Left Hand Corner	Parapet Inner	Render	Delamination			1100	800			
51-14	Parapet Inner	Top Left Hand Side	Parapet Inner	Render	Spall			430	160	20		
51-15	Parapet Inner	Top Centre	Parapet Inner	Render	Delamination			710	130			
Parapet-51	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	10						
52-1	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Stain			3000	2000			
52-2	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			1300	1			
52-3	Parapet	Left-Right Hand Side	Parapet	Concrete	Horizontal Crack			1500	1			
52-4	3	Left Hand Side	Panel	Concrete	Rust Stain			1850	30			
52-5	3	Top Left-Right Hand Side	Panel	Concrete	Calcite Deposit			1950	20			
52-6	3	Top Right Hand Corner	Panel	Concrete	Spall With Exposed Corroding Reinforcement			150	60	40	30	20
52-7	3	Bottom Left-Right Hand Side	Panel	Concrete	Horizontal Crack			1950	0.5			
52-8	3	Bottom Left-Right Hand Side	Column	Concrete	Horizontal Crack			1000	0.5			
52-9	3	Left Hand Side	Column	Concrete	Calcite Deposit			1400	50			
52-10	2	Top Left Hand Corner	Panel	Concrete	Calcite Deposit			900	400			
52-11	2	Top Left Hand Corner	Panel	Concrete	Diagonal Crack With Calcite			1070	1			
52-12	2	Top Left-Right Hand Side	Column	Concrete	Horizontal Crack With Calcite			1000	1			
52-13	2	Top Right Hand Corner	Panel	Concrete	Horizontal Crack With Calcite			790	0.5			
52-14	2	Right Hand Side	Column	Concrete	Horizontal Crack With Spall			1000	20	5		
52-15	2	Right Hand Side	Column	Concrete	Horizontal Crack With Spall			1000	30	5		
52-16	1	Top Right Hand Corner	Panel	Concrete	Rust Stain			500	3000			
52-17	1	Left Hand Side	Panel	Concrete	Delamination			560	1450	20		

KEY
HL = Hairline crack

APPENDIX 29 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
52-18	1	Right Hand Side	Panel	Concrete	Spall With Exposed Corroding Reinforcement		Yes	1250	300	40	40	30
52-19	1	Top Right Hand Side	Panel	Concrete	Spall		Yes	160	140	30	30	
52-20	1	Top Left Hand Side	Column	Concrete	Drill Hole	2		15	15			
52-21	1	Top Left Hand Side	Panel	Concrete	Delamination			320	540			
52-22	1	Bottom Left Hand Corner	Column	Concrete	Spall			90	100			
51-23	Parapet Inner	Bottom Centre	Parapet Inner	Render	Delamination			1800	770			
52-24	Parapet Inner	Top Right Hand Side	Parapet Inner	Render	Delamination			470	150			
Parapet-52	Parapet	Left-Right Hand Side	Parapet	Concrete	Rust Spots	11						
53-1	Parapet	Right Hand Side	Parapet	Concrete	Horizontal Crack			1050	1			
53-2	Parapet	Top Centre	Parapet	Concrete	Delamination With Rust Stain			200	60			
53-3	Parapet	Top Left Hand Corner	Parapet	Concrete	Rust Stain			70	140			
53-4	Parapet	Top Left Hand Corner	Parapet	Concrete	Delamination With Rust Stain			300	120			
53-5	3	Centre	Panel	Concrete	Vertical Crack With Delamination			1340	530	1		
53-6	3	Bottom Centre	Panel	Concrete	Rust Stain			190	80			
53-7	3	Centre	Panel	Concrete	Vertical Crack			1270	15			
53-8	3	Centre	Panel	Concrete	Delamination Removed - Spall			200	160	20		
53-9	3	Centre	Panel	Concrete	Vertical Crack			1350	2			
53-10	2	Top Centre	Panel	Concrete	Rust Stain			80	45			
53-11	2	Centre	Panel	Concrete	Rust Stain			400	300			
53-12	2	Centre	Panel	Concrete	Delamination Removed - Spall			310	150	30		
53-13	2	Bottom Left Hand Corner	Panel	Concrete	Delamination Removed - Spall			450	40	20		
53-14	2	Bottom Centre	Panel	Concrete	Rust Stain			400	200			
53-15	2	Left Hand Side	Panel	Concrete	Rust Stain			80	80			
53-16	2	Bottom Centre	Panel	Concrete	Rust Stain			400	200			
53-17	2	Bottom Left Hand Corner	Panel	Concrete	Delamination Removed - Spall			120	120	10		

KEY
HL = Hairline crack

APPENDIX 30 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
53-18	2	Bottom Left Hand Corner	Panel	Concrete	Rust Stain			260	200			
53-19	2	Bottom Left Hand Corner	Panel	Concrete	Rust Stain			140	120			
53-20	2	Bottom Left Hand Corner	Panel	Concrete	Rust Stain			120	20			
53-21	2	Bottom Left Hand Corner	Panel	Concrete	Rust Stain			60	60			
53-22	Parapet	Top Centre	Parapet	Concrete	Horizontal Crack	2		1560	1			
53-23	Parapet	Right Hand Side	Parapet	Concrete	Vertical Crack			1250	0.5			
53-24	Parapet	Right Hand Side	Parapet	Concrete	Vertical Crack			1250	0.5			
53-25	Parapet	Bottom Right Hand Side	Parapet	Concrete	Vertical Crack With Rust Stain							
53-26	Parapet	Bottom Left-Right Hand Side	Parapet	Concrete	Horizontal Crack With Calcite			8000	2			
53-27	Parapet	Top Left Hand Corner	Parapet	Concrete	Spall With Exposed Corroding Reinforcement			60	60	10		10
53-28	3	Top Left Hand Corner	Panel	Concrete	Rust Stain			70	90			
53-29	3	Top Left Hand Corner	Panel	Concrete	Rust Stain			90	200			
53-30	3	Top Centre	Panel	Concrete	Delamination			1000	380			
53-31	2	Bottom Left Hand Corner	Panel	Concrete	Spall With Delamination			1090	500	20		
53-32	2	Bottom Right Hand Corner	Panel	Concrete	Spall With Delamination			700	260	10		
53-33	2	Bottom Right Hand Corner	Panel	Concrete	Spall With Delamination			240	300	10		
53-34	2	Bottom Right Hand Corner	Panel	Concrete	Previous Repair With Multi Directional Cracking			2000	1600		1	
53-35	1	Centre	Panel	Concrete	Spall With Delamination			640	900	20		
53-36	1	Top Right Hand Corner	Panel	Concrete	Spall With Delamination			300	200	15		
53-37	1	Right Hand Side	Panel	Concrete	Previous Repair			2500	380			
53-38	1	Top Right Hand Corner	Panel	Concrete	Drill Hole			45	45	40		
53-39	1	Bottom Centre	Panel	Concrete	Spall With Delamination			300	230	15		
53-40	1	Bottom Right Hand Corner	Panel	Concrete	Spall			300	80	15		
53-41	Parapet	Left Hand Side	Parapet	Concrete	Horizontal Crack With Rust Stain			650	1			
53-42	3	Left Hand Side	Panel	Concrete	Rust Stain			40	40			

KEY
HL = Hairline crack

APPENDIX 31 to 31

ABSEIL SURVEY DEFECT RESULTS

Drop / Defect Ref.	Level	Location	Element	Material	Defect Details	Frequency of Defect	Arris Defect	Length (L1)	Width (W1)	Depth (D1)	Width (W2)	Depth to Bar (D2)
53-43	3	Left Hand Side	Panel	Concrete	Horizontal Crack With Calcite			1250	0.5			
53-44	2	Top Right Hand Side	Panel	Concrete	Diagonal Crack With Calcite & Rust Stain			1300	0.5			
53-45	2	Left-Right Hand Side	Panel	Concrete	Spall With Rust Stain			280	250	30		
53-46	2	Bottom Left Hand Corner	Panel	Concrete	Multi Directional Cracking With Calcite			790	650		0.5	
53-47	1	Right Hand Side	Panel	Concrete	Delamination With Spalling and Rust Stain			550	480			
53-48	Base	Right Hand Side	Base	Concrete	Spall			800	530	190		

KEY
HL = Hairline crack

APPENDIX 32

FLANK WALL PANEL

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Level	Element	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Cement Content by Weight of Sample (%)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Reinforcement Depth*
1	1	Top	Flank Panel	5-30	64	78	75	72	70	72	64	1	14.0	0.32	2.29	Extremely High	Extremely High
2				30-55									14.0	0.24	1.71	Extremely High	
3				55-80									14.0	0.26	1.86	Extremely High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 33

PARAPET PANELS

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Level	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
16	28	Centre	5-30	48	42	45	31	58	50	31	4	0.52	3.71	Extremely High	Extremely High
17			30-55									0.48	3.43	Extremely High	
18			55-80									0.43	3.07	Extremely High	
19	10	Centre	5-30	37	33	44	27	14	21	14	5	0.42	3.00	Extremely High	Extremely High
20			30-55									0.43	3.07	Extremely High	
21			55-80									0.39	2.79	Extremely High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 34

COLUMNS UPPER

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
4	2	5-30	47	50	48	54	50	52	47	1	0.17	1.21	High	High
5		30-55									0.14	1.00	High	
6		55-80									0.12	0.86	High	
10	28	5-30	48	50	47	49	46	42	42	1	0.11	0.79	Moderate	Moderate
11		30-55									0.11	0.79	Moderate	
12		55-80									0.07	0.50	Moderate	
22	10	5-30	46	44	46	52	54	48	44	2	0.19	1.36	High	High
23		30-55									0.12	0.86	High	
24		55-80									0.11	0.79	Moderate	
43	49	5-30	53	41	50	60	61	57	41	3	0.12	0.86	High	Moderate
44		30-55									0.09	0.64	Moderate	
45		55-80									0.08	0.57	Moderate	
64	36	5-30	51	49	43	67	51	68	43	1	0.07	0.50	Moderate	Low
65		30-55									0.05	0.36	Low	
66		55-80									0.05	0.36	Low	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 35

COLUMNS LOWER

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
7	2	5-30	56	54	55	58	59	59	54	13	0.59	4.21	Extremely High	Extremely High
8		30-55									0.30	2.14	Extremely High	
9		55-80									0.40	2.86	Extremely High	
13	28	5-30	44	42	46	46	46	47	42	20	0.31	2.21	Extremely High	Extremely High
14		30-55									0.25	1.79	Extremely High	
15		55-80									0.19	1.36	High	
25	10	5-30	38	44	46	48	47	54	38	1	0.18	1.29	High	High
26		30-55									0.13	0.93	High	
27		55-80									0.12	0.86	High	
46	49	5-30	45	46	45	52	51	49	45	4	0.15	1.07	High	Moderate
47		30-55									0.10	0.71	Moderate	
48		55-80									0.08	0.57	Moderate	
67	36	5-30	44	45	46	46	44	62	44	1	0.11	0.79	Moderate	Moderate
68		30-55									0.08	0.57	Moderate	
69		55-80									0.05	0.36	Low	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 36

LEVEL 3 PANELS

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
28	50	5-30	64	65	64	65	67	67	64	1	0.24	1.71	Extremely High	High
29		30-55									0.13	0.93	High	
30		55-80									0.18	1.29	High	
49	36	5-30	74	76		70	57	50	50	4	0.10	0.71	Moderate	High
50		30-55									0.12	0.86	High	
51		55-80									0.10	0.71	Moderate	
70	28	5-30	73	73	74	66	62	79	62	2	0.33	2.36	Extremely High	Extremely High
71		30-55									0.28	2.00	Extremely High	
72		55-80									0.25	1.79	Extremely High	
85	11	5-30	72	68	71	61	67	59	59	2	0.28	2.00	Extremely High	Extremely High
86		30-55									0.26	1.86	Extremely High	
87		55-80									0.24	1.71	Extremely High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 37

LEVEL 2 PANELS

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Level	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
31	50	2 Top	5-30	79	80	79	80	79	80	79	1	0.12	0.86	High	High
32			30-55									0.12	0.86	High	
33			55-80									0.12	0.86	High	
34	50	2 Bottom	5-30	60	60	61	47	45	54	45	1	0.16	1.14	High	High
35			30-55									0.15	1.07	High	
36			55-80									0.13	0.93	High	
52	36	2 Top	5-30	76			73	59	54	54	2	0.13	0.93	High	High
53			30-55									0.14	1.00	High	
54			55-80									0.14	1.00	High	
55	36	2 Bottom	5-30	79			85			79	3	0.23	1.64	Extremely High	High
56			30-55									0.19	1.36	High	
57			55-80									0.18	1.29	High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 38

LEVEL 2 PANELS

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Level	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
73	28	2 Top	5-30	80	77	73	70	72	74	70	3	0.13	0.93	High	High
74			30-55									0.14	1.00	High	
75			55-80									0.12	0.86	High	
76	28	2 Bottom	5-30	70	69	80	61	72	73	61	3	0.30	2.14	Extremely High	High
77			30-55									0.18	1.29	High	
78			55-80									0.12	0.86	High	
88	11	2 Top	5-30				37	66		37	1	0.14	1.00	High	High
89			30-55									0.13	0.93	High	
90			55-80									0.13	0.93	High	
91	11	2 Bottom	5-30	67	66	64	51	49	50	49	1	0.13	0.93	High	High
92			30-55									0.15	1.07	High	
93			55-80									0.14	1.00	High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 39

LEVEL 1 PANELS

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Level	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
37	50	1 Top	5-30	53	55	55	64	48	67	48	2	0.36	2.57	Extremely High	Extremely High
38			30-55									0.38	2.71	Extremely High	
39			55-80									0.48	3.43	Extremely High	
40	50	1 Bottom	5-30	72	72	71				71	1	0.26	1.86	Extremely High	High
41			30-55									0.17	1.21	High	
42			55-80									0.13	0.93	High	
58	36	1 Top	5-30	75			65	65	69	65	2	0.36	2.57	Extremely High	Extremely High
59			30-55									0.36	2.57	Extremely High	
60			55-80									0.45	3.21	Extremely High	
61	36	1 Bottom	5-30	43	76	77	62	62	63	43	1	0.59	4.21	Extremely High	Extremely High
62			30-55									0.54	3.86	Extremely High	
63			55-80									0.55	3.93	Extremely High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 40

LEVEL 1 PANELS

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Level	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
79	28	1 Top	5-30	75	75	77	67	78	66	66	3	0.24	1.71	Extremely High	High
80			30-55									0.22	1.57	Extremely High	
81			55-80									0.17	1.21	High	
82	28	1 Bottom	5-30	70	74	77	76	77	73	70	2	0.57	4.07	Extremely High	High
83			30-55									0.29	2.07	Extremely High	
84			55-80									0.19	1.36	High	
94	11	1 Top	5-30	63	65	65	63	61	60	60	2	0.60	4.29	Extremely High	Extremely High
95			30-55									0.33	2.36	Extremely High	
96			55-80									0.30	2.14	Extremely High	
97	11	1 Bottom	5-30	78	79	78	71	78	73	71	2	0.50	3.57	Extremely High	Extremely High
98			30-55									0.50	3.57	Extremely High	
99			55-80									0.40	2.86	Extremely High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 41

BASE UNITS

CONCRETE COVER TO REINFORCEMENT, CARBONATION DEPTH & CHLORIDE RESULTS

Sample	Drop Ref.	Sample Increment (mm)	Minimum Concrete Cover to Horizontal Reinforcement (mm)			Minimum Concrete Cover to Vertical Reinforcement (mm)			Minimum Concrete Cover (mm)	Depth of Carbonation (mm)	Chloride Content By Weight of Sample (%)	Chloride Content By Weight of Cement (%)	Chloride Risk Level	Corrosion Risk Level at Min. Rebar Depth*
100	34	5-30	63	67	56	56	57	57	56	1	0.50	3.57	Extremely High	High
101		30-55									0.30	2.14	Extremely High	
102		55-80									0.20	1.43	High	
103	7	5-30	55	56	52	58	59	57	52	1	0.80	5.71	Extremely High	Extremely High
104		30-55									0.40	2.86	Extremely High	
105		55-80									0.30	2.14	Extremely High	
106	20	5-30	57	56	55	59	55	51	51	1	0.50	3.57	Extremely High	High
107		30-55									0.20	1.43	High	
108		55-80									0.20	1.43	High	

An assumed cement content of 14.0% was used to calculate the corrosion risk levels

APPENDIX 42

PHOTOGRAPHS

Photograph 1 – Seawall South end

Photograph 2 – Seawall North end

APPENDIX 43

DEFECT PHOTOGRAPHS

Photograph 3 – Defect 4-13 corrosion damage to parapet wall

Photograph 4 – Defect 10-11 spalling parapet wall

APPENDIX 44

PHOTOGRAPHS

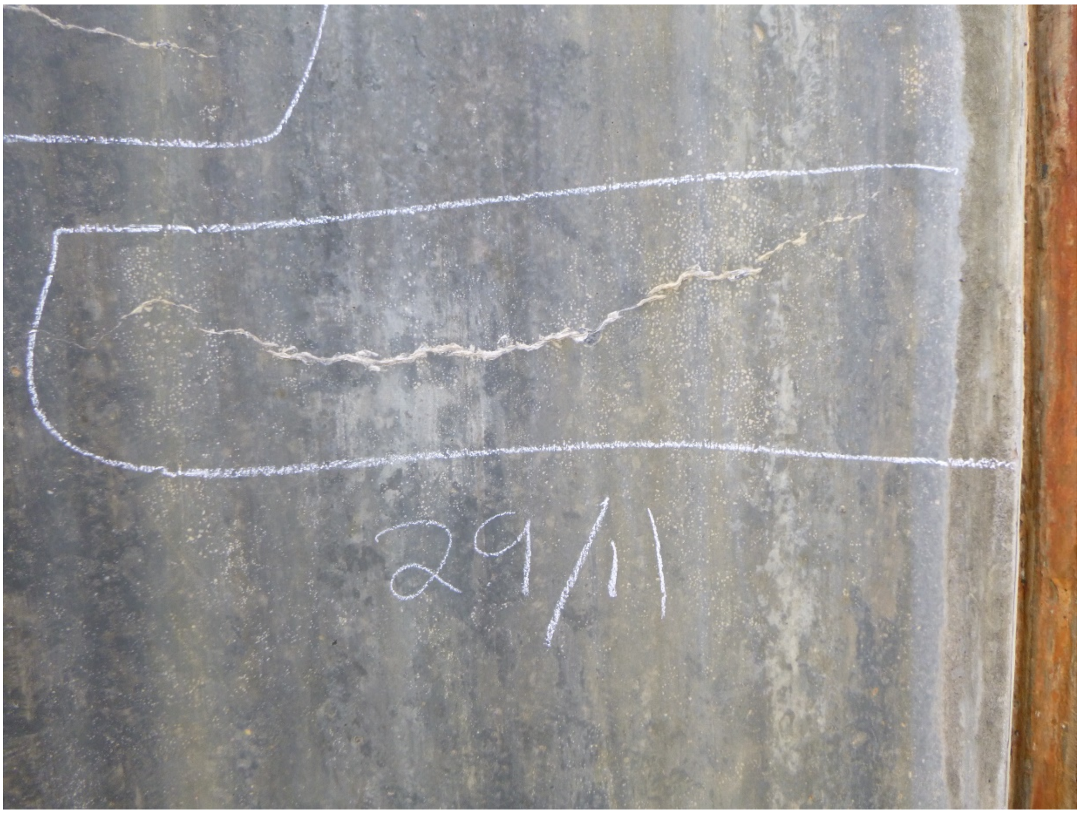
Photograph 5 – Defect 14-2 leakage through wall forming calcite dripstone

Photograph 6 – Defect 17-9 area of delamination and corrosion staining

APPENDIX 45

PHOTOGRAPHS

Photograph 7 – Defect 24-8 spalling



Photograph 8 – Defect 29/11 calcite filled cracks

APPENDIX 46

PHOTOGRAPHS


Photograph 9 – Defect 33-8 cracking and calcite staining


Photograph 10 – Defect 42-3 corrosion staining to panel

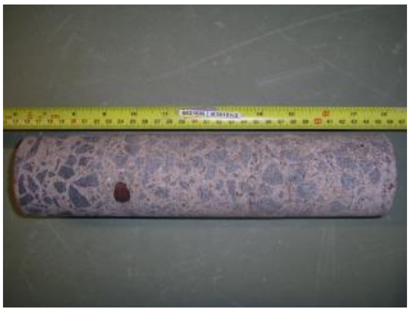
SANDBERG
CONSULTING ENGINEERS
INVESTIGATION INSPECTION
MATERIALS TESTING

Sandberg LLP
5 Carpenters Place
London SW4 7TD

Tel: 020 7565 7000
Fax: 020 7565 7101
email: mike.eden@sandberg.co.uk
web: www.sandberg.co.uk

Report - 68316/K

REPORT ON THE PETROGRAPHIC EXAMINATION OF FIVE CONCRETE CORES
(Project: Robin Hood Bay – Sea Wall 20H/01363, Cores 1-5)


Birmingham City Laboratories
Phoenix House
Valepits Road
Garretts Green
Birmingham
B33 0TD

This report comprises
8 pages of text
Appendix A – 8 pages
Appendix B – 15 pages / photographs
Appendix C – 10 pages / photomicrographs
Appendix D – 6 pages / photomicrographs
Appendix E – 6 pages

For the attention of Trevor Box

10 November 2019

SANDBERG
CONSULTING ENGINEERS
INVESTIGATION INSPECTION
MATERIALS TESTING

Sandberg LLP
5 Carpenters Place
London SW4 7TD

Tel: 020 7565 7000
Fax: 020 7565 7101
email: mike.eden@sandberg.co.uk
web: www.sandberg.co.uk

Report - 68316/K

REPORT ON THE PETROGRAPHIC EXAMINATION OF FIVE CONCRETE CORES (Project: Robin Hood Bay – Sea Wall 20H/01363, Cores 1-5)

1 INTRODUCTION

Five concrete cores were provided on the 23 September 2020. It was requested that the samples be examined petrographically and that the cover concrete between the outer surfaces and the reinforcement in Cores 3, 4 and 5 be examined with the scanning electron microscope with particular reference to the free lime content of the binder. Instructions to proceed with the analysis were submitted under Purchase Order No. 4510693386.

2 SAMPLES

The following samples were provided for analysis:

GMRS Ref.	Client / site reference	Core diameter / length
K16151/1	**Core 1**, Column 17 - full thickness of front "flange" (high level)	70mm / 311-325mm
K16151/2	**Core 2**, Column 16 - part thickness (tidal zone)	70mm / 149-159mm
K16151/3	**Core 3**, Panel 21 - full thickness (high level)	70mm / 294-211mm
K16151/4	**Core 4**, Panel 11 - full thickness (tidal zone)	70mm / 278-291mm
K16151/5	**Core 5**, Parapet 11 - full thickness with concrete infill behind (base of seaward face 150mm above joint with top panel)	70mm / 206-210mm

3 TEST METHODS

The petrographic testing was carried out in accordance with BS 1881-211, 2016. A summary of the procedures followed and a glossary of terms used in the description of the samples are given in Appendix E. In brief, the following work was carried out.

(i) The samples were examined as received and photographed.

(ii) Fourteen fluorescent-resin impregnated thin sections were prepared from each core as follows:

GMRS Ref.	Client / site reference	Thin section locations:
K16151/1	Core 1, Column - High level	TS1 – 0-44mm from outer end TS2 – mid-depth (46x30mm) TS3 – 0-44mm from inner end
K16151/2	Core 2, Column - Tidal zone	TS1 – 0-42mm from outer end TS2 – 42-85mm from outer end
K16151/3	Core 3, Panel - High level	TS1 – 0-28mm from outer end TS2 – 19-50mm from outer end TS3 – 50-80mm from outer end TS4 – 70-100mm from outer end
K16151/4	Core 4, Panel - Tidal zone	TS1 – 0-29mm from outer end TS2 – 20-50mm from outer end TS3 – 50-110mm from outer end
K16151/5	Core 5, Parapet - Base of seaward face	TS1 – 0-43mm from outer end TS2 – 0-46mm from inner end

(iii) The thin sections were examined with a Zeiss petrological photomicroscope and the distribution of porosity and microcracking was assessed from an examination of the thin sections in fluorescent light using the petrological microscope.

(iv) Multiple resin-impregnated polished surfaces were prepared to represent the cover concrete between the reinforcement and the outer surfaces at the outer ends of Cores 3, 4 and 5. Each polished surface measured about 30x30mm.

(v) The polished surfaces were examined with a Hitachi SU 3500 scanning electron microscope and chemical analyses were made of the residual cement grains and cement paste using an Oxford Instruments INCA energy-dispersive X-ray microanalysis system calibrated with certified mineral standards.

4 PETROGRAPHIC EXAMINATION RESULTS

4.1 Visual description of the samples

Visual descriptions of the samples as received are given in Tables A1-A3 in Appendix A and photographs illustrating the samples as received are given in Appendix B.

4.2 Petrographic description of the aggregate

A petrographic description of the aggregate is given in Tables A4 and A5 in Appendix A.

4.3 Petrographic description of the paste

A petrographic description of the paste in each sample is given in Tables A6-A8 in Appendix A. Photomicrographs illustrating the typical appearance of the paste in the thin sections are given in Appendix C.

5 SCANNING ELECTRON MICROSCOPY AND X-RAY MICROANALYSIS OF THE OUTER COVER CONCRETE IN CORES 3, 4 AND 5

The polished surfaces where scanned for the presence of residual free lime (anhydrous calcium oxide) in the remaining unhydrated cement grains present in the paste of each sample. X-ray phase mapping was used to assist in the detection of free lime in the residual unhydrated cement particles and some of these phase maps are given in Figures D1 to D6 in Appendix D.

The results are summarised in the following table:

<table>
<tr><th>GMRS Ref.</th><th>Client / site reference</th><th>Cement hydration</th><th>Free lime occurrence</th></tr>
<tr><td>K16151/3</td><td>Core 3,
Panel - High level</td><td rowspan="3">Almost complete hydration. No fully unhydrated cement grains seen. Throughout all samples there are abundant pseudomorphically hydrated cement grains that contain residual unhydrated calcium-alumino-ferrite. The occurrence of portlandite (calcium hydroxide) indicates the hydration residual lime in the Portland cement.</td><td rowspan="3">No unhydrated / free lime observed in the remaining unhydrated cement particles in these samples.</td></tr>
<tr><td>K16151/4</td><td>Core 4,
Panel - Tidal zone</td></tr>
<tr><td>K16151/5</td><td>Core 5,
Parapet - Base of seaward face</td></tr>
</table>

6 DISCUSSION

6.1 Aggregate characteristics – Column cores (Cores 1 and 2)

The coarse aggregate is flint gravel with particles graded from about 20mm down and the fine aggregate is composed of a mixture of siliceous medium sand and crushed particles of flint of the same type as those described in the coarse aggregate. The coarse and fine aggregates are composed of dense and robust rock types that would be expected to have a high compressive strength and low water absorption.

6.2 Aggregate characteristics – Panel and Parapet cores (Cores 3, 4 and 5)

The coarse aggregate is composed entirely of crushed particles of basalt. The fine fraction of the aggregate consists of a mixture of siliceous fine to medium sand composed mainly of quartz and crushed particles of basalt of the same type as those present in the coarse aggregate. The sand contains a wide range of rock types that includes particles of shell indicating that it is probably of marine origin.

6.3 Alkali-aggregate reaction (AAR) and aggregate deterioration

The aggregate in all samples includes rock types that are potentially reactive with alkalies in cement paste. None of the samples however show evidence to suggest the occurrence of AAR.

6.4 General paste characteristics in the samples at depth

(i) Binder type

The binder in all samples is based on Portland cement and the paste contains very small quantities of unhydrated cement grains that typically resemble particles of sulfate-resisting Portland cement. None of the samples contain cement replacement materials such as PFA or GGBS.

(ii) General moisture ingress and paste alteration

Core 1 shows no evidence for general moisture ingress or for recrystallization of the cement hydrates. In Cores 2, 3, 4 and 5 the general ingress of moisture through the concrete has led to a low level of recrystallization of the cement hydrates and the formation of small quantities of secondary ettringite and occasionally portlandite within the voids.

In Core 2 there is localised extensive moisture movement along cracks associated with reinforcement corrosion and this is discussed in more detail in Section 6.5 (ii) of this report.

It should be noted that there is little evidence to suggest that the samples have been generally weakened as a result of moisture ingress and the general extent of alteration of the paste in all samples is low.

(iii) Apparent water/cement ratio

The current levels of microporosity of the paste, the size and distribution of the portlandite crystals and the amounts of unhydrated cement have been used in conjunction with laboratory control concretes to make a petrographic assessment of the water/cement ratios for these samples.

The current levels of paste microporosity and general petrographic observations are consistent with the following water/cement ratios:

GMRS Ref.	Client reference	Apparent Water / cement ratio Note 1
K16151/1	Core 1, Column - High level	0.45-0.50, typically 0.45
K16151/2	Core 2, Column - Tidal zone	0.45-0.50, typically 0.45
K16151/3	Core 3, Panel - High level	0.45-0.50, typically 0.50
K16151/4	Core 4, Panel - Tidal zone	0.45-0.50, typically 0.50
K16151/5	Core 5, Parapet - Base of seaward face	0.45-0.50, typically 0.50

Note 1: The error in this measurement is typically of the order of +/- 0.1. The possible effects of moisture ingress on the microporosity of the paste contribute to uncertainty in the petrographic measurement of the water/cement ratios of these samples.

6.5 Reinforcement corrosion

(i) Core 1, Column - High level

This sample contains no reinforcement or reinforcement corrosion products.

(ii) Core 2, Column - Tidal zone

This sample has the remains of substantially corroded reinforcement at about 50mm depth. There are locally abundant surface-parallel cracks at the level of the corroded reinforcement, many of which are completely infilled with corrosion products. There is also some localised calcite deposition along cracks associated with the corroded reinforcement.

The paste surrounding the remains of the reinforcement is predominantly uncarbonated and in the absence of significant carbonation it is considered highly probably that the reinforcement results from chloride ingress from seawater.

(iii) Core 3, Panel - High level

This sample has a 14mm diameter reinforcing bar with a minimum depth of cover of about 81mm. There are minor of corrosion products on the surface of the reinforcement, but there is minimal loss of section of the reinforcement (See Figure A7 in Appendix A). The paste surrounding the reinforcement is uncarbonated and it is therefore probable that the corrosion reflects the ingress of sea water containing chlorides. It should be noted that the SEM analysis of the hydrated cement grains in this sample shows elevated chloride levels.

(iv) Core 4, Panel - Tidal zone

There is moderate corrosion and loss of section of the reinforcement at the outer core end located at a depth of about 97mm (See Figure A10 in Appendix A). The corrosion of the reinforcement at the outer core end has led to the development of surface-parallel cracks infilled with corrosion products. The paste surrounding the outer reinforcement at 97mm depth is uncarbonated and it is therefore probable that the corrosion is related to chloride ingress from seawater. It should be noted that the SEM analysis of the hydrated cement grains in this sample shows elevated chloride levels.

No evidence is seen to suggest significant corrosion of the reinforcement at the inner core end other than traces of corrosion products on the reinforcement surface (See Figure A10 in Appendix A).

(v) Core 5, Parapet - Base of seaward face

This sample has reinforcing bars with minimum depths of cover of 80mm, 134mm and 150mm. No evidence is seen to suggest significant corrosion or loss of section of the bar located as 80mm (See Figure A13 in Appendix A).

The bars at 134, and 150mm depth have undergone moderate corrosion with very minor loss of section (See Figure A13 in Appendix A). The paste surrounding the reinforcement at 134mm and 150mm is uncarbonated and it is therefore probable that the corrosion is related to chloride ingress from seawater. It should be noted that the SEM analysis of the hydrated cement grains in this sample shows elevated chloride levels.

6.6 Free lime content of the cover concrete (between the outer surfaces and the reinforcement) in Cores 3, 4 and 5

(i) Unhydrated lime in the residual unhydrated Portland cement grains

Data given in Lee, 1988 indicates that typical UK Portland cements have free lime contents of between 0.6 and 2.9%. Free lime hydrates rapidly in the presence of moisture and residual free lime would not normally be expected to be seen in concrete other than within the centres of the larger unhydrated Portland cement grains where it would not have had the opportunity to hydrate. The degree of cement hydration in all samples is exceptionally high and no fully unhydrated cement grains have been found within these samples. Extensive X-ray phase mapping was carried out for the presence of free lime in the occasional residual cement grains found within each sample, but no free lime has been detected in the cover concrete in these samples.

(ii) Hydrated lime (portlandite)

Free lime typically undergoes rapid reaction with water to form calcium hydroxide (portlandite) during the early stages of cement hydration. Portlandite occurs in abundance in all samples and the observed quantities of portlandite are typically within the normal range to be expected for hydrated Portland cement paste in concrete.

6.7 Surface deterioration

The outer surfaces of Cores 1, 2, 3 and 4 are coated with layered deposits of calcite and the surfaces of the two panel cores appear to have been partially ground with exposed aggregate particles that appear to be ground flush with the surface.

In Core 2 there is some shallow surface-parallel cracking with calcite occurring within cracks. The origin of the shallow surface-parallel cracking at the outer end of Core 2 is unclear, but it is possible that it results from localised sulfate attack that has subsequently been over printed by calcite deposition.

The occasional presence of traces of thaumasite within elongate crack-like voids at the outer surface of Core 4 is indicative of thaumasite formation as a result of exposure to sea water but there is little unambiguous evidence to suggest weakening at the surface of this core as a result of sulfate attack.

6.8 Magnitude of deterioration

With respect to the Grades of Deterioration table given in Appendix E the levels of deterioration of these samples are considered to be as follows:

GMRS Ref.	Client sample reference	Level of deterioration
K16151/1	Core 1, Column - High level	Level 2
K16151/2	Core 2, Column - Tidal zone	Level 4 [Note 1]
K16151/3	Core 3, Panel - High level	Level 2
K16151/4	Core 4, Panel - Tidal zone	Level 4 [Note 1]
K16151/5	Core 5, Parapet - Base of seaward face	Level 2

Note 1: The deterioration is localised to the corroded reinforcement where localised cracking has developed as a result of reinforcement corrosion. It should however be noted that the concrete distant from the corroded reinforcement is at Level 2.

7 CONCLUSIONS

7.1 The aggregate throughout all samples is composed of dense and robust rock types showing no evidence for deterioration within the concrete.

7.2 The aggregate includes rock types that are possibly reactive with alkalies in cement paste in all samples. No evidence however has been found to suggest the occurrence of AAR in these samples.

7.3 The binder in all samples resembles sulfate-resisting Portland cement. The current levels of microporosity and general petrographic observations point to moderately low water/cement ratios of the order of 0.45 – 0.50.

7.4 Substantial reinforcement corrosion and some loss of section to the reinforcement have occurred in Cores 2 and 4 both of which are from the tidal zone. The minimum depths of cover to the reinforcement are 50mm and 97mm respectively for Cores 2 and 4. The reinforcement corrosion in Cores 2 and 4 is likely to be related to the ingress of sea water into the concrete and elevated chloride levels in the cement paste surrounding the reinforcement.

7.5 Much lower degrees of reinforcement corrosion are seen in Cores 3 (High level core) and 5 (Parapet) with minimal loss of section and no evidence for cracking in these samples as a result of reinforcement corrosion. It is again probable that the corrosion reflects elevated chloride levels in the paste surrounding the reinforcement due to the ingress of seawater.

7.6 The SEM analysis of the paste in Cores 3, 4 and 5 shows elevated levels of chloride at the depth of the outer reinforcement indicating the potential for further chloride-induced corrosion of the reinforcement in damp conditions.

7.7 No free lime has been detected in Cores 3, 4 and 5. The almost complete hydration of the Portland cement grains in these samples is likely to be a factor in the lack of free lime in these cores.

8 REMARKS

The above concludes the requested programme of testing. Please do not hesitate to contact us if we can be of any further assistance in this matter.

Birmingham City Laboratories
Phoenix House
Valepits Road
Garretts Green
Birmingham
B33 0TD

for GEOMATERIALS RESEARCH SERVICES
(part of Sandberg LLP)

M. A. Eden, BSc., MSc., FGS., C.Geol., FIMMM
Partner

For the attention of Trevor Box

10 November 2020

Samples can only be retained for a period of one month from the date of issue of the report unless we are instructed otherwise. Samples can be returned or retained for a further charge.
Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.

APPENDIX A – PETROGRAPHIC DESCRIPTION OF THE SAMPLES

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A1 OF 8: VISUAL DESCRIPTION OF THE SAMPLES

GMRS Ref.	**K16151/1**	**K16151/2**
Client Ref.	**Core 1, Column 17 - full thickness of front "flange" (high level)**	**Core 2, Column 16 - part thickness (tidal zone)**
Core Diameter / length	70mm / 311-325mm	70mm / 149-159mm
Description of outer end	Front: Flat surface covered with layered calcite deposits	Front: Flat partially spalled surface coated with the remnants of a bituminous coating. Abundant white deposits present on the broken areas of surface.
Description of inner end	Rear: Slightly uneven surface coated with the remnants of a fine mortar layer	Rear: Broken end
Paste colour	Medium brownish grey	Medium grey
Macroscopic cracking	Core breaks at 117mm and 215mm below outer end. Surface-parallel fine crack close to inner end at 305mm below outer end.	Core break associated with severe reinforcement corrosion at 50mm depth below the outer core end.
Carbonation at outer end:		
General depth (mm)	0.1-0.5mm	0.5-1.5mm
Maximum depth (mm)	2.3mm	41mm - very patchy, minor carbonation along occasionally penetrating along perpendicular microcracks
Carbonation at inner end:		
General depth (mm)	0.5-0.8mm	Not measured
Maximum depth (mm)	2.5mm	-
Reinforcement:		
Diameter / Min depth of cover	None seen	None seen
Corrosion	None seen	Extensive corrosion products on core break at 50mm depth
Carbonation at the reinforcement	No reinforcement	Uncarbonated but traces of calcite deposition in cracks.
Voids:		
Maximum size (mm)	9mm	4mm
Typical size (mm)	1-2mm	1mm
Estimated excess void content (%)	1.5%	1.0%

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APPENDIX A – PETROGRAPHIC DESCRIPTION OF THE SAMPLES

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A2 OF 8: VISUAL DESCRIPTION OF THE SAMPLES

GMRS Ref.	**K16151/3**	**K16151/4**
Client Ref.	**Core 3, Panel 21 - full thickness (high level)**	**Core 4, Panel 11 - full thickness (tidal zone)**
Core Diameter / length	70mm / 294-211mm	70mm / 278-291mm
Description of outer end	Flat, ground surface coated with layered calcite deposits.	Flat, ground surface coated with layered calcite deposits.
Description of inner end	Slightly uneven and rough surface	Slightly uneven and rough surface
Paste colour	Medium brownish grey	Medium to dark greyish brown
Macroscopic cracking	None seen	Extensive surface-parallel fine cracking associated with corroded reinforcement at about 100mm depth.
Carbonation at outer end:		
General depth (mm)	0.4-1.0mm	0.5-1.0mm
Maximum depth (mm)	5.1mm	2.9mm
Carbonation at inner end:		
General depth (mm)	Not measured	Not measured
Maximum depth (mm)	-	-
Reinforcement:		
Diameter / Min depth of cover	14/81mm	12mm / 97mm 17mm / 232mm
Corrosion	Minor corrosion products, negligible loss of section. (See Figure A7)	Bar at 97mm: Moderate corrosion with moderate loss of section and extensive corrosion staining and associated cracking (See Figure A10). Bar at 232mm: Trace corrosion, no loss of section (See Figure A10).
Carbonation at the reinforcement	Uncarbonated	Uncarbonated
Voids:		
Maximum size (mm)	3mm	5mm
Typical size (mm)	1mm	1mm
Estimated excess void content (%)	0.5%	0.5%

APPENDIX A – PETROGRAPHIC DESCRIPTION OF THE SAMPLES

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A3 OF 8: VISUAL DESCRIPTION OF THE SAMPLES

GMRS Ref.	**K16151/5**
Client Ref.	**Core 5, Parapet 11 - full thickness with concrete infill behind (base of seaward face 150mm above joint with top panel)**
Core Diameter / length	70mm / 206-210mm
Description of outer end	Flat, slightly rough surface with a thin resin-like coating that contains Portland cement
Description of inner end	Flat, slightly rough surface
Paste colour	Medium brownish grey
Macroscopic cracking	None seen
Carbonation at outer end:	
General depth (mm)	5.5mm
Maximum depth (mm)	8.8mm
Carbonation at inner end:	
General depth (mm)	0.5-0.8mm
Maximum depth (mm)	3.7mm
Reinforcement:	
Diameter / Min depth of cover	10mm / 80mm, 10mm / 134mm, 12mm / 150mm
Corrosion	Bar at 80mm: Negligible corrosion, no loss of section (See Figure A13). Bar at 134mm: Negligible corrosion, no loss of section (See Figure A13). Bar at 150mm: Moderate corrosion, very minor loss of section (See Figure A13).
Carbonation at the reinforcement	Uncarbonated
Voids:	
Maximum size (mm)	3mm
Typical size (mm)	1mm
Estimated excess void content (%)	1.0%

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A4 OF 8: PETROGRAPHIC DESCRIPTION OF THE AGGREGATE

Laboratory ref.	**K16151/1**	**K16151/2**	**K16151/3**
Client sample ref.	**Core 1, Column 17 - full thickness of front "flange" (high level)**	**Core 2, Column 16 - part thickness (tidal zone)**	**Core 3, Panel 21 - full thickness (high level)**
Coarse aggregate:			
Maximum size (mm)	17mm	15mm	15mm
Typical shape	Subangular	Angular	Angular
Major rock types	Flint	Flint	Basalt
Minor rock types	-	-	-
Trace rock types	Sandstone	Limestone, Quartzite	-
Fine aggregate:			
Grading (estimated grading classification)	Medium	Medium	Fine to medium
Maximum size (mm)	4mm	4mm	4mm
Typical shape	Subangular to subrounded	Subangular to subrounded	Subangular
Major rock types	Quartz, Flint	Quartz, Flint	Quartz, Basalt
Minor rock types	Quartzite	Quartzite	Quartzite, Sandstone, Ironstone, Chert
Trace rock types	Ironstone, Glauconite	Ironstone, Glauconite	Limestone, Shell, Meta-argillite
Alkali-aggregate reaction:			
Gel on sides of core	None seen	None seen	None seen
Gel in voids	None seen	None seen	None seen
Gel in cracks	None seen	None seen	None seen

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A5 OF 8: PETROGRAPHIC DESCRIPTION OF THE AGGREGATE

Laboratory ref.	**K16151/4**	**K16151/5**
Client sample ref.	**Core 4, Panel 11 - full thickness (tidal zone)**	**Core 5, Parapet 11 - full thickness with concrete infill behind (base of seaward face 150mm above joint with top panel)**
Coarse aggregate:		
Maximum size (mm)	15mm	19mm
Typical shape	Angular	Angular
Major rock types	Basalt	Basalt
Minor rock types	-	-
Trace rock types	-	-
Fine aggregate:		
Grading (estimated grading classification)	Fine to medium	Fine to medium
Maximum size (mm)	4mm	4mm
Typical shape	Subangular	Subangular
Major rock types	Quartz, Basalt	Quartz, Basalt
Minor rock types	Quartzite, Sandstone, Ironstone, Chert	Quartzite, Sandstone, Ironstone, Chert
Trace rock types	Limestone, Shell, Meta-argillite	Limestone, Shell, Meta-argillite
Alkali-aggregate reaction:		
Gel on sides of core	None seen	None seen
Gel in voids	None seen	None seen
Gel in cracks	None seen	None seen

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A6 OF 8: PETROGRAPHIC DESCRIPTION OF THE PASTE

GMRS Ref.	**K16151/1**	**K16151/2**
Client Ref.	**Core 1, Column 17 - full thickness of front "flange" (high level)**	**Core 2, Column 16 - part thickness (tidal zone)**
Cement type	Portland - resembles SRPC	Portland - resembles SRPC
Cement replacement	None seen	None seen
Unhydrated cement (estimated. vol.% of paste)	<1%	<1%
Portlandite (estimated. vol.% of paste)	7%	12% - patchy distribution with extensive leaching of portlandite from the paste cracking and core break.
Portlandite - typical crystal size	0.01-0.04mm	0.01-0.05mm
Apparent water/cement ratio	0.45-0.50, typically 0.45	0.45-0.50, typically 0.45
Porosity		
General level	Low to moderate	Low to moderate
Porosity distribution	Patchy	Patchy
Microcracking level	Moderate there are two zones of surface-parallel microcracks at closer to mid-depth in the core the cause of which is uncertain.	Minor radial microcracking around aggregate surfaces
Fine cracking	Narrow zone of surface-parallel fine cracks and microcracks about 10-15mm from the rear end. The cracks pass through aggregate and paste and are empty.	Surface-parallel cracking associated with the corroded reinforcement. The cracks contain corrosion products and calcite. Substantial leaching of portlandite from the paste within about 10mm of the crack surfaces.
Crack fillings	None seen	Calcite and corrosion products seen in cracks close to the core break. Traces of portlandite sometimes seen in cracks in the cover concrete.
Void fillings	None seen	Minor amounts of euhedral secondary portlandite and ettringite
Outer surface alteration	The surface is coated with layered calcite deposits. Very shallow fine-textured carbonation.	Shallow surface-parallel microcracking with calcite deposition within the cracks.
Inner surface alteration	Shallow fine-textured carbonation.	Not examined

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A7 OF 8: PETROGRAPHIC DESCRIPTION OF THE PASTE

GMRS Ref.	**K16151/3**	**K16151/4**
Client Ref.	**Core 3, Panel 21 - full thickness (high level)**	**Core 4, Panel 11 - full thickness (tidal zone)**
Cement type	Portland - resembles SRPC	Portland - resembles SRPC
Cement replacement	None seen	None seen
Unhydrated cement (estimated. vol.% of paste)	<1%	<1%
Portlandite (estimated. vol.% of paste)	10%	10%
Portlandite - typical crystal size	0.01-0.08mm	0.01-0.07mm
Apparent water/cement ratio	0.45-0.50, typically 0.50	0.45-0.50, typically 0.50
Porosity		
General level	Low to moderate	Low to moderate
Porosity distribution	Slightly patchy	Slightly patchy
Microcracking level	Minor radial microcracking around aggregate surfaces	Minor radial microcracking around aggregate surfaces
Fine cracking	Traces of irregular cracks partially infilled with calcite at the outer core end, probably compaction-related	Abundant surface-parallel cracks infilled with corrosion products surround the corroded reinforcement at 100mm.
Crack fillings	Traces of calcite seen in irregular cracks at the surface.	Abundant corrosion products seen in cracks surrounding the corroded reinforcement
Void fillings	Minor secondary ettringite. Occasional fine portlandite-filled voids indicative of the presence of plasticiser.	None seen throughout the majority of the depth of the core
Outer surface alteration	Calcite deposition on the surface. Traces of calcite in elongate crack-like voids.	Calcite deposition on the surface. Traces of calcite and possibly thaumasite seen in an elongate crack-like void at the surface.
Inner surface alteration	Not examined	Not examined

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PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE
BS 1881-211, 2016

TABLE A8 OF 8: PETROGRAPHIC DESCRIPTION OF THE PASTE

GMRS Ref.	**K16151/5**
Client Ref.	**Core 5, Parapet 11 - full thickness with concrete infill behind (base of seaward face 150mm above joint with top panel)**
Cement type	Portland - resembles SRPC
Cement replacement	None seen
Unhydrated cement (estimated. vol.% of paste)	<1%
Portlandite (estimated. vol.% of paste)	12%
Portlandite - typical crystal size	0.01-0.05mm
Apparent water/cement ratio	0.45-0.50, typically 0.50
Porosity	
General level	Low to moderate
Porosity distribution	Slightly patchy
Microcracking level	Low to moderate
Fine cracking	None seen
Crack fillings	None seen
Void fillings	None seen
Outer surface alteration	None seen other than fine-textured carbonation.
Inner surface alteration	None seen other than fine-textured carbonation.

APPENDIX B – PHOTOGRAPHS ILLUSTRATING THE SAMPLES AS RECEIVED

Figure B1

Sample K16151/1

<u>The sample as received, side view of core:</u>

Figure B2

Sample K16151/1

<u>The sample as received, outer surface:</u>

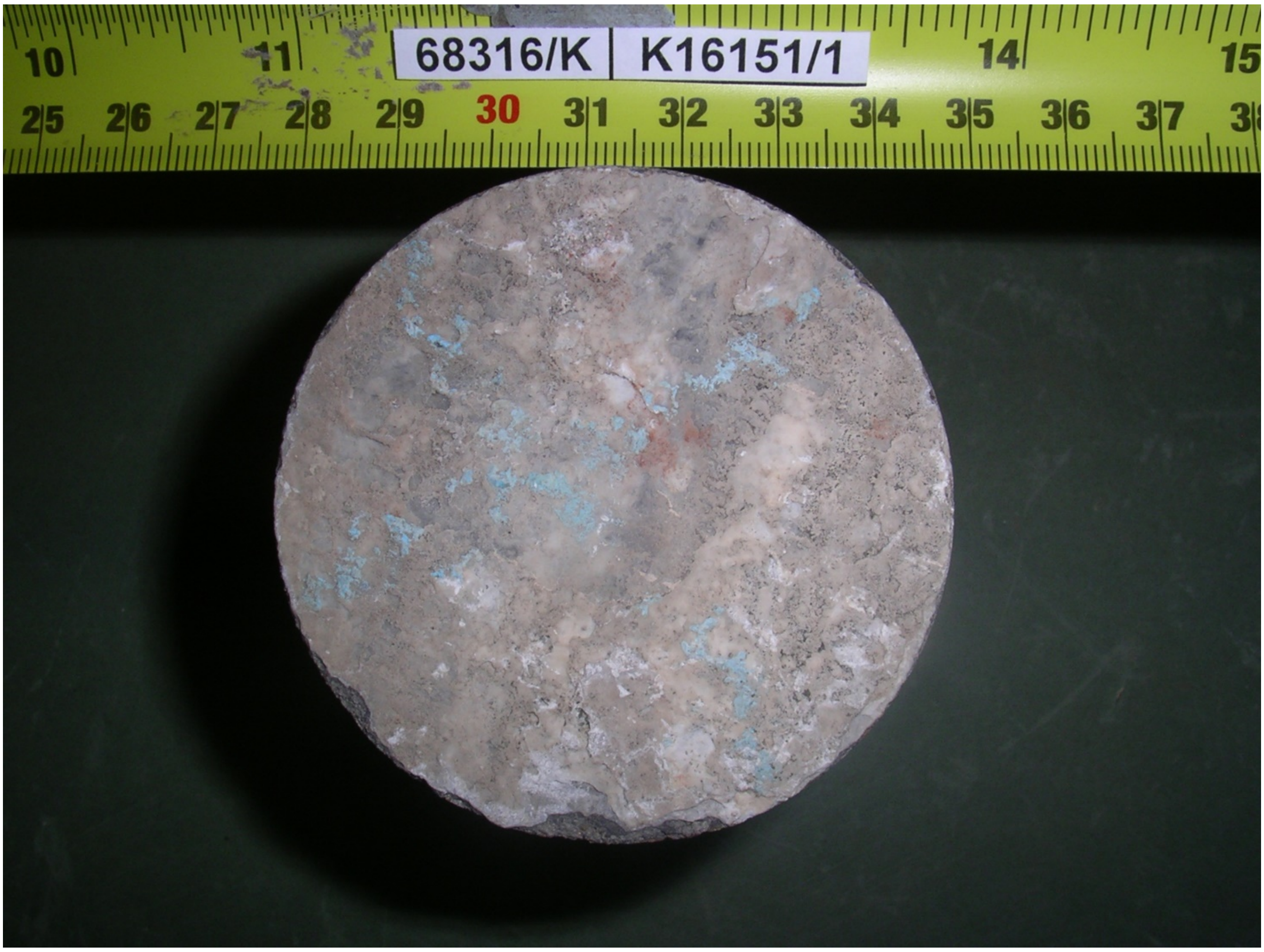

Figure B3

Sample K16151/1

<u>The sample as received, inner surface:</u>

Figure B4

Sample K16151/2

<u>The sample as received, side view of core:</u>

Figure B5

Sample K16151/2

<u>The sample as received, outer surface:</u>

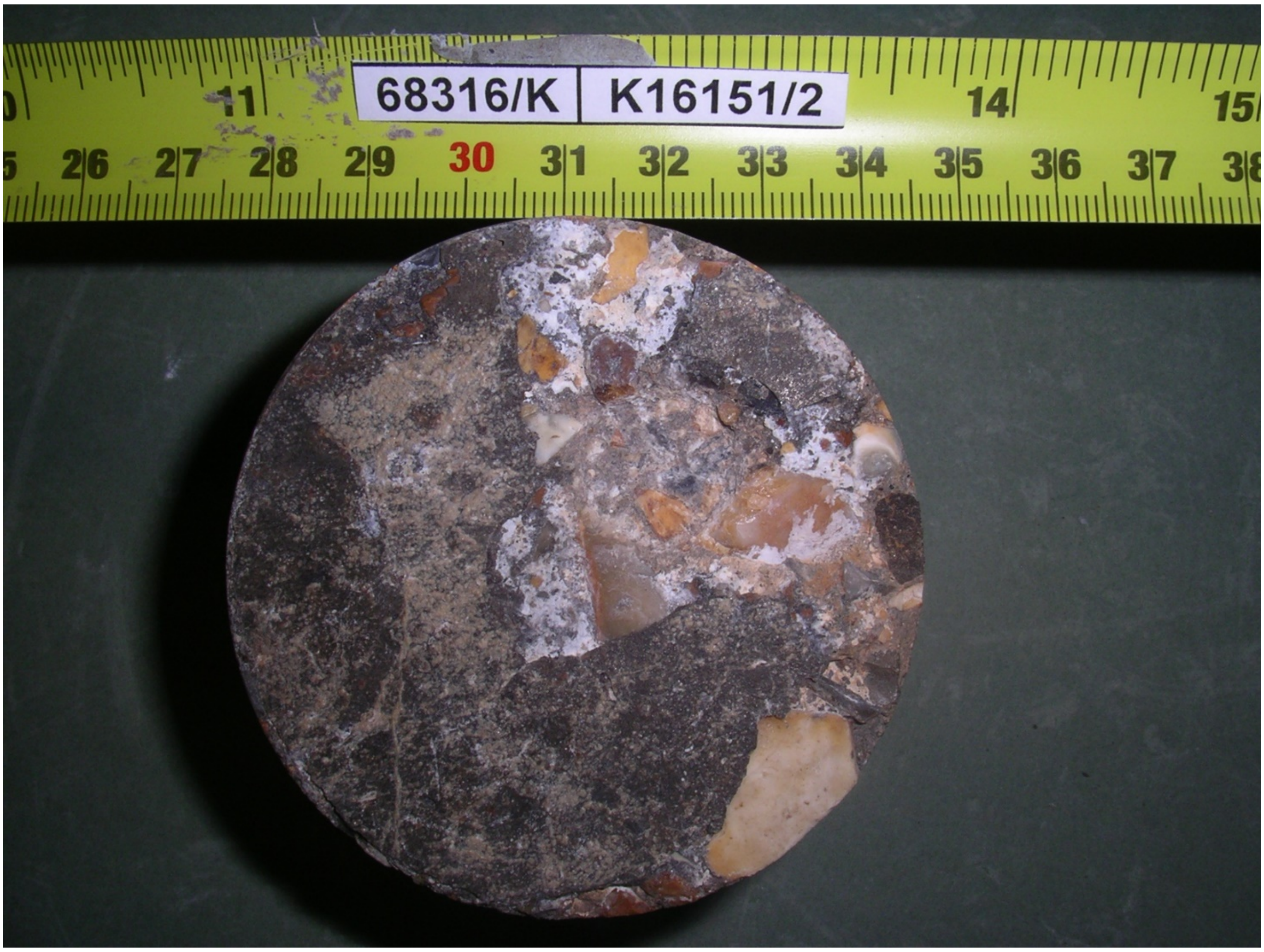

Figure B6

Sample K16151/2

<u>The sample as received, inner surface:</u>

Figure B7

Sample K16151/3

<u>The sample as received, side view of core:</u>

Figure B8

Sample K16151/3

<u>The sample as received, outer surface:</u>

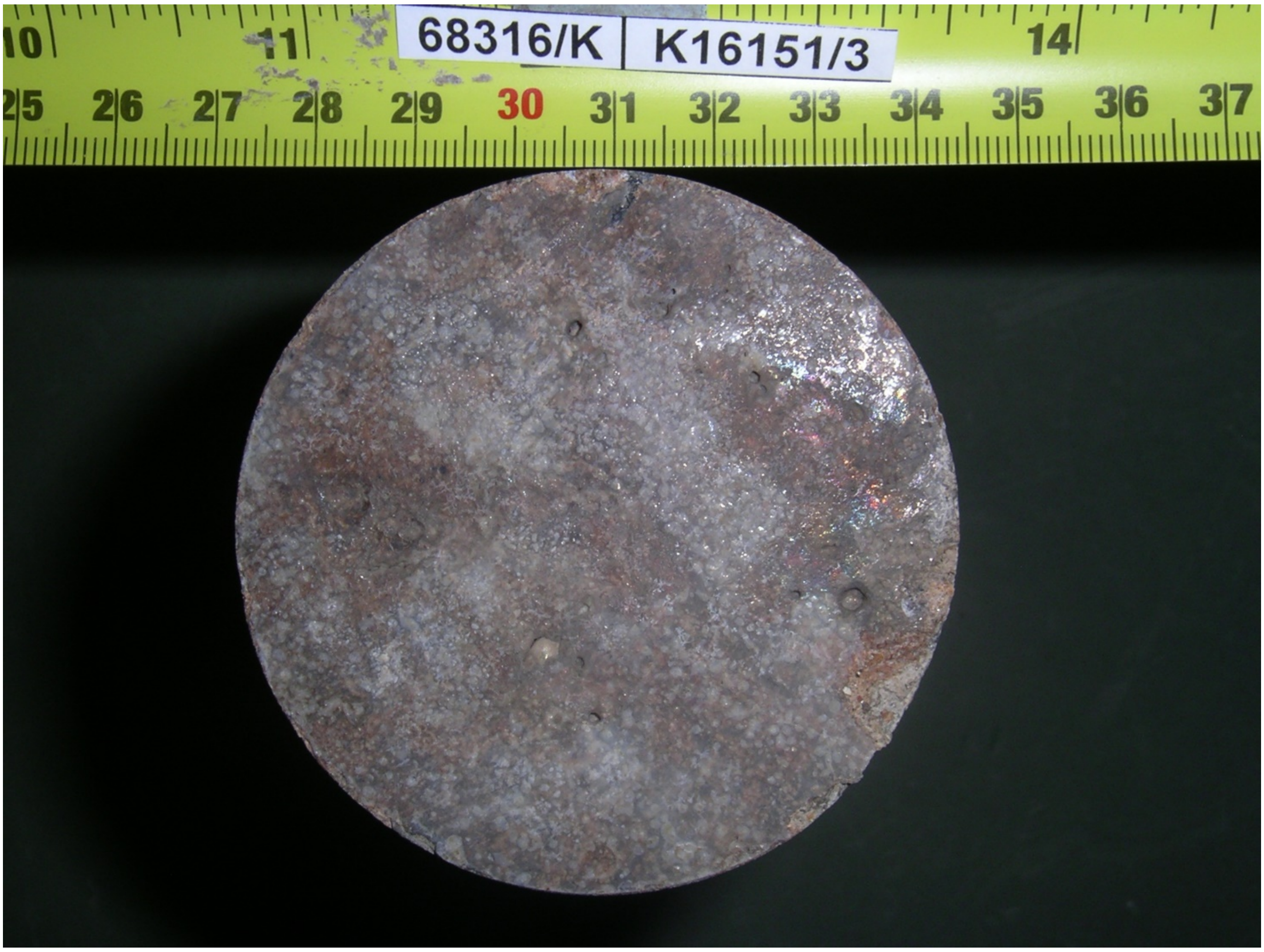

Figure B9

Sample K16151/3

<u>The sample as received, inner surface:</u>

Figure B10

Sample K16151/4

<u>The sample as received, side view of core:</u>

Figure B11

Sample K16151/4

<u>The sample as received, outer surface:</u>

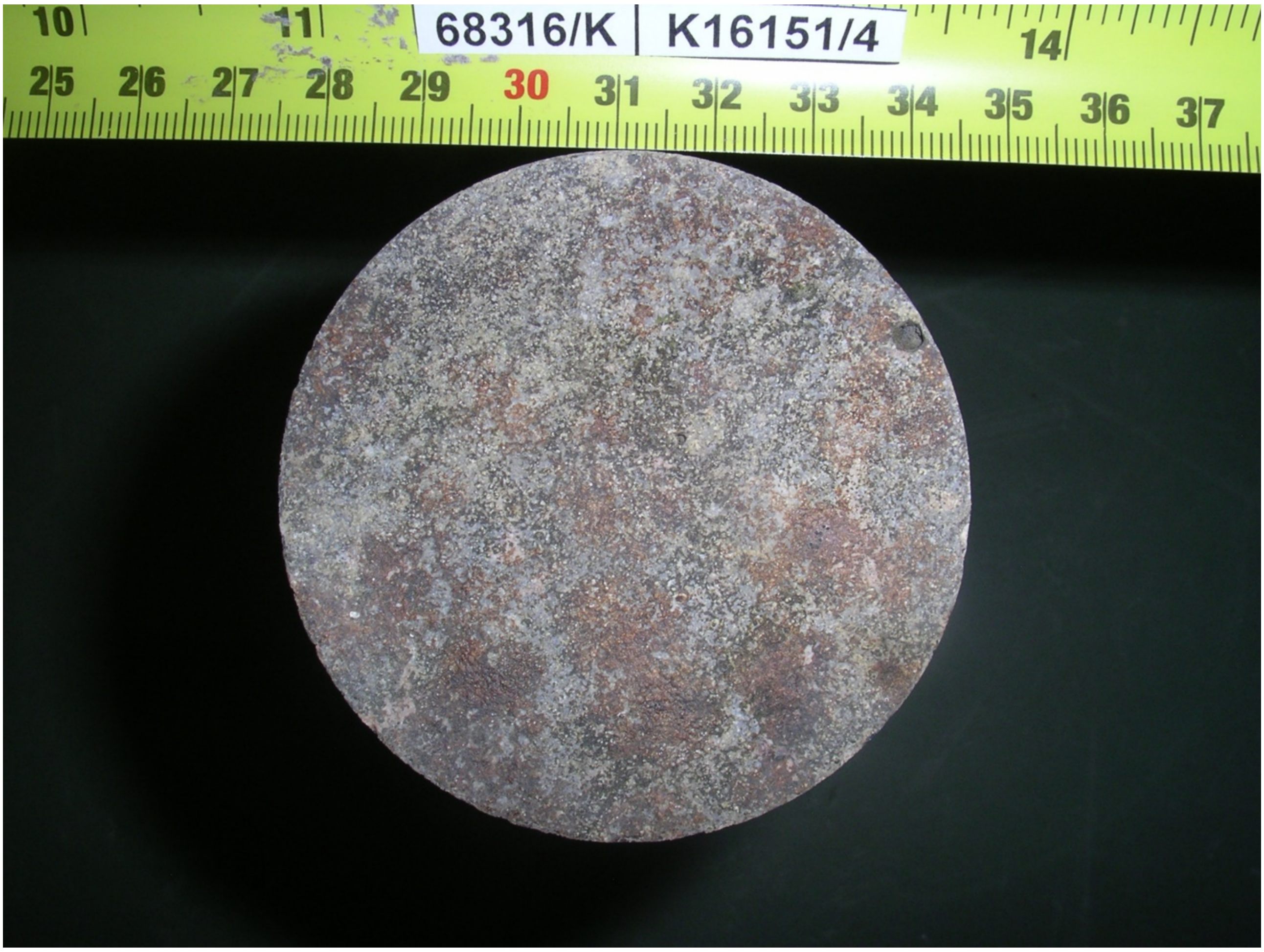

Figure B12

Sample K16151/4

<u>The sample as received, inner surface:</u>

Figure B13

Sample K16151/5

<u>The sample as received, side view of core:</u>

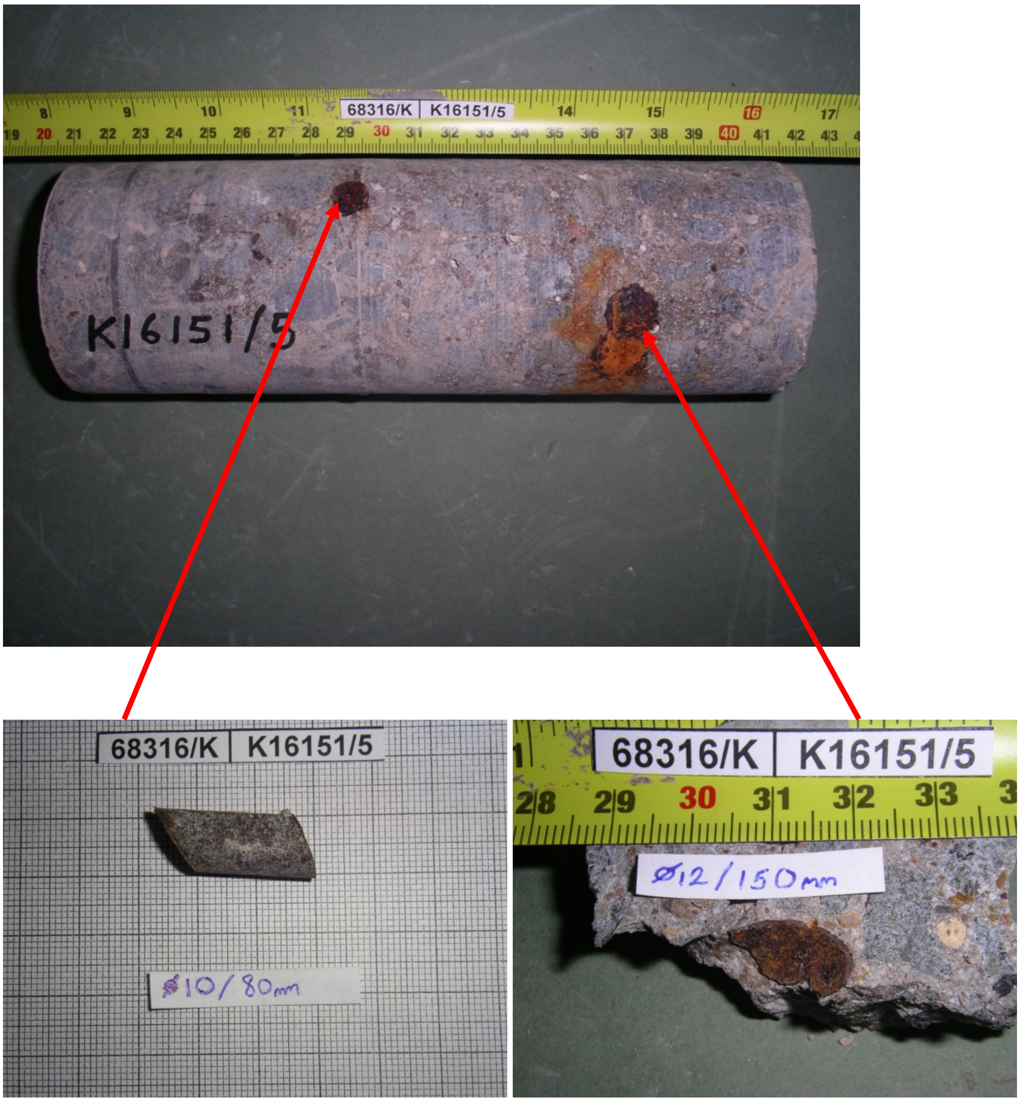

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Figure B14

Sample K16151/5

<u>The sample as received, outer surface:</u>

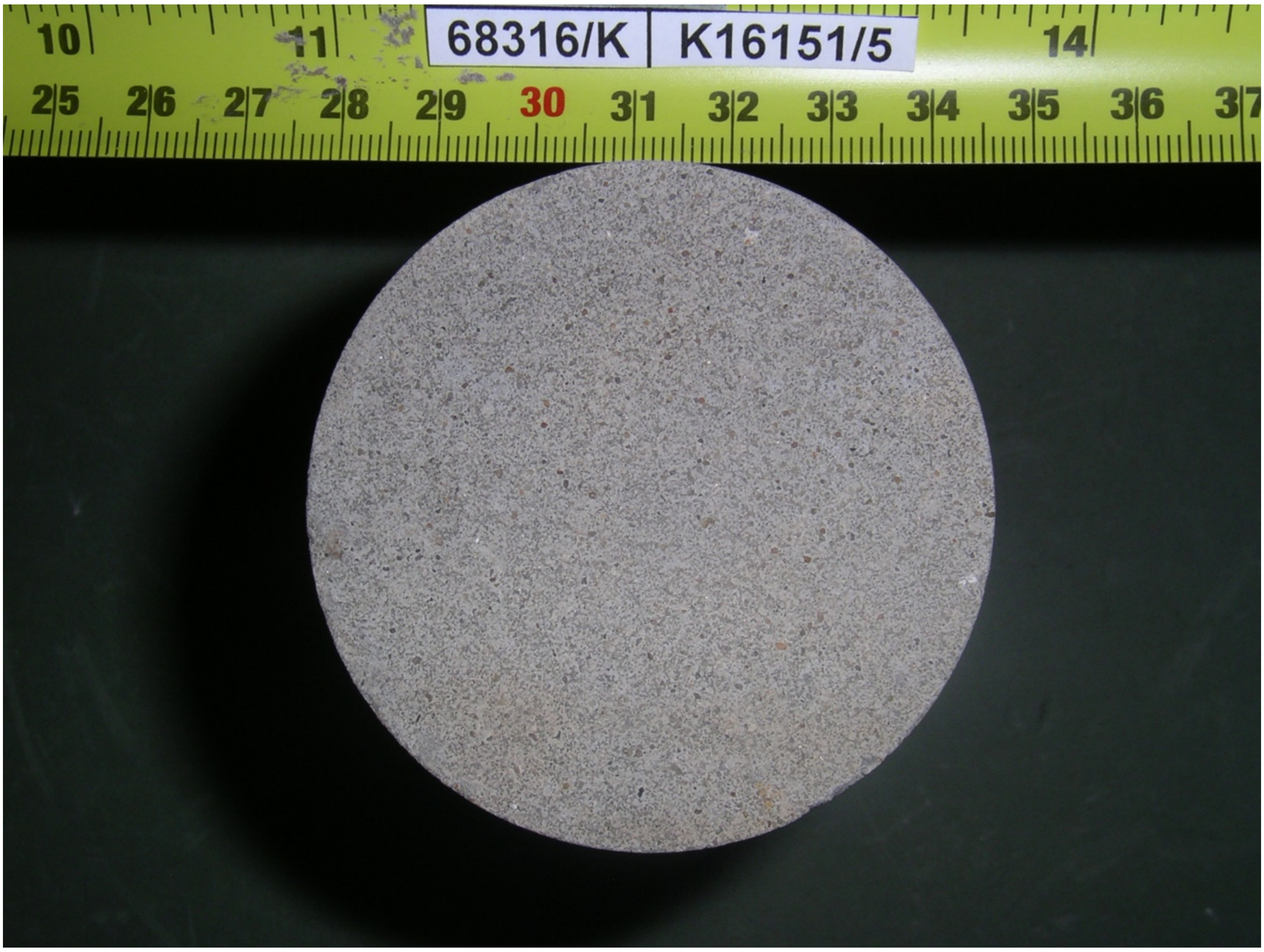
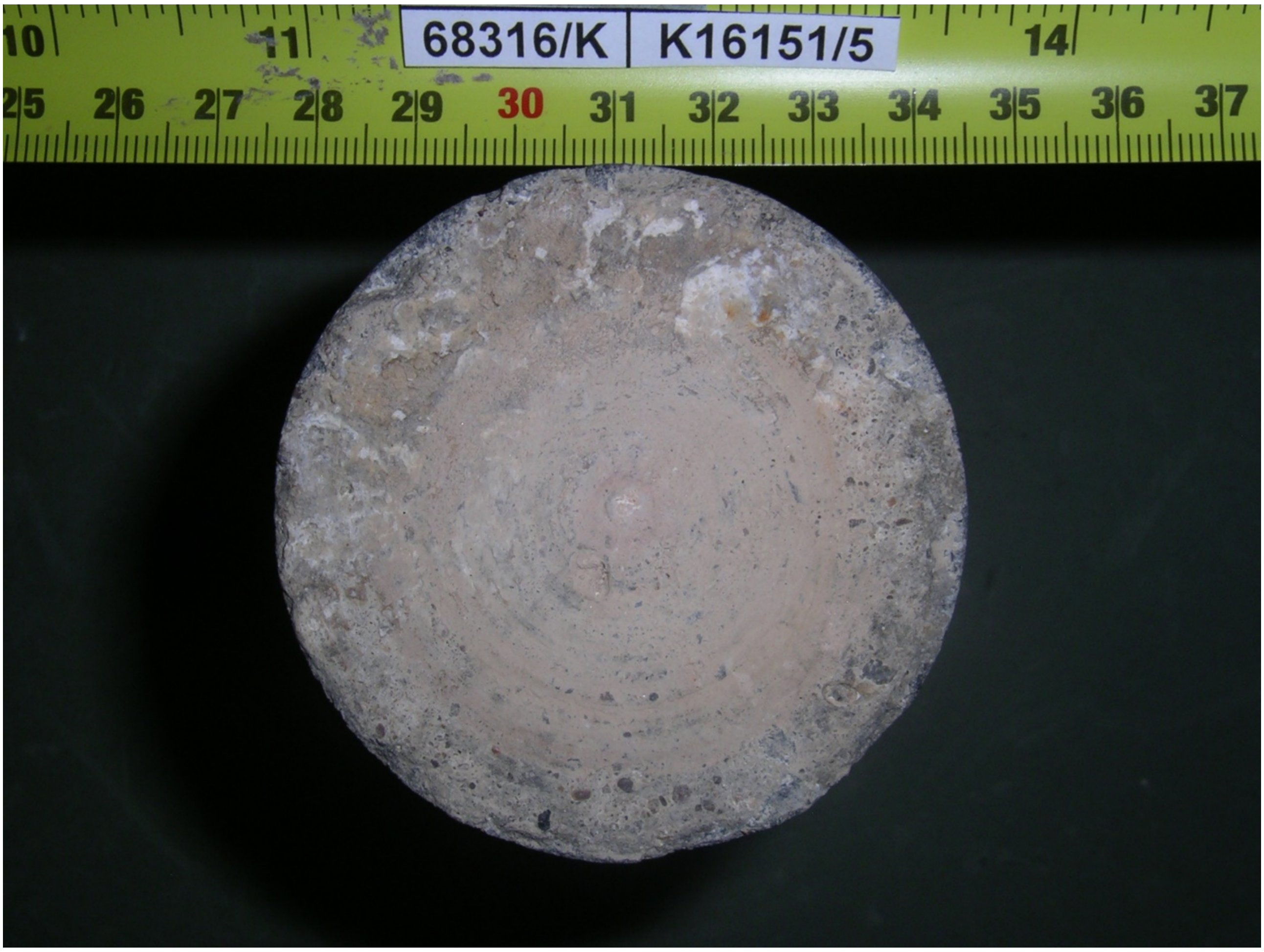


Figure B15

Sample K16151/5

<u>The sample as received, inner surface:</u>



APPENDIX C – PHOTOMICROGRAPHS ILLUSTRATING THE THIN SECTIONS

Figure C1

Sample K16151/1

<u>Thin section, oblique polars:</u> View showing a cross section through the outer surface. Layered calcite deposits are visible from B/C1 to B/C6. A shallow zone of carbonated paste occurs in the concrete surface from D/E1 to D/E6. Much of the lower half of the field of view is occupied by uncarbonated Portland cement paste containing fine portlandite crystals that are visible for example in H/I5.

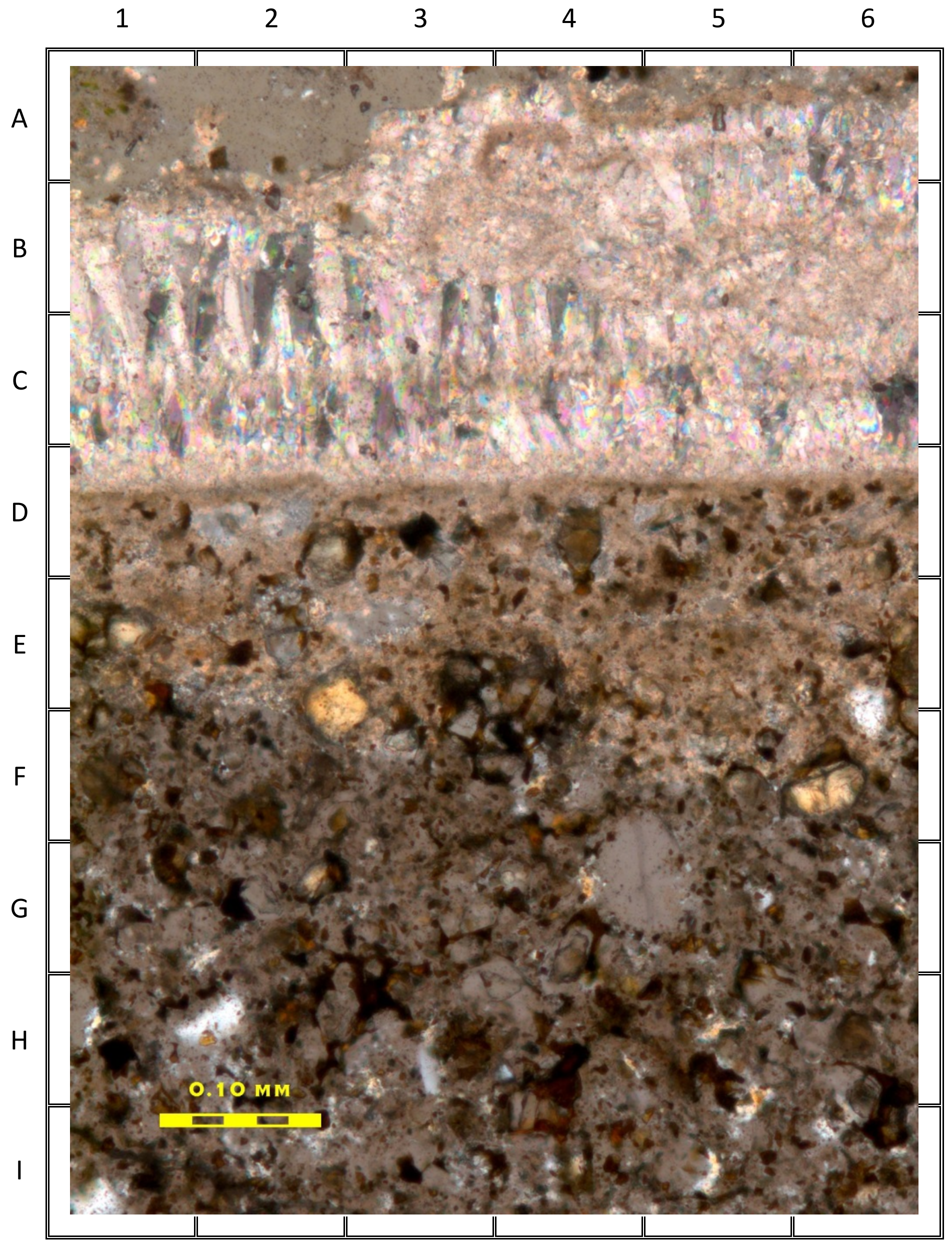


Figure C2

Sample K16151/1

Thin section, oblique polars: View showing the typical appearance of the paste in thin section. Particles of pseudomorphically hydrated Portland cement are visible for example in E2/3 and G4. Fine portlandite crystals appearing mottled yellow to white occur for example in G/H5. A flint particle occurs in A4/5 and a particle of quartz occurs in I6.

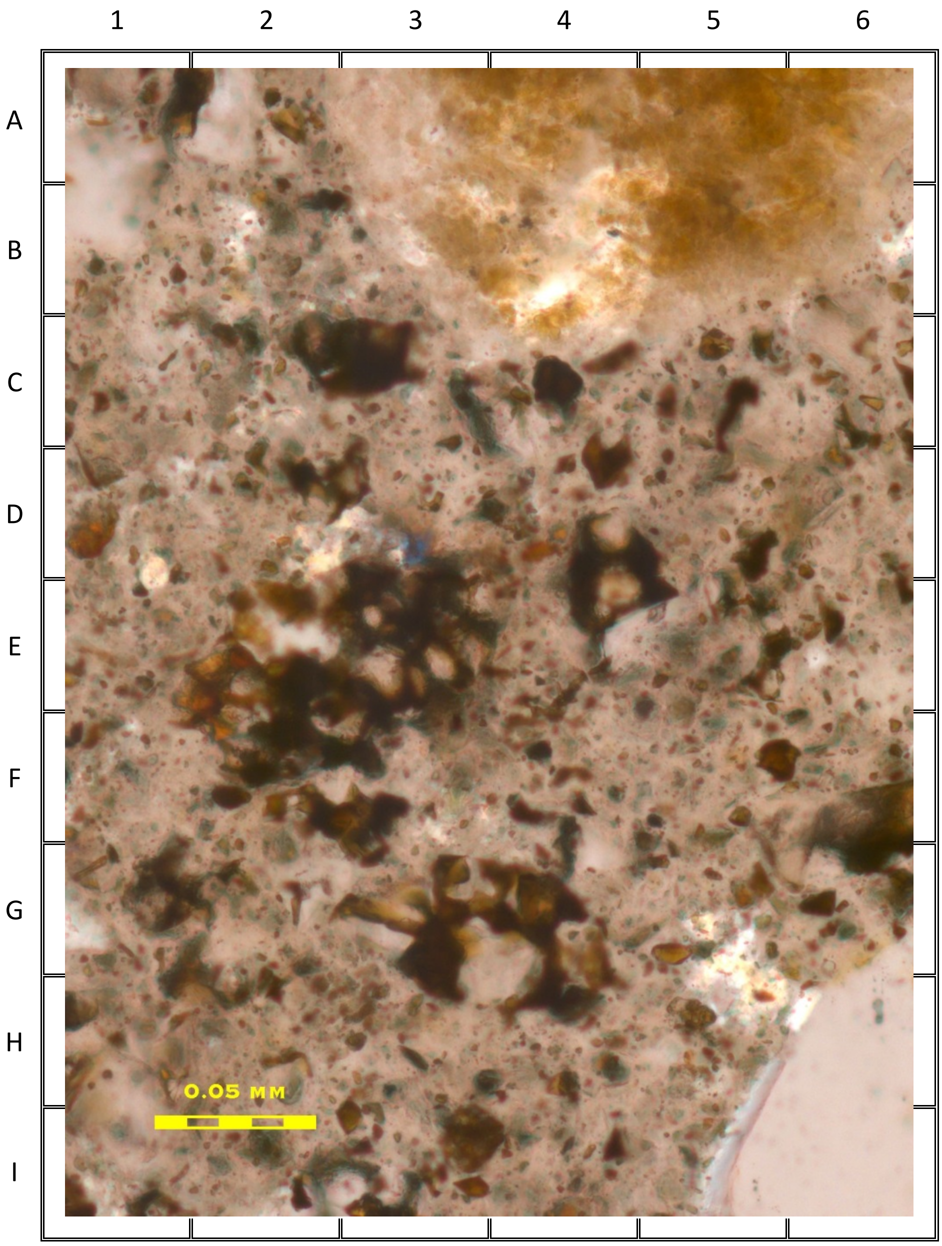


Figure C3

Sample K16151/2

<u>Thin section, crossed polars, reflected light:</u> View showing the severely corroded reinforcement with abundant cracks infilled with corrosion products visible for example from C/D1 to E/F6. Small areas of uncarbonated paste are visible for example in G/H6 and I5. Quartz particles occur in E1 and I3. A small flint fragment occurs in H/I6.

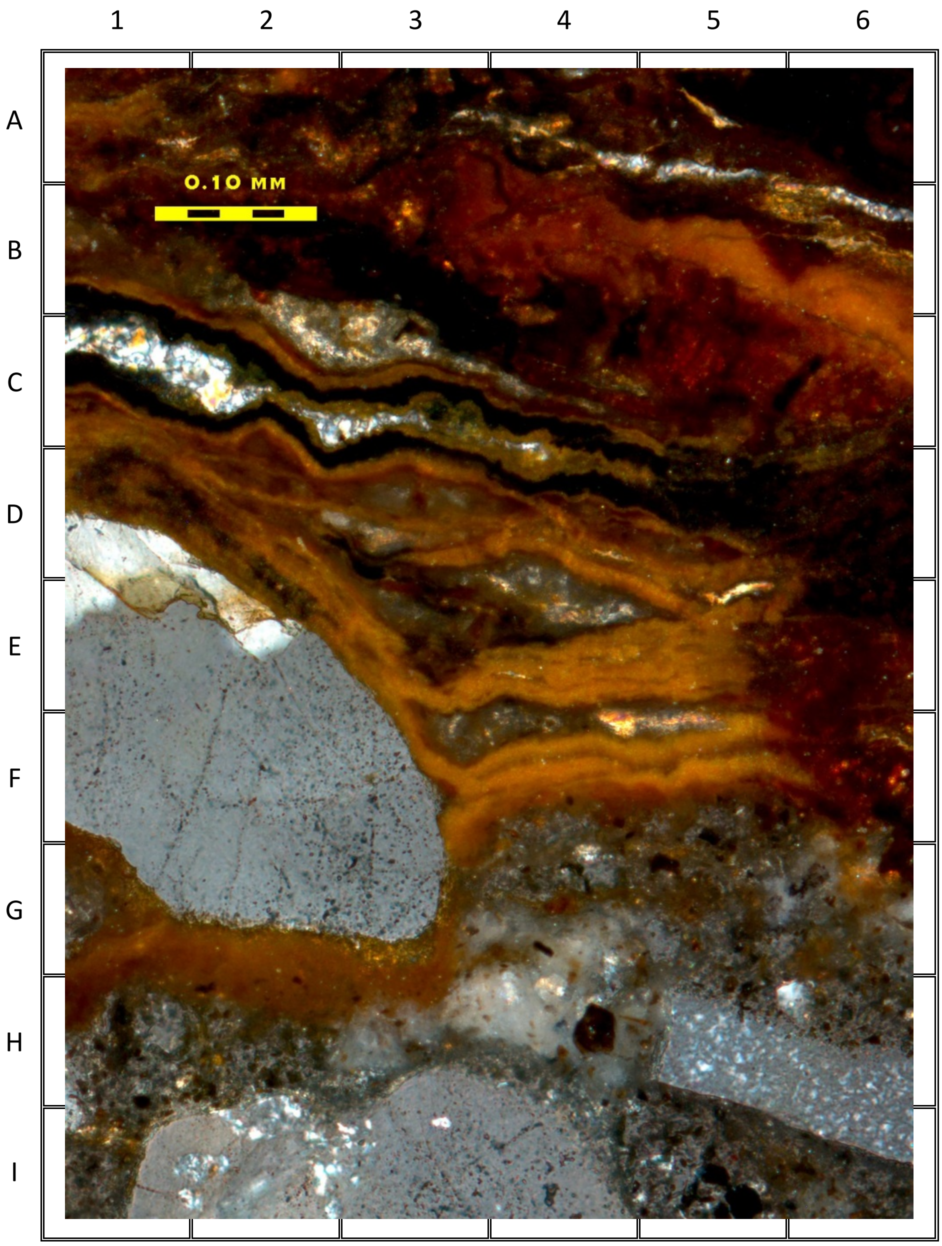


Figure C4

Sample K16151/2

<u>Thin section, oblique polars:</u> A fine crack infilled with corrosion products runs diagonally through the field of view from A1 to H6. The crack is surrounded by portlandite-depleted paste with pseudomorphically hydrated Portland cement grains visible in E/F6 and G/H4. A quartz particle occurs in I1/2.

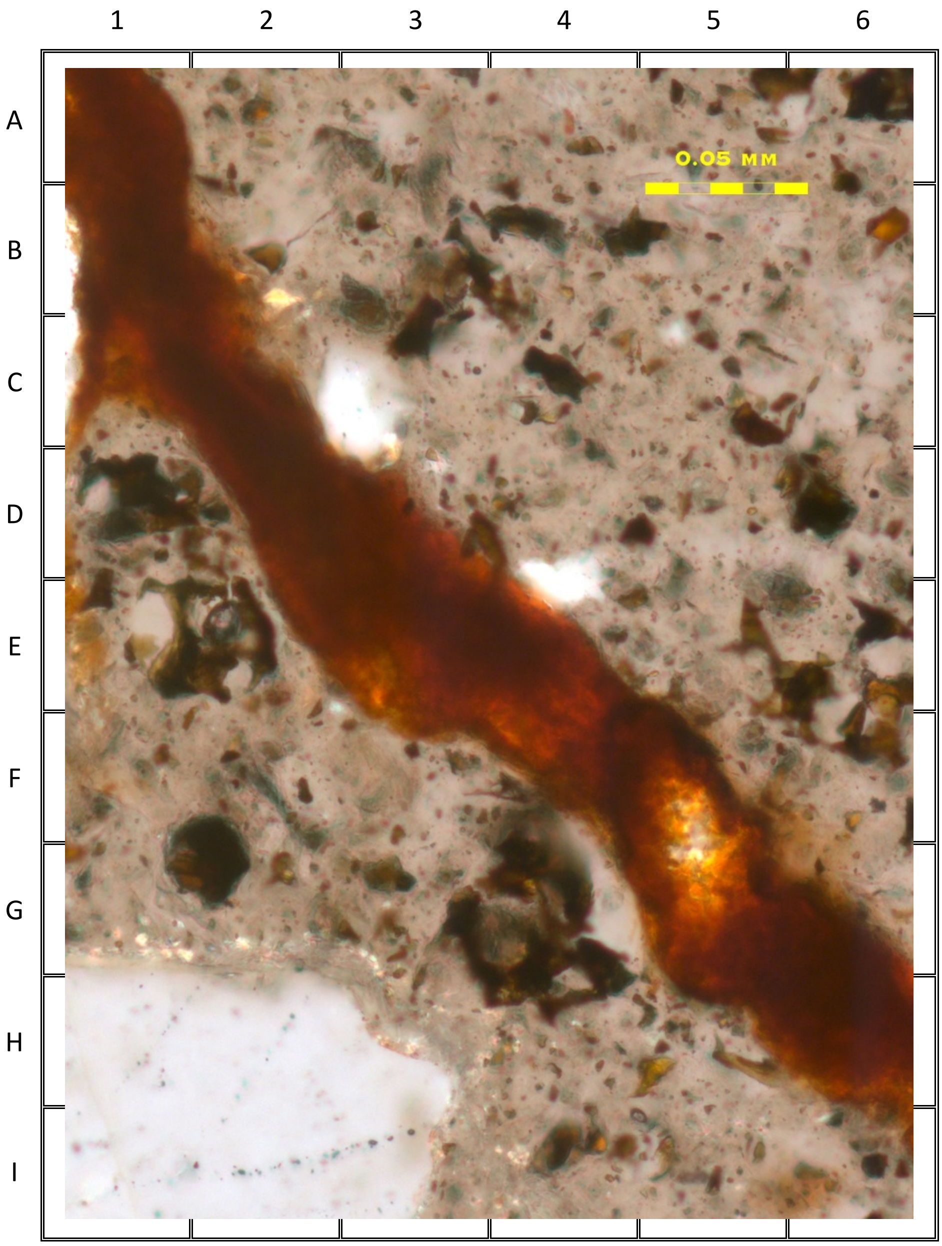


Figure C5

Sample K16151/3

<u>Thin section, oblique polars:</u> Particles of quartz are visible in B/C2, B/C5 and G1. An unhydrated Portland cement grain resembling a particle of sulfate-resisting Portland cement occurs in E3. Fine portlandite crystals can be seen for example in B6 and I5/6.

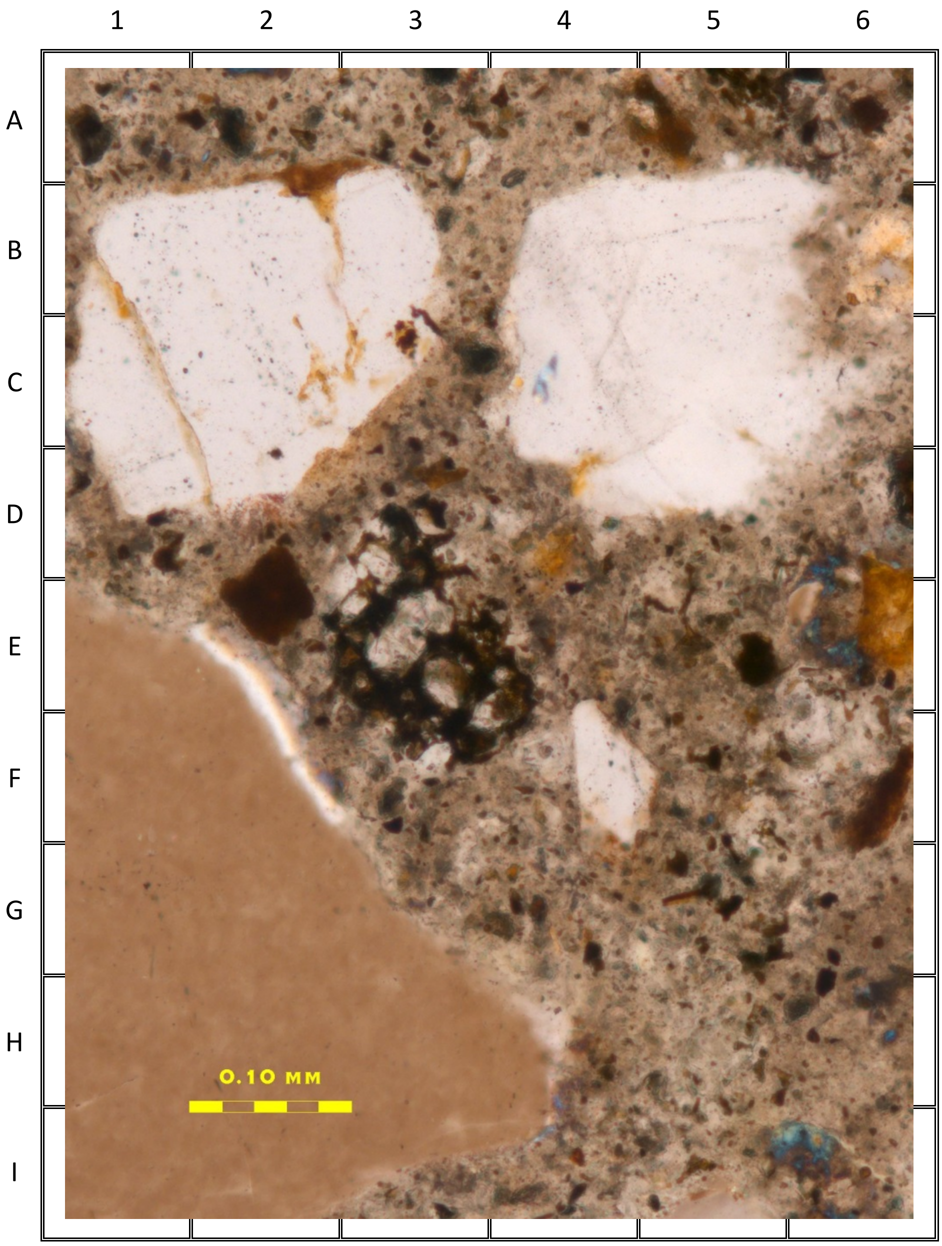


Figure C6

Sample K16151/3

<u>Thin section, crossed polars:</u> The field of view is dominated by uncarbonated paste containing moderately coarse portlandite crystals appearing mottled yellow to orange and visible for example in F/G2 and F/G6. A particle of unhydrated Portland cement resembling sulfate-resisting Portland cement occurs in D3/4.

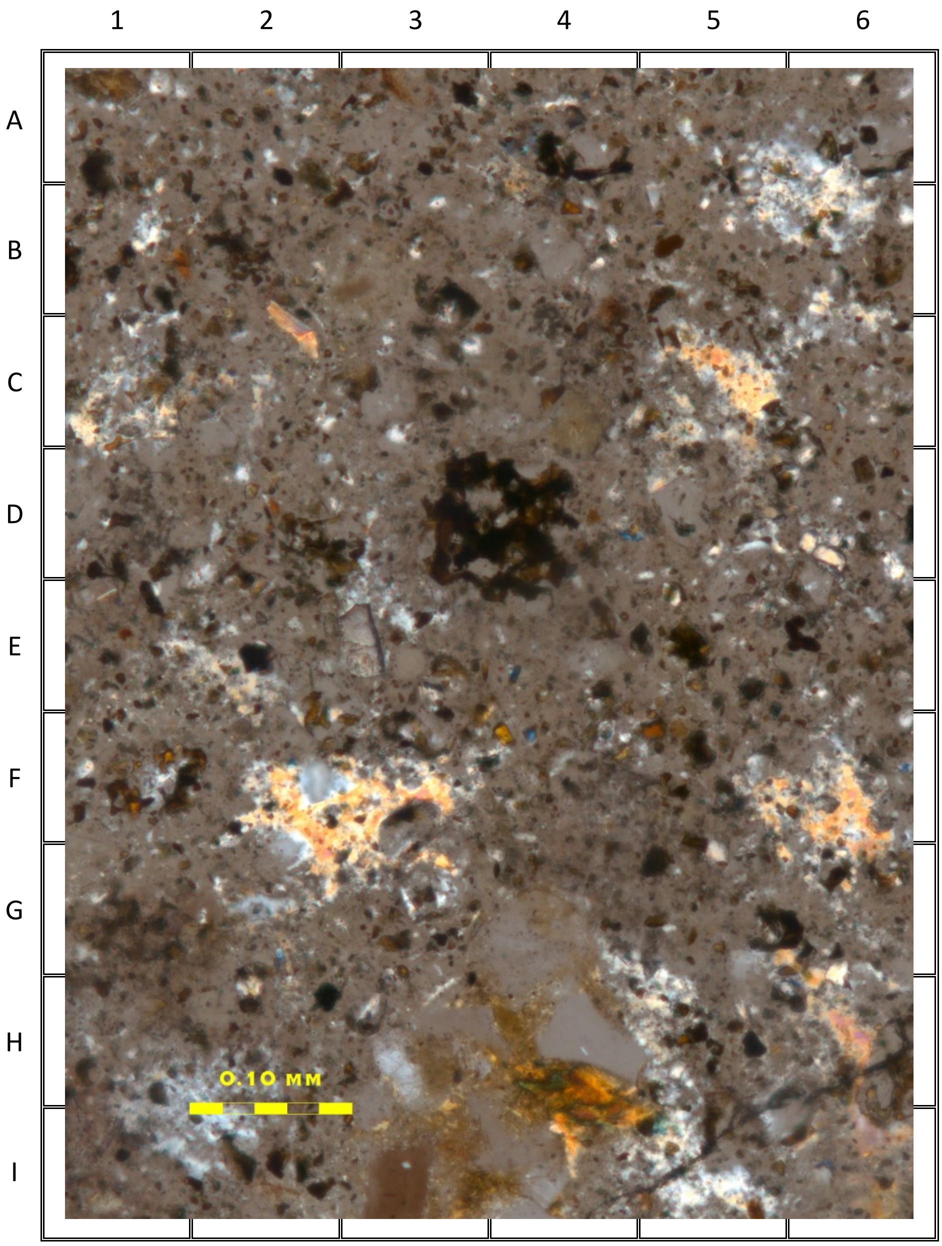


Figure C7

Sample K16151/4

Thin section, crossed polars, reflected light: View showing abundant fine cracks infilled with corrosion products close to the corroded reinforcement. The cracks are visible from A3 – A5 to G/H6. Much of the field of view is occupied by uncarbonated paste visible for example in A2 and G4. A pseudomorphically hydrated Portland cement grain can be seen in E/F3.

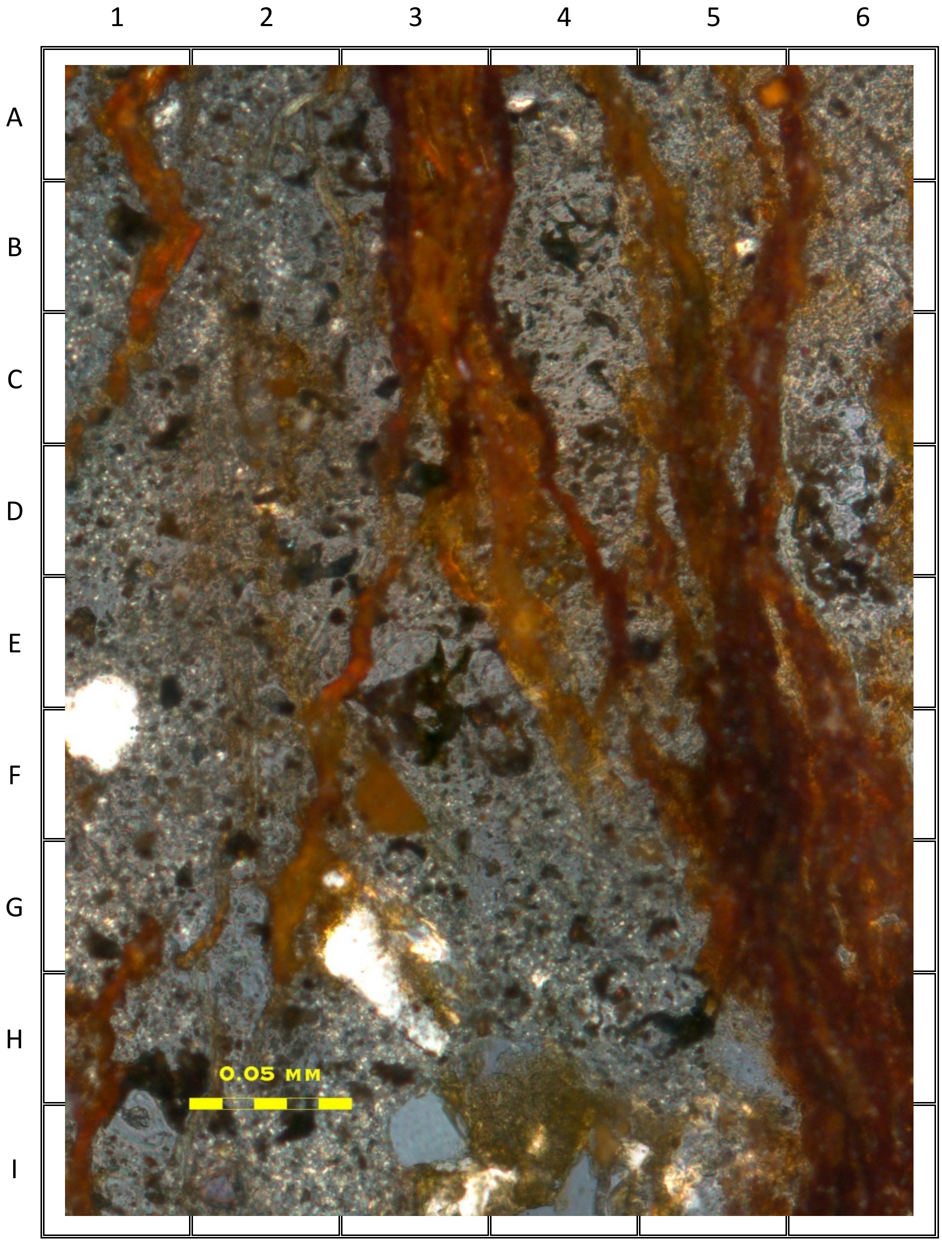


Figure C8

Sample K16151/4

<u>Thin section, crossed polars:</u> The field of view is dominated by uncarbonated paste that is typically of low porosity and contains fine portlandite crystals appearing mottled yellow to orange and visible for example in C6 and E3. A basalt particle occurs in A/B1. A quartz sand particle occurs in D/E5.

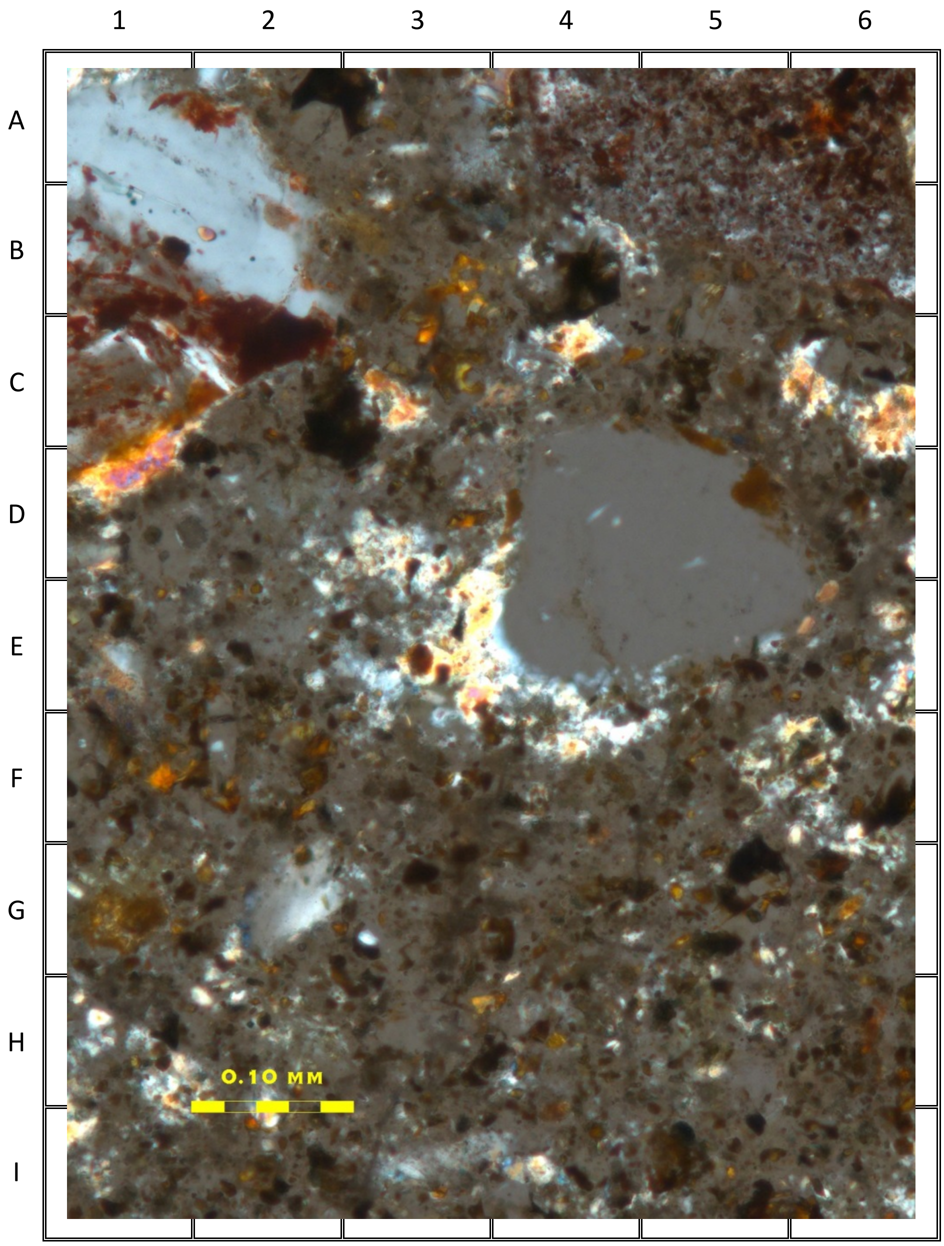


Figure C9

Sample K16151/5

<u>Thin section, oblique polars:</u> Low magnification view showing the imprint of the reinforcement. The reinforcement surface runs from C1 to C6. Note the lack of corrosion products. Much of the field of view is occupied by uncarbonated, predominantly low porosity paste appearing dark grey for example in E2/3. Quartz particles appear various shades of grey and are visible throughout the field of view.

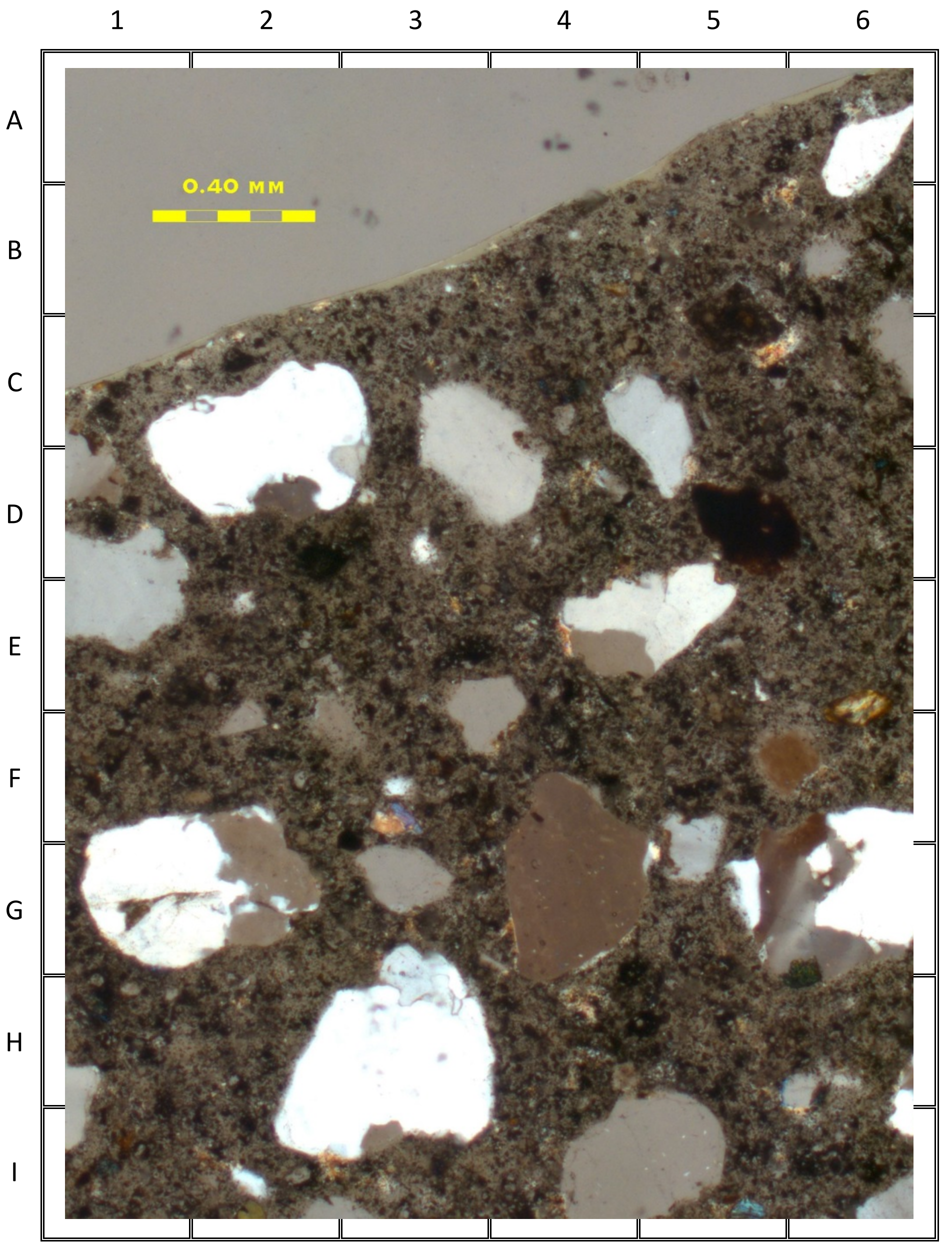
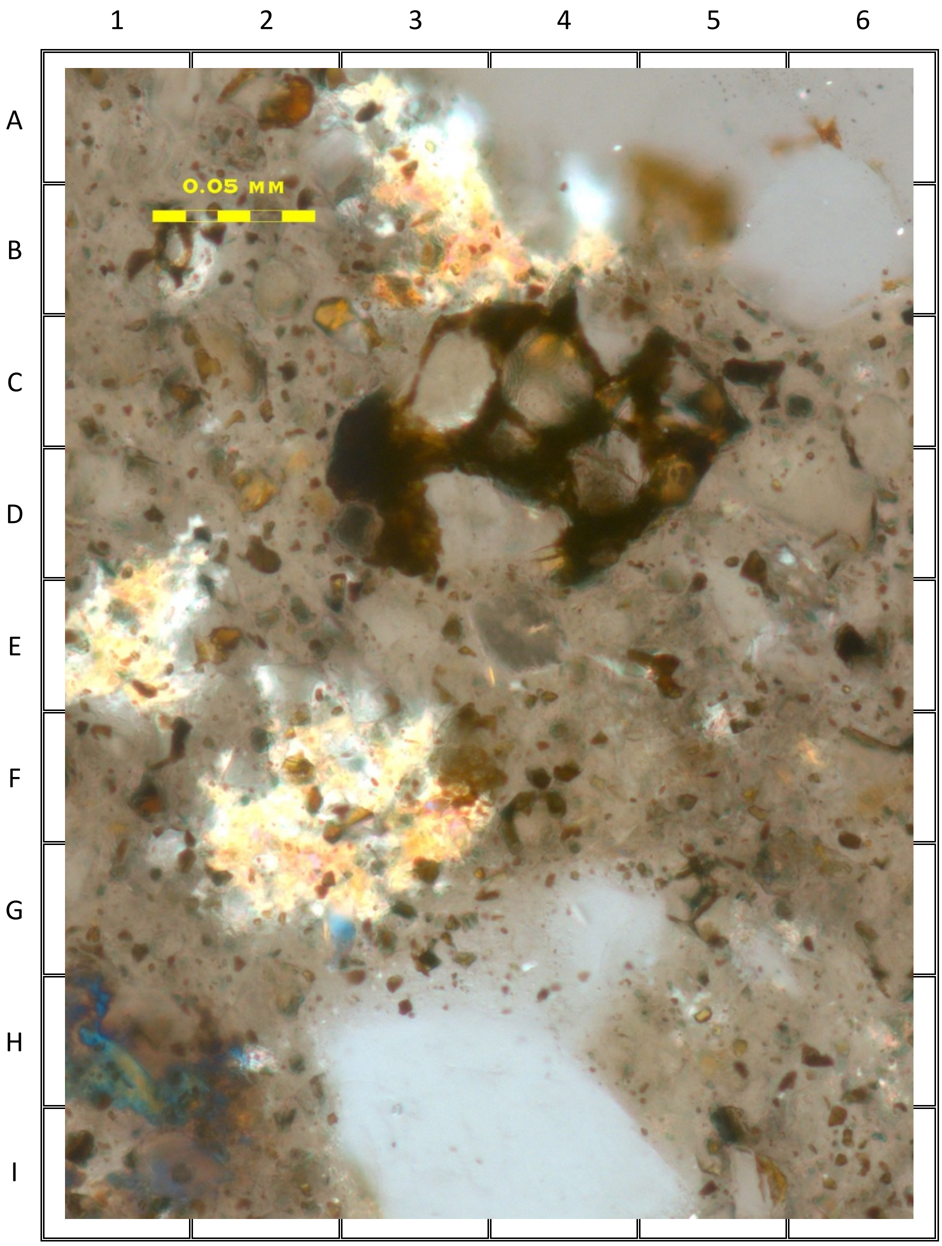


Figure C10

Sample K16151/5

<u>Thin section, oblique polars:</u> A particle of unhydrated Portland cement resembling a particle of sulfate-resisting Portland cement occurs in C/D4. Irregular portlandite crystals appearing mottled yellow to orange occur on the surface of a quartz particle in B3 and in the paste in E1 and F/G3. Particles of quartz occur in A5 and I3/4.



APPENDIX D – X-RAY PHASE MAPS ILLUSTRATING THE RESIDUAL PORTLAND CEMENT GRAINS IN CORES 3, 4 AND 5

Figure D1

Sample K16151/3

Polished surface, backscattered electron image with superimposed X-ray phase map: View showing an area of hydrated Portland cement paste at 74mm depth. A pseudomorphically hydrated Portland cement grain dominates the field of view and this includes unhydrated calcium-alumino-ferrite (highlighted in blue). The cement grain is surrounded by cement hydrates with abundant portlandite (highlighted in red).

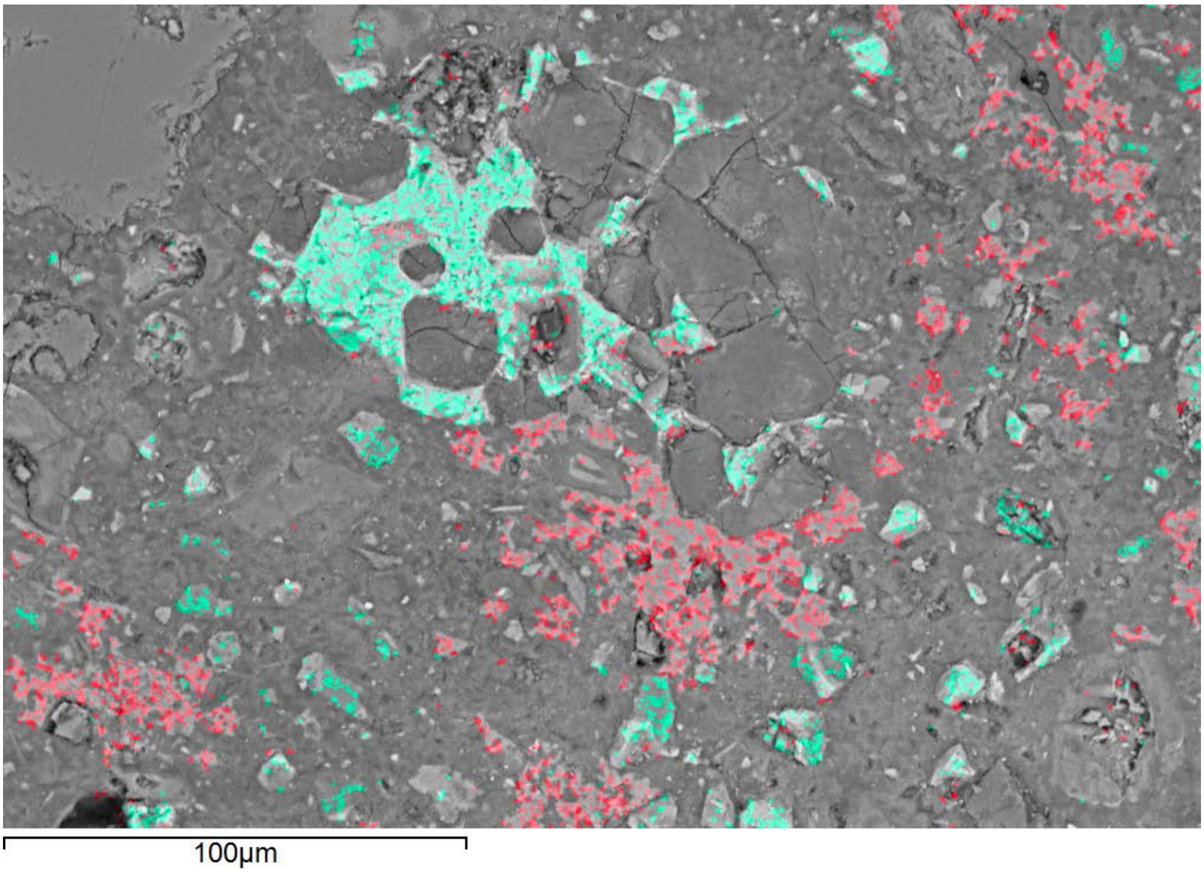


Figure D2

Sample K16151/3

Polished surface, backscattered electron image with superimposed X-ray phase map: View showing a rare almost unhydrated cement grain at 0.6mm depth. Unhydrated calcium silicate is highlighted in green and unhydrated calcium-alumino-ferrite is highlighted in pink.

Figure D3

Sample K16151/4

<u>Polished surface, backscattered electron image with superimposed X-ray phase map:</u> View showing an area of hydrated Portland cement paste at 30mm depth. A pseudomorphically hydrated Portland cement grain dominates the field of view and this includes unhydrated calcium-alumino-ferrite (highlighted in green), patches of secondary ettringite highlighted in red. The field of view is dominated by hydrated calcium silicates highlighted in blue.

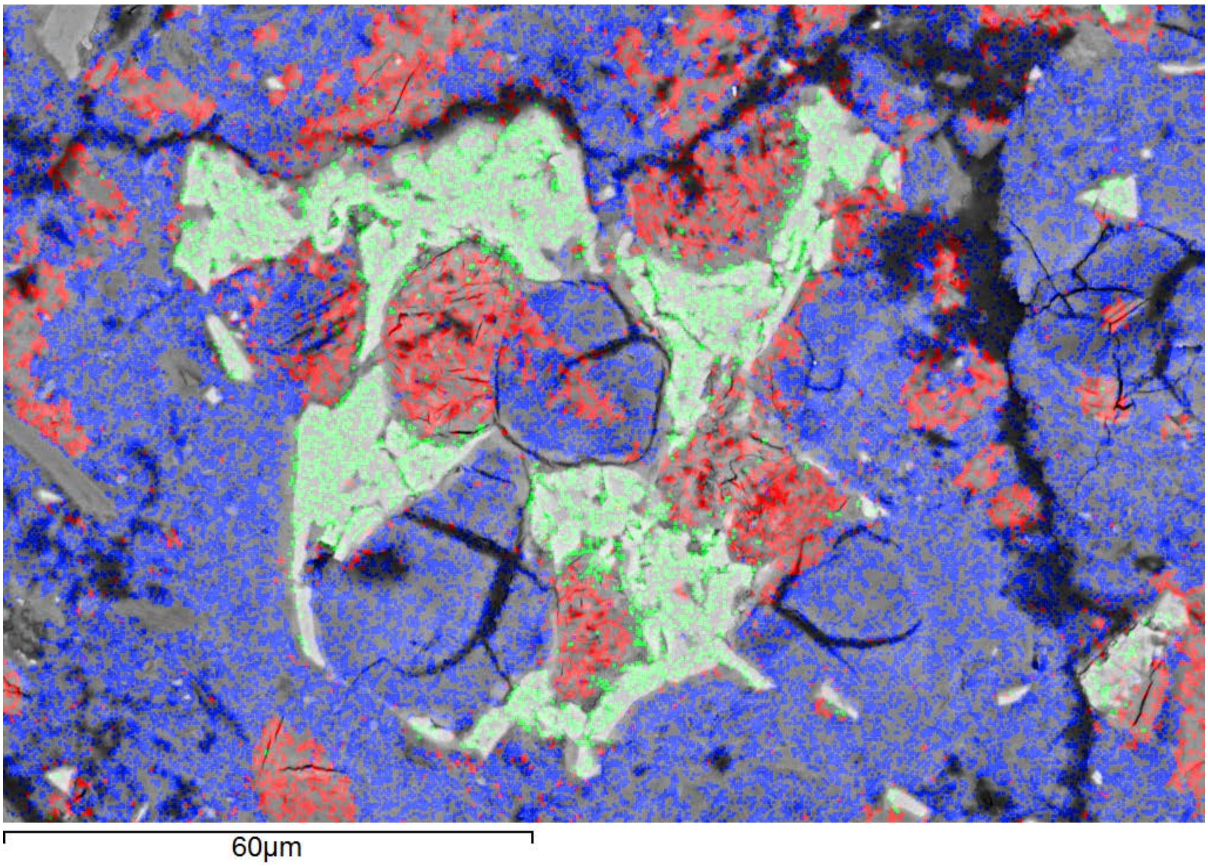


Figure D4

Sample K16151/4

<u>Polished surface, backscattered electron image with superimposed X-ray phase map:</u> View showing an area of hydrated Portland cement paste at 78mm depth. A pseudomorphically hydrated Portland cement grain dominates the field of view and this includes unhydrated calcium-alumino-ferrite (highlighted in red). The cement grain is surrounded by cement hydrates with moderate amounts of portlandite (highlighted in green).

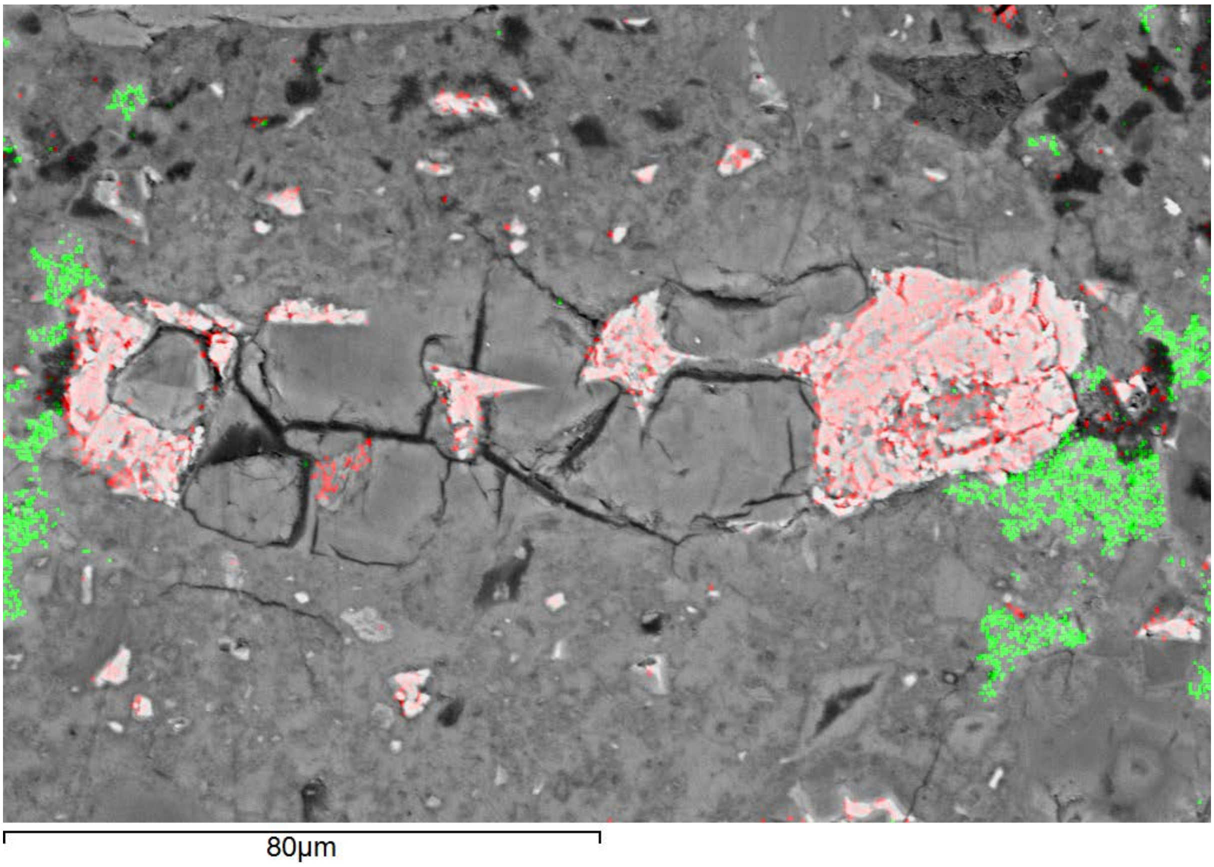


Figure D5

Sample K16151/5

Polished surface, backscattered electron image with superimposed X-ray phase map: View showing an area of hydrated Portland cement paste at 64mm depth. A pseudomorphically hydrated Portland cement grain dominates the field of view and this includes unhydrated calcium-alumino-ferrite (highlighted in red). The cement grain is surrounded by cement hydrates with moderate amounts of portlandite (highlighted in green). Calcium silicate hydrate dominates the field of view and is highlighted in blue in this view.

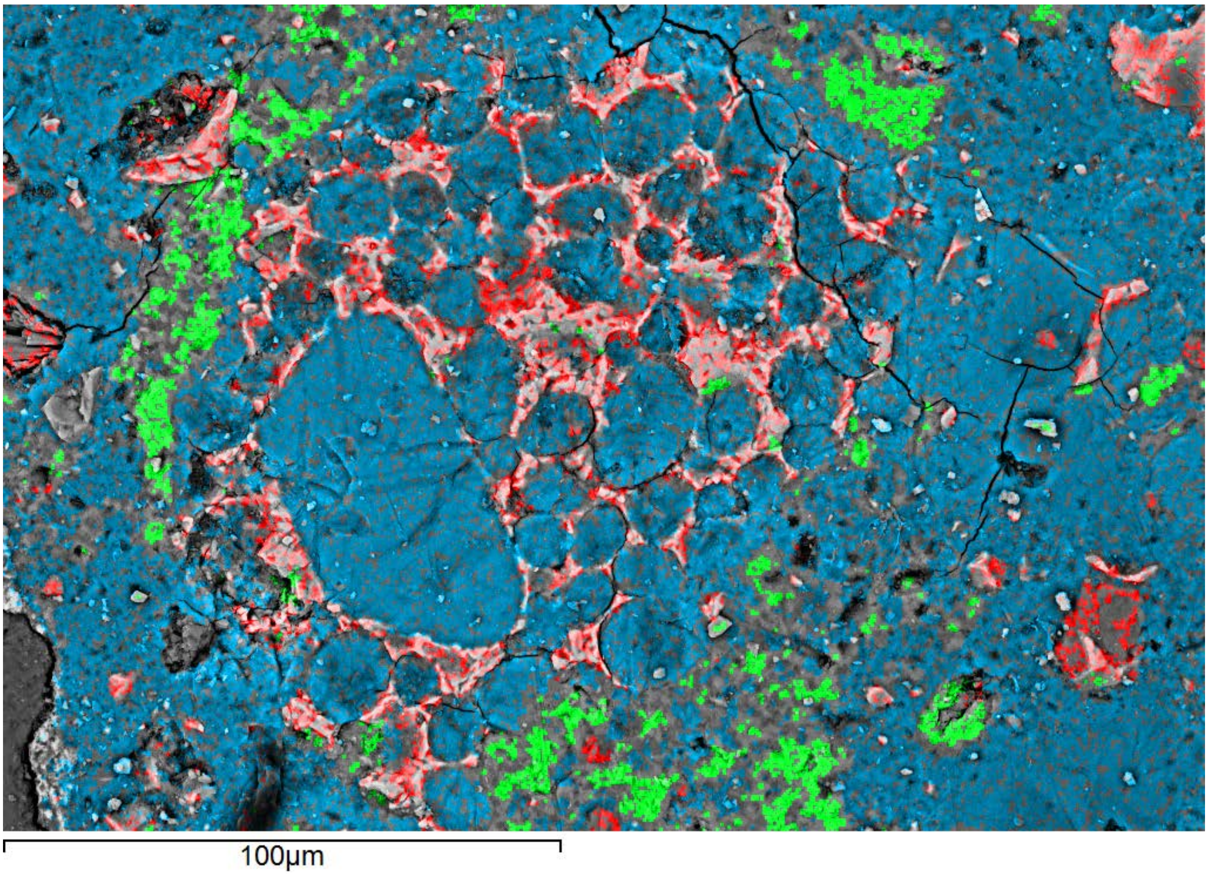
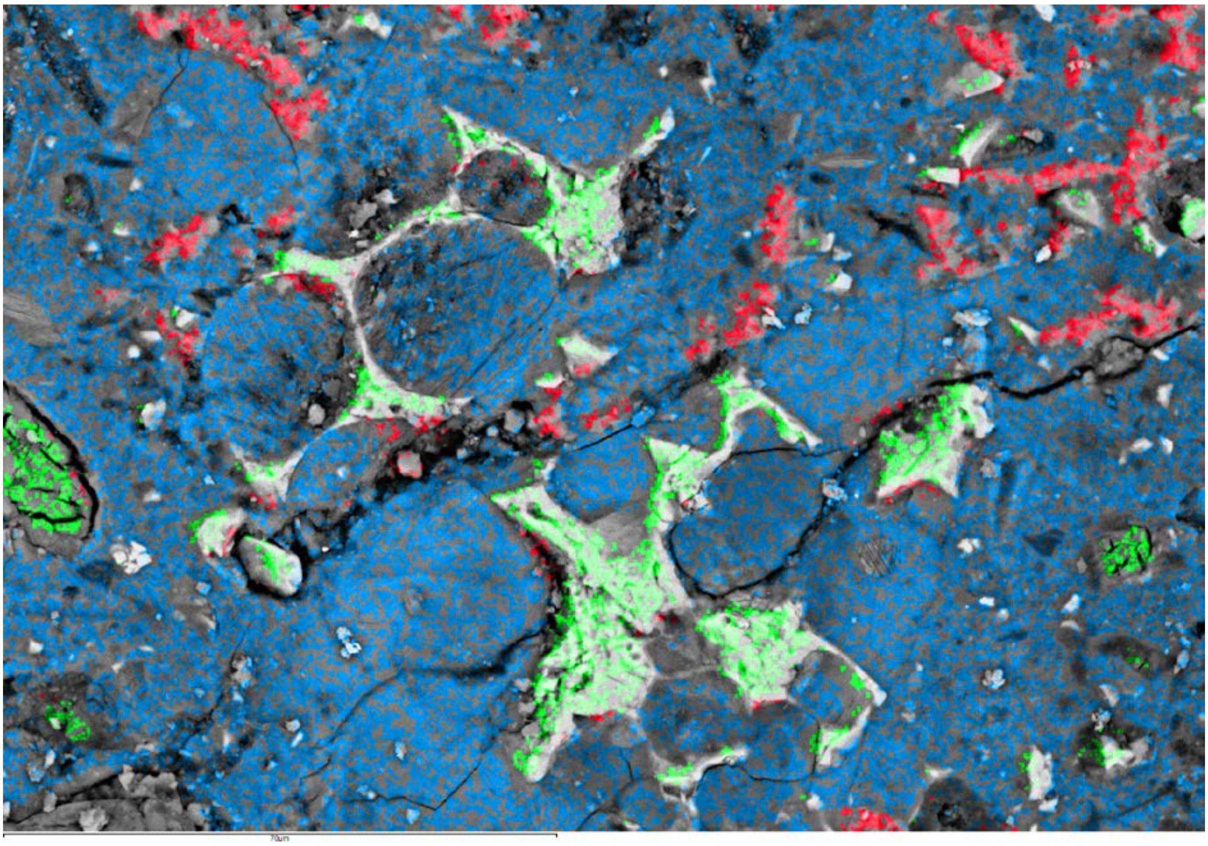


Figure D6

Sample K16151/5

Polished surface, backscattered electron image with superimposed X-ray phase map: View showing an area of hydrated Portland cement paste at 120mm depth. Several pseudomorphically hydrated Portland cement grains are present and these include unhydrated calcium-alumino-ferrite (highlighted in green). The cement grains are surrounded by cement hydrates with moderate amounts of portlandite (highlighted in green). Calcium silicate hydrates dominate the field of view and are highlighted in blue in this view.



APPENDIX E – PETROGRAPHIC PROCEDURES AND GLOSSARY

GRADES OF DETERIORATION

COHERENT CONCRETE WITH NO MACROSCOPIC EVIDENCE OF DETERIORATION

1. Normal homogeneous concrete with few microcracks. Void content in keeping with the amount of paste. Paste structure in keeping with water/cement ratio. Portlandite abundance in keeping with water/cement ratio.

2. Slight deterioration, possibly through slightly excess voidage, excess microcracking, uneven paste composition, low levels of alkali-aggregate reaction, drying shrinkage, low temperature curing, possibly slightly lean mixture.

3. Moderately low deterioration, possibly with enhanced voidage, microcracking frequency fairly high, excessive paste porosity, evidence of leaching or other forms of secondary alteration, possible lean mixture.

COHERENT CONCRETE WITH MACROSCOPIC EVIDENCE OF DETERIORATION

4. Moderate deterioration, possibly with evident macrocracking or fine cracking, enhanced voidage, high frequencies of microcracking or fine cracks, evidence of significant leaching or other forms of secondary alteration, evidence of ettringite in cracks and voids, evidence of significant alkali-aggregate reaction with gel in cracks.

5. Moderate deterioration, possibly with much fine cracking and some macrocracking, high frequency of microcracks, very high excess voidage, evidence of paste recrystallization, excessive porosity, carbonation highly penetrative, evidence of significant alkali-aggregate in some abundance.

6. As for 5, but with enhanced level of deterioration but with concrete remaining intact.

CONCRETE LACKS COHERENCE AND IS FRIABLE OR READILY DECOMPOSED

7. Concrete shows deterioration and may be partly decomposed or friable. May be difficult to cut and to polish.

8. As 7, but enhanced friability and tending to break into fragments. Loose aggregate particles, honeycombed.

9. As 8, but enhanced deterioration. Much cracking and fragmentation.

10. All cementitious value, coherence and strength lost.

1. Preliminary examination:

The samples are examined with the binocular microscope as received and their dimensions and main features are recorded. The features observed include the following.

(a) The presence and position of reinforcement.

(b) The extent to which reinforcement is corroded.

(c) The nature of the external surfaces of the concrete.

(d) The features and distribution of macro and fine cracks.

(e) The distribution and size range and type of the aggregate.

(f) The type and condition of the cement paste.

(g) Any superficial evidence of deleterious processes affecting the concrete.

2. Polished surfaces:

A plate is cut, where possible, from each sample. This is typically about 20 mm thick and usually provides as large a section of the sample as is possible and typically has a polished surface area of >100cm^2. The plate is polished to give a high quality surface that can be examined with a high quality binocular microscope or even with the petrological microscope if necessary. The polished plate is used to assess the following.

(a) The size, shape and distribution of coarse and fine aggregate.

(b) The coherence, colour, and porosity of the cement paste.

(c) The distribution, size, shape, and content of voids.

(d) The composition of the concrete in terms of the volume proportions of coarse aggregate, fine aggregate, paste and void.

(e) The distribution of fine cracks and microcracks. Often the surface is stained with a penetrative dye, so that these cracks can be seen. Microcrack frequency is measured along lines of traverse across the surface.

(f) The relative abundance of rock types in the coarse aggregate is assessed.

3. Thin sections:

A thin section is prepared for each sample as appropriate. The section is usually made from a plate cut at right angles to the external surface of the concrete, so that the outer 70 mm or so of the concrete are included in the section. Sometimes it is more appropriate to make the section from inner parts of the concrete. This might be appropriate where specific problems are being investigated for example. The section normally measures about 50 x 70 mm.

In manufacturing the thin section a plate some 10 mm thick is cut from the sample. This is impregnated with a penetrative resin containing a yellow fluorescent dye. The resin penetrates into cracks, microcracks, and capillary pores in the sample. One side of the impregnated plate is then polished and the plate is mounted on to a glass slide. The surplus sample is then removed and the plate is ground and polished to give a final thickness of between 20 and 30 micrometres. At all stages the cutting and grinding is carried out using an oil based coolant in order to prevent further hydration of the cement and excessive heating of the section. The thin section is covered and then examined with a high quality Zeiss petrological photomicroscope.

The thin section supplies the following types of information:

(a) Details of the rock types present in the coarse and fine aggregate and in particular structures seen within those rocks.

(b) Details of the aggregate properties are measured such as the degree of strain in quartz.

(c) The size, distribution and abundance of phases in the cement paste are assessed including, for example, the occurrence of calcium hydroxide and the amount of residual unhydrated clinker.

(d) The presence of cement replacement phases such as slag or PFA can usually be recognised (though the amount of these phases cannot be judged accurately). The presence of high alumina cement can be detected and the type of cement clinker can often be assessed.

(e) Any products of processes of deterioration of either the cement paste or the aggregate can be recognised.

4. Broken surfaces:

After the specially prepared surfaces and sections are completed, the remainder of the core is examined with the binocular microscope. In particular, the pieces are broken to produce fresh surfaces. These surfaces allow the contents of voids to be studied and the nature of aggregate surfaces or crack surfaces to be investigated.

5. Composition:

Where the size of the sample is appropriate the composition of the sample can be measured using either the polished slice or the thin section, depending on the size of the sample and on details of the aggregate type and paste. The thin section is preferable, for example where large quantities of dust are present. The volume proportions are found by the method of point counting using a mechanical stage. The amount of coarse aggregate can also be assessed by this method if a distinction can be made between coarse and fine aggregate. The results obtained usually represent the sample reasonably, but may not represent the concrete.

6. Water/cement ratio:

The hydration processes of cement paste vary significantly with the original water/cement ratio. Concretes with a low water/cement ratio tend to leave substantial quantities of unhydrated cement clinker and to develop only limited amounts of coarsely crystalline calcium hydroxide. In particular, the extent to which calcium hydroxide is separated into layers on aggregate surfaces and occurs in voids and on void surfaces varies with the original water/cement ratio. The number and proportion of unhydrated cement clinker particles varies inversely with the original water/cement ratio. Comparison with standard concretes made with known water/cement ratios visually, and by measurement allows the water/cement ratio of the cement paste to be assessed directly. The standard error attached to the estimation of water/cement ratio by this means is considered to be approximately +/- 0.1 for unaltered concrete of similar type that in the Sandberg Reference Concrete Collection. It should be noted that aggregate dust, the presence of admixtures and additives all contribute to uncertainty in the petrographic measurement of the water/cement ratio of the concrete.

7. Glossary:

The following is a short list of technical terms in common use in the petrographic examination of concrete.[1]

Alkali-aggregate reaction (AAR): This is a broad term encompassing both alkali carbonate reaction (ACR) and alkali silicate reaction and alkali-silica reaction (ASR). It refers to reactions between alkalies in usually derived from the cement in the cement paste and aggregate particles. Some forms of alkali-aggregate reaction such as ASR result in the formation of an alkali-silicate gel that is readily detectable in thin sections. Other forms of alkali-carbonate reaction such as ACR may not result gel formation.

Alkali carbonate reaction (ACR): This form of reaction is very rare in the UK and there is some debate over the precise mechanism of this reaction. Most documented cases of ACR involve argillaceous, dolomitic limestone. The reaction which is expansive is rarely associated with the formation of obvious gel deposits.

Alkali-silicate/silica reaction (ASR): This is by far the most common form of AAR and generally results from reactions between either microcrystalline, cryptocrystalline, or substantially strained quartz and associated microcrystalline quartz at grain margins and alkalies in cement paste. On rare occasions, ASR may result from the presence of highly reactive opaline silica in aggregate. Petrographic examination is the definitive method for the detection of this form of concrete deterioration. The reaction commonly results in the development of cracking that originates within reactive aggregate particles and continues into the surrounding paste and gel deposits are commonly associated with the occurrence of ASR.

Calcium aluminate cement (CAC): This is a general term that encompasses high alumina cement (HAC) as well as some of the more modern aluminate cements used in rapid setting concrete repair materials or some types of sprayed concretes and grouts.

Carbonation: Carbonation most commonly results from the exposure of concrete to atmospheric carbon dioxide and results in the conversion of portlandite to calcium carbonate and also affects some of the cement hydrate phases forming complex calcium silicate hydrate carbonate compounds. In damp conditions or in concrete exposed to moisture containing dissolved carbon dioxide, coarse-textured carbonation may develop and coarse crystals of calcium carbonate may develop within the cement paste. “Popcorn” calcite deposition (PCD) is one form of this type of carbonation.

Cracking: Cracks are classified using the following terms:

- **Macroscopic cracks:** These cracks are visible in the hand specimen or with the aid of a stereo binocular microscope and are typically >0.01mm wide.
- **Macrocrack:** These are cracks that are readily visible to the naked eye without the aid of a stereo binocular microscope and are typically >0.1mm wide.
- **Fine crack:** These are cracks that are only readily visible with a stereo binocular microscope or in thin section. Cracks of this type are typically between 0.01 and 0.10mm wide.
- **Microcracking:** These cracks cannot be detected with a stereo binocular microscope. They are typically <0.01mm wide and are most easily seen in petrographic thin sections containing fluorescent dye and by using fluorescent illumination.

Delayed ettringite formation (DEF): This term describes deleterious ettringite formation in concrete that has been cured at elevated temperatures, typically >65°C. Ettringite formation resulting from this process can be readily detected using thin sections and the ettringite tends to form in peripheral cracks around aggregate surfaces and sometimes within microcracks in the paste.

[1] From APG SR-2

Drying shrinkage cracking: Drying shrinkage microcracks tend to develop radially around the surfaces of fine aggregate particles in concrete. Fine cracks and macrocracks caused by drying shrinkage tend to be parallel-sided cracks and orientated perpendicular to concrete surfaces.

Ettringite: This is a very common calcium-alumino-sulfate mineral. It occurs in most concretes where moisture ingress has occurred. Ettringite formation may be deleterious in the case of DEF or sulfate attack where it can give rise to a deleterious expansion and distinctive forms of cracking but in most cases secondary ettringite formation is non-deleterious.

Fine crack: See section on cracking.

GGBS: Ground, granulated blast furnace slag. This material is commonly employed as a cement replacement material in concrete and can be easily recognised in thin section. The GGBS particles are typically angular and are composed almost entirely of glass.

High alumina cement (HAC): This is a form of cement manufactured from the fusion of limestone and bauxite. It is readily distinguishable in thin section from most other types of cement. Petrographic examination is the definitive method for the detection of carbonation in concrete containing HAC.

Macrocrack: See section on cracking.

Macroscopic: This is a general term referring to features that are visible to the naked eye or with the aid of a stereo microscope.

Microcrack: See section on cracking.

Microsilica: Well dispersed microsilica cannot be directly observed in thin sections. However, distinctive clots of undispersed microsilica area commonly present in concrete containing microsilica – even where most of the microsilica is well dispersed. Microsilica clots are isotropic, and tend to be spherical and are sometimes concentrically layered. They are typically <100µm in diameter.

PFA: Pulverised fly ash. This material is a by-product of coal burning power stations and can be readily recognised in thin sections, where it is visible as spherical glass particles, some of which may be hollow. Hollow PFA particles may be referred to as cenospheres. PFA is also commonly associated with small quantities of graphite particles that appear black in thin section.

Plastic shrinkage cracking: This form of cracking occurs in concrete prior to its hardening. It can be distinguished from many other forms of cracking in that it results in cracks that are generally restricted to the cement paste and are non-parallel sided. Cracks of this type typically appear on the concrete surface and commonly diminish in width rapidly with depth and the paste surrounding cracks of this type is commonly of locally high porosity reflecting the migration of moisture towards the cracks during the drying out of the concrete surfaces.

Porosity: This term is distinct from void content. It refers to microscopic pores within cement hydrates. Porosity is directly related to water/cement ratio, but is also strongly influenced by curing and many forms of concrete deterioration. Porosity is sometimes used as an indicator of water/cement ratio in hardened concrete.

Portland cement: Portland cement is the most common form of binder used in concrete and is manufactured from the burning of limestone and an alumino-silicate rock (clay or shale) at temperatures of up to 1500^{o}C. There are many forms of Portland cement and it is commonly possible to distinguish sulfate-resisting and white Portland cement and ordinary Portland cement using petrographic thin sections.

Portlandite: Portlandite is calcium hydroxide and is one of the products formed during cement hydration. Portlandite is readily recognisable in thin sections and has a distinctively high birefringence that contrasts with the much lower birefringence of the hydrated cement phases.

Sulfate attack: This is a general term encompassing both conventional sulfate attack resulting in gypsum and ettringite formation, but also includes sulfate attack associated with thaumasite formation. Sulfate attack can be readily recognised in thin sections and commonly results in the development of surface-parallel cracks infilled with ettringite or thaumasite.

Thaumasite: This is a carbonate-sulfate calcium hydrate mineral with a complex composition. It is a common reaction product in concrete exposed to moisture containing both carbonate and sulfate ions. Thaumasite is most commonly encountered in concrete exposed to temperatures of <4°C. Some forms of thaumasite can be readily distinguished from ettringite and have a high birefringence. However, some forms of thaumasite have a much lower birefringence and can be difficult to distinguish from ettringite without recourse to SEM micro-analysis.

Void: This describes empty spaces present in concrete that are typically greater than about 5 micrometres in diameter. It encompasses both entrained air voids (spherical voids typically <1mm in diameter) as well as much larger entrapped air voids. It should be noted that it is possible for concrete to have a low porosity, but a high void content.

End of report

A - DEFECT SURVEY

To conduct a defect/hammer/soundness survey one or a combination of the following methods of access shall be utilised.

- Industrial rope access techniques
- MEWP
- Mobile tower scaffold
- Steps/hop-up

Areas exhibiting distress are hammer tested for signs of movement and/or acoustic variation. During survey, any loose or potentially loose material is removed, and the location/details recorded. The results of the defect/hammer/soundness survey can only be considered valid for a limited period, which is dependent upon many factors, most critically: -

- Element age
- Element location/orientation
- Environmental conditions
- Material quality

Also, the force applied to each hammer blow, in order to highlight deficiencies, should not in the first instance cause additional or excessive damage to the material or structure. The force used is subjective and variable between operatives. Defects such as concrete delamination can be difficult to accurately measure when sub-surface cracking is very minor or deep within the body of the concrete. When areas of delamination identified by hammer tapping or chain drag are broken out for repair purposes, using percussive tools or hydro demolition, the area of defective concrete can be more than 20% greater than that indicated by the delamination survey.

In order to standardise the correct measurement of concrete defects the following methodology has been used to help facilitate the calculations of the required volume of repairs. This methodology is based after the Concrete Repair Association, Standard Method of Measurement 3rd edition 2015.

Spalling to Plain Vertical or Horizontal Surfaces; Decks, Soffits, Walls, Columns, Beams, Panels

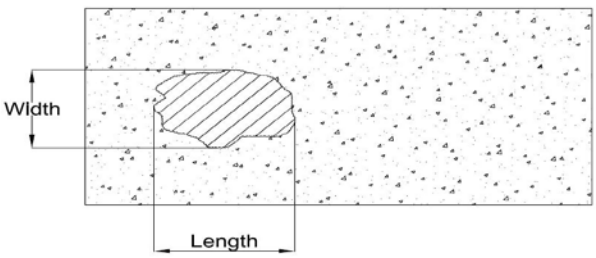


Fig 1.

Area of repair = Length x Width (L x W1)

Depth of repair (D1) = maximum depth of the repair within a substantial proportion of the repair area. Localised deeper areas which in total do not exceed 10% of the area shall not be considered when assessing the repair depth.
Where reinforcement is exposed the average depth to the front face of main reinforcement can be recorded as D2.

Two Vertical or Horizontal Surfaces, One Arris (E.G. Column, Beam, Slab Edge, Panel Edge)

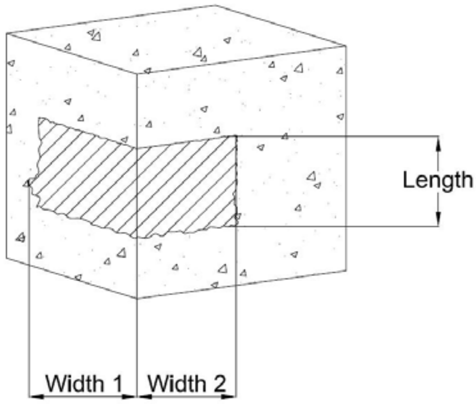


Fig 2.
Length is longest length measurement
Width measurements should be taken on a left to right basis.
Where the area of damage includes a soffit, this is recorded as Width 1.
Girth = Width 1 + Width 2
Depth of repair (D1) = maximum depth of the repair within a substantial proportion of the repair area. Localised deeper areas which in total do not exceed 10% of the area shall not be considered when assessing the repair depth.
Where reinforcement is exposed the average depth to the front face of main reinforcement can be recorded as D2.

Three Vertical or Horizontal Surfaces, Two Arrises; Column, Beam

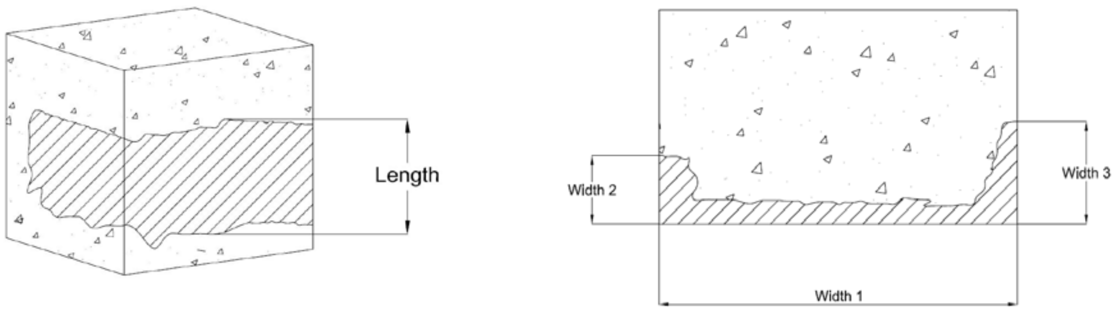


Fig. 3
When an area of damage has two arises and three planes the central plane width dimension or soffit should be recorded as width 1. Remaining width dimensions should be taken on a left to right basis.
Girth = Width 1 + Width 2 + Width 3
Depth of repair(D1) = maximum depth of the repair within a substantial proportion of the repair area. Localised deeper areas which in total do not exceed 10% of the area shall not be considered when assessing the repair depth.
Where reinforcement is exposed the average depth to the front face of main reinforcement can be recorded as D2.

Slab Corner Repairs

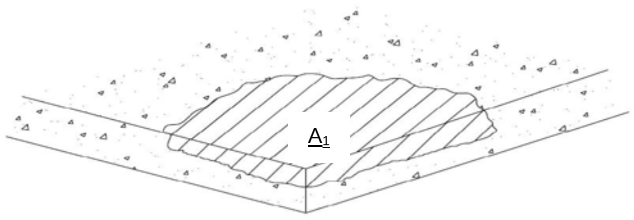


Fig 4.
Repairs on slab extending along two edges, measured as one repair A1 (L x W1). Depth of repair (D1) = maximum depth of the repair within a substantial proportion of the repair area. Where reinforcement is exposed the average depth to the front face of main reinforcement can be recorded as D2

Slab Repairs Extending Along Three Edges

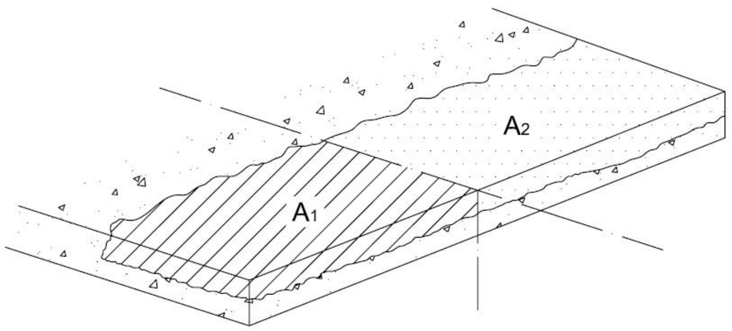


Fig. 5
Repairs on slab extending along three edges, measured as two repairs – one of area A1, and one of area A2.

Cracking & Crack Width Measurement	
Surface crack width (mm)	**Crack Width Description**
<0.1	Very fine (CVF)
0.1 - 0.3	Fine (CF)
0.3 - 1	Moderately wide (CMW)
1-5	Wide (CW)
5-10	Very wide (CVW)
>10	Extremely wide (CEW)

Table 1: Crack width measurement

Mean crack width recorded as W1. I If crack width narrows etc. then start, midle and end can be recorded as W1, W2, W3
Crack Length (L) recorded in in mm
Crack orientantion: Vertical, Horizontal, Diagonal, Multi Directional (crazing / map cracking)

Descriptions Of Crack Spacing	
Distance between adjacent cracks (mm)	**Description**
<25	Extremely closely spaced (CSEC)
25-100	Very closely spaced (CSVC)
100-250	Closely spaced (CSCS)
250-500	Moderately spaced (CSMS)
500-1000	Widely spaced (CSWS)
1000-5000	Very widely spaced (CSVW)
<50000	Extremely widely spaced (CSEW)

Table 2: Crack spacing measurement

B – CONCRETE COVER TO REINFORCEMENT

Site determinations of concrete cover to reinforcement are made using an electromagnetic covermeter in accordance with British Standard 1881: Part 204: 1988. This equipment is designed to locate steel within circa 100mm of the concrete surface.

During use of the covermeter a calibration check is made against a reinforcement, exposed as part of the survey process.

C - CONCRETE SAMPLING

The concrete dust samples are taken by percussive drilling, in accordance with BS EN 14629: 2007.

Where single increment samples are taken, material is recovered to a depth of 40mm, with the outermost 5mm being discarded. If chloride profiling is deemed necessary, then samples are generally taken to a depth of 80mm, in 25mm sample increments, with the outermost 5mm being discarded. The number of increments taken, depth of each increment and total depth to which samples are recovered can be changed depending the structure under investigation and the associated reinforcement depth.

All concrete sampling and breakout locations are reinstated with a proprietary hand place repair mortar conforming the BS EN 1504.

D - CARBONATION SURVEY

Depth of carbonation is determined using phenolphthalein indicator in accordance, with BS EN 14630: 2006. The mean and maximum depth of the carbonation was measured to an accuracy of 1mm, using a depth gauge.

E - CHLORIDE ION CONTENT

Recovered samples are analysed to determine the chloride ion content in accordance with BS EN 14629: 2007. Results are presented by weight of sample and by weight of cement. Samples can also be analysed for cement content in accordance with the directives of BS 1881: Part 124: 2015, to allow an accurate level of chlorides to be expressed by weight of cement. If chlorides levels are low or the mix design of the concrete is known an assumed cement content of may be used.

Chloride risk levels have been classified in accordance with criteria given in Building Research Establishment Digest 444: Part 2. Where chlorides are considered as cast into the concrete at the time of manufacture then BRE Digest 444: Part 2 table 4 is used to assess the corrosion risk.

<table>
<tr><th>Reinforcement Environment</th><th colspan="5">Cast-in Chloride Risk of Corrosion (Chloride content % by weight of Cement)</th></tr>
<tr><td>Damp pH <10</td><td colspan="2">Moderate 0 to 0.6%</td><td>High 0.6 to 1.0%</td><td colspan="2">Very High 1.0 to >1.5%</td></tr>
<tr><td>Dry pH <10</td><td>Low 0 to 0.4%</td><td>Moderate 0.4 to 0.7%</td><td>High 0.7 to 1.0%</td><td colspan="2">Very High 1.0 to >1.5%</td></tr>
<tr><td>Damp pH >10</td><td>Negligible 0 to 0.4%</td><td>Low 0.4 to 0.7%</td><td>Moderate 0.7 to 1.0%</td><td>High 1.0 to 1.5%</td><td>Very High >1.5%</td></tr>
<tr><td>Dry pH >10</td><td>Negligible 0 to 0.4%</td><td colspan="2">Low 0.4 to 1.0%</td><td>Moderate 1.0 to 1.5%</td><td>High >1.5%</td></tr>
</table>

Table 3: Cast-in chloride corrosion risk, 25-year-old structures

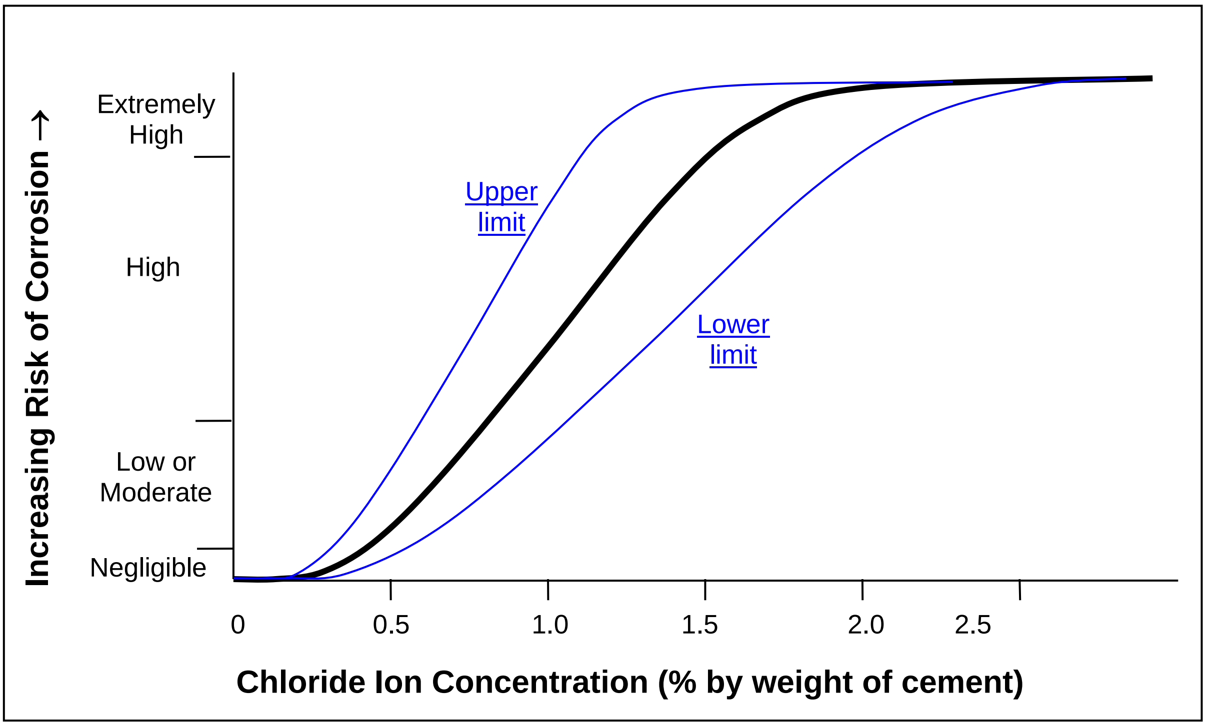
<table>
<tr><th>Reinforcement Environment</th><th colspan="5">Cast-in Chloride Risk of Corrosion (Chloride content % by weight of Cement)</th></tr>
<tr><td>Damp pH <10</td><td>Moderate 0 to 0.4%</td><td>High 0.4 to 0.7%</td><td>Very High 0.7 to 1.0%</td><td colspan="2">Extremely High >1.0%</td></tr>
<tr><td>Dry pH <10</td><td>Low 0 to 0.3%</td><td>Moderate 0.3 to 0.6%</td><td>High 0.6 to 1.0%</td><td>Very High 1.0 to 1.5%</td><td>Extremely High >1.5%</td></tr>
<tr><td>Damp pH >10</td><td>Low 0 to 0.5%</td><td>Moderate 0.5 to 0.7%</td><td>High 0.7 to 1.0%</td><td>Very High 1.0 to 1.5%</td><td>Extremely High >1.5%</td></tr>
<tr><td>Dry pH >10</td><td>Negligible 0 to 0.4%</td><td>Low 0.4 to 0.7%</td><td>Moderate 0.7 to 1.0%</td><td>High 1.0 to 1.5%</td><td>Very High >1.5%</td></tr>
</table>

Table 4: Cast-in chloride corrosion risk, 40-year-old structures

<table>
<tr><th>Reinforcement Environment</th><th colspan="5">Cast-in Chloride Risk of Corrosion (Chloride content % by weight of Cement)</th></tr>
<tr><td>Damp pH <10</td><td>Moderate 0 to 0.4%</td><td>High 0.4 to 0.6%</td><td>Very High 0.6 to 0.8%</td><td colspan="2">Extremely High >0.8%</td></tr>
<tr><td>Dry pH <10</td><td>Low 0 to 0.2%</td><td>Moderate 0.2 to 0.6%</td><td>High 0.6 to 0.8%</td><td>Very High 0.8 to 1.5%</td><td>Extremely High >1.5%</td></tr>
<tr><td>Damp pH >10</td><td>Low 0 to 0.4%</td><td>Moderate 0.4 to 0.6%</td><td>High 0.6 to 0.8%</td><td>Very High 0.8 to 1.5%</td><td>Extremely High >1.5%</td></tr>
<tr><td>Dry pH >10</td><td>Negligible 0 to 0.4%</td><td>Low 0.4 to 0.6%</td><td>Moderate 0.6 to 0.8%</td><td>High 0.8 to 1.5%</td><td>Very High >1.5%</td></tr>
</table>

Table 5: Cast-in chloride corrosion risk, 60-year-old structures (extrapolated data)

For ingressing chlorides there is an empirical relationship between chloride concertation at the reinforcement and corrosion risk; represented by the following graph (Figure 5 of BRE Digest 444: Part 2) which can be translated into Table 6.



Risk of steel reinforcement corrosion with increasing chloride concentration in the concrete in the vicinity of the steel (un-carbonated concrete)

Ingressing Chloride Content by Weight of Cement %	Risk of Corrosion Uncarbonated concrete (pH >10)	Risk of Corrosion Carbonated concrete* (pH <10)
<0.20	Negligible	Low
0.20 to 0.40	Low	Moderate
0.40 to 0.80	Moderate	High
0.80 to 1.50	High	Extremely High
>1.50	Extremely High	Extremely High

Table 6: Corrosion risk with increasing ingressing chloride contamination (* Risk based on extrapolated data for chlorides in circa >40 year old damp concrete with pH <10 - carbonated concrete)

F - HALF-CELL POTENTIAL SURVEY

Half-cell potential surveys are undertaken in accordance with American Standard ASTM C876-80 (Standard Test Method for Half-cell Potentials of Reinforcing Steel in concrete). Generally using a wheel electrode device, readings are taken at intersection points within a 500mm grid. However, the grid size may be altered to depending upon the size of the element under investigation or to provide a greater level of detail.

The potential difference between a corroding reinforcement area (anode) and passive reinforcement (cathode) can be detected by means of potential field measurements, allowing the position where active corrosion is taking place to be located.

Potential field measurements record the potentials at the concrete surface, in order to get a characteristic picture of the state of corrosion of the steel surface within the concrete. For this purpose, a reference electrode is connected via a high-impedance voltmeter to the steel reinforcement and is moved in a grid over the concrete surface. The reference electrode is normally a $Cu/CuSO_4$ half-cell. It consists of a copper rod immersed in a saturated copper sulphate solution, which maintains a constant, known potential. The contact of the reference electrode with the concrete surface is achieved by means of a moist sponge in the case of the rod electrode or by means of a felt band with a moisturising water supply in the case of wheel electrodes. As the voltage of the reference electrode is known, the measured voltage (potential difference) gives the potential at the concrete surface and thereby indirectly a reference value for the potential at the steel surface. Typical orders of magnitude for the half-cell potential of steel in concrete measured against a $Cu/CuSO_4$- reference electrode is in the following range (RILEM TC 154-EMC):

- water saturated concrete without O_2: -1000 to -900 mV
- moist, chloride contaminated concrete: -600 to -400 mV
- moist, chloride free concrete: -200 to +100 mV
- moist, carbonated concrete: -400 to +100 mV
- dry, carbonated concrete: 0 to +200 mV
- dry, non-carbonated concrete: 0 to +200 mV

Provided that the corrosion conditions are equal (chloride content or carbonation of the concrete at the steel surface) the main influences upon the half-cell potentials are; the concrete cover thickness, the electrical resistivity of the concrete cover and the oxygen content at the reinforcement, whereby the latter is coupled with the first two. These influences vary between different structures and also locally within a single concrete component under investigation.

ASTM C-876 states that there is a high risk of corrosion if the potential is more negative than -350mV v's sat., $Cu/CuSO_4$ reference electrode. If the potential is less negative than -200mV v's sat., $Cu/CuSO_4$ reference electrode there is a low risk of corrosion. Between -200mV and -350mV v's sat. $Cu/CuSO_4$ reference electrode the risk is uncertain.

The aforementioned interpretation does not apply to carbonated concrete, pre-cast concrete or concrete elements with chlorides cast-in at the time of manufacture.

G - SURFACE RESISTIVITY MEASUREMENT

Surface resistivity measurements are taken in order to ascertain the likelihood of corrosion and corrosion rate. A Proceq Resipod, with 50mm probe spacing, is used to conduct the surface resistivity measurements. The Resipod is a fully integrated 4-point Webber probe, designed to measure the electrical resistivity of concrete.

The electrical resistivity of the concrete cover decreases under practical conditions due to increasing concrete water content (this depends on how porous the concrete is, exposure conditions and dimensions of the concrete element), increasing concrete porosity, increasing temperature and increasing chloride content. Carbonation of the cover concrete can also increase surface resistivity.

The interpretation of resistivity measurements with regard to corrosion is empirical. The following interpretation of resistivity measurements has been cited when referring to de-passivated steel.

- >20 k ohm cm — Low corrosion rate
- 10-20 k ohm cm — Low to moderate corrosion rate
- 5-10 k ohm cm — High corrosion rate
- <5 k ohm cm — Very High corrosion rate

H - COMPRESSIVE STRENGTH TESTING

Using diamond drilling apparatus, core samples are removed from the element under investigation. Where possible 100mm dia. core are taken, however in some instances the core diam. May be reduced to 75-80mm to prevent damage to reinforcement. Compressive strength testing is conducted in accordance with BS EN 12504-1:2000 Testing concrete in structures - Cored specimens - Taking, examining and testing in compression.

F - CORROSION MECHANISMS of STEEL IN CONCRETE

General corrosion of reinforcement is caused by the loss of protection afforded to steel in concrete. Steel in concrete is protected (passivated) by the high alkalinity of the concrete.

Carbonation of the concrete, due to atmospheric carbon dioxide, causes a reduction in the concrete alkalinity. This results in the steel reinforcement being susceptible to corrosion in the presence of moisture and oxygen.

Corrosion can also be caused by chlorides, either introduced into the concrete from an external source or cast in at the time of construction. Chlorides within the concrete result in the formation of an electrochemical cell, which can result in pitting corrosion.

Carbonation Induced Corrosion (General Corrosion)

Carbonation of concrete cover occurs when atmospheric carbon dioxide dissolves in the concrete's pore solution and forms carbonic acid, which reacts with the calcium hydroxide generated in cement hydration and with the sodium and potassium hydroxides generated from the alkalis in cement. This precipitates calcium carbonate and reduces the pH to below the level required for the steel to be passive.

The relatively low concentrations of soluble sodium and potassium carbonate produced from the alkalis offset this reduction somewhat but are not enough to passivate the steel. Carbonation takes place most rapidly in conditions of low to intermediate humidity (50-70% relative humidity). At high humidity carbon dioxide cannot penetrate the water filled pores to react with calcium hydroxide and other calcium silicate phases. In very dry concrete there is insufficient water for the carbon dioxide to dissolve and form carbonic acid. When the carbonation zone reaches the reinforcing steel, the steel becomes at risk of corrosion in the presence of moisture and oxygen.

Chloride Induced Corrosion

Corrosion due to chloride ions can be a much greater problem as it can occur even when the surrounding concrete is alkaline. Chlorides are a common species but are generally present in concrete from marine contamination, from de-icing salts or from the use of chloride-based admixtures. Calcium chloride admixture was widely used well into the 1970's as an accelerating and cold-weather admixture for reinforced concrete. The use of chloride-based admixtures was prohibited in the UK in 1977.

Chloride admixtures, introduced during mixing, are mostly bound by the aluminate phase in ordinary Portland cement concrete. Carbonation releases the bound chlorides and can cause them to concentrate ahead of the carbonation front. The problems associated with chloride admixtures are closely linked to the extent of carbonation. Hence reinforcement, located within the carbonation zone, due to poor bar spacing, will be at a far greater risk of suffering chloride-induced corrosion. When steel is in a passive condition, its oxide film is believed to be in a state of dynamic equilibrium, constantly undergoing local, small breakdown and repair processes, randomly over the surface.

Chloride ions interfere with this process, the local environment inside the zone of film breakdown is transformed to an acidic, chloride-rich solution. This causes the anodic activity of the metal to increase locally so that the region develops into a pit, which grows leading to localised penetration of the metal. This localised degradation of embedded steel is known as pitting corrosion. It can lead to rapid loss of cross-sectional area and load bearing capacity of the metal, as well as causing expansive forces which can cause spalling of the concrete. However, in some instances the volumetric expansion of the corrosion products is minimal compared with the section loss caused by the pit formation. This can lead to significant loss in section before obvious surface cracking or spalling is noticed.