URS

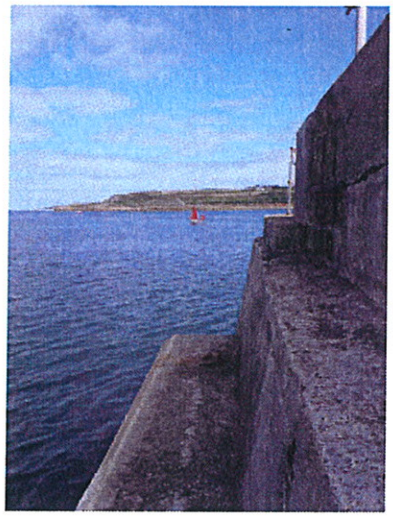
St. Mary's Quay – Wave Wall Inspection

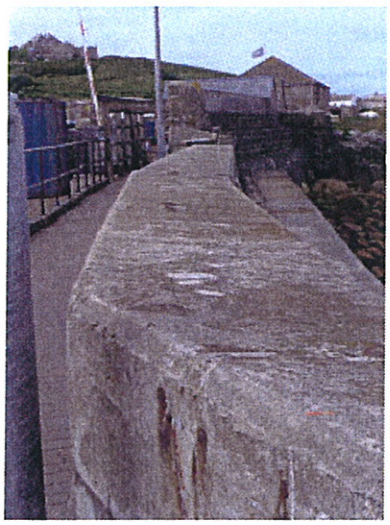
Inspection Report

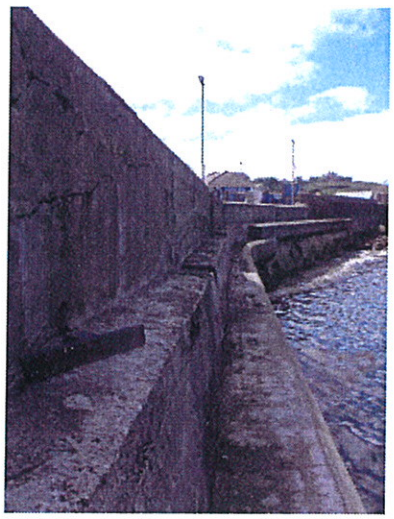
October 2013

Prepared for:
Duchy of Cornwall

UNITED KINGDOM & IRELAND







DUCHY of CORNWALL

REVISION SCHEDULE

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The methodology adopted and the sources of information used by URS in providing its services are outlined in this Report. The survey work described in this Report was undertaken between 02/09/2013 and 27/09/2013 and is based on the conditions encountered and the information available during the said period of time. The scope of this Report and the services are accordingly factually limited by these circumstances.

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Where field investigations are carried out, these have been restricted to a level of detail required to meet the stated objectives of the services. The results of any measurements taken may vary spatially or with time and further confirmatory measurements should be made after any significant delay in issuing this Report.

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APPENDICES

1 INTRODUCTION

1.1 General

URS Infrastructure & Environment UK Limited was appointed by the Duchy of Cornwall to undertake the inspection of the existing reinforced concrete wave wall at St. Mary's Harbour, Isles of Scilly. The inspection was required to assess the condition of the existing concrete to determine the suitability for future constructions on the wave wall.

In order to determine the condition of the existing concrete wall, the following methods were incorporated;

- Visual and photo survey of seaward and leeward sides of the wave wall
- Tactile and hammer sounding survey over the length of the leeward side of the wall
- Crack mapping including locations and sizes of leeward side of the wave wall
- Cover meter readings along the length of the leeward side of the wall
- Chloride testing at incremental depths into the existing concrete on the leeward side of the wave wall
- Carbonation testing along the length of the leeward side of the wall

This document outlines the methodology, results and gives conclusions based on findings from the testing given above.

1.2 Location

The wave wall is located on the quay within the Harbour of St. Mary's, Isles of Scilly. The wall runs North West as shown in Figure 1. The wave wall is approximately 60m long by 1.1m high and runs along the west face of the existing quay. The wall is separated into two straight sections with a corner located approximately equidistant from both ends as shown in Figure 1.

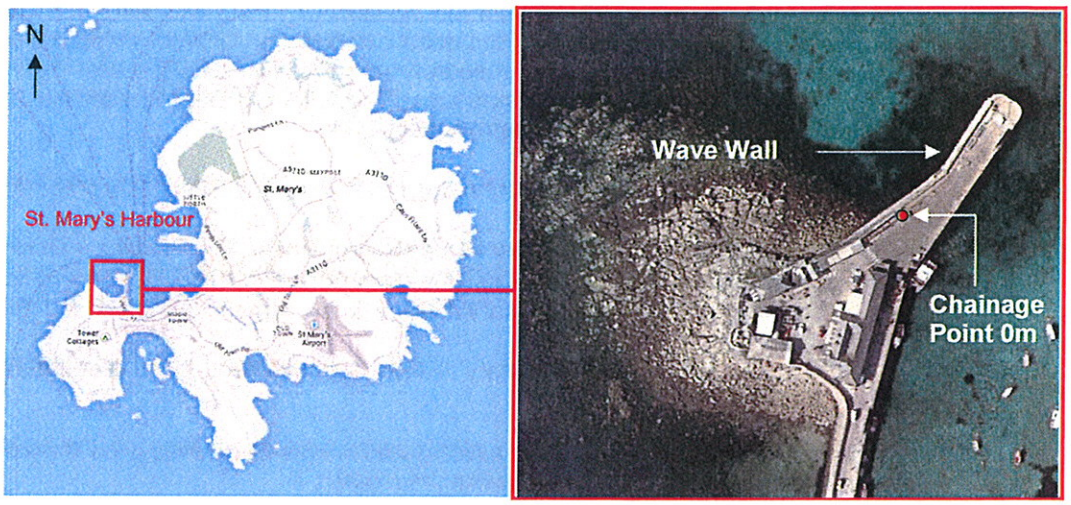


Figure 1: Location and Arrangement of St. Mary's Wave Wall

2 WAVE WALL DESCRIPTION

The original quay structure comprised of stonework masonry gravity quay wall construction on both the east and west faces of the quay. This original construction also included a stonework masonry wave wall in the location specified in Figure 1 and shown in section as the hatched area in Figure 2.

Under the 1993 works for the extension and improvement of St. Mary's Quay, a reinforced concrete face was added to the wave wall increasing the leeward face by 125mm, the seaward face by 150mm and the height by 300mm. A summary of the 1993 improvements on the wave wall is shown in Figure 2 (extracted from Beckett Rankine Partnership Drawing 90/017/53 [1]).

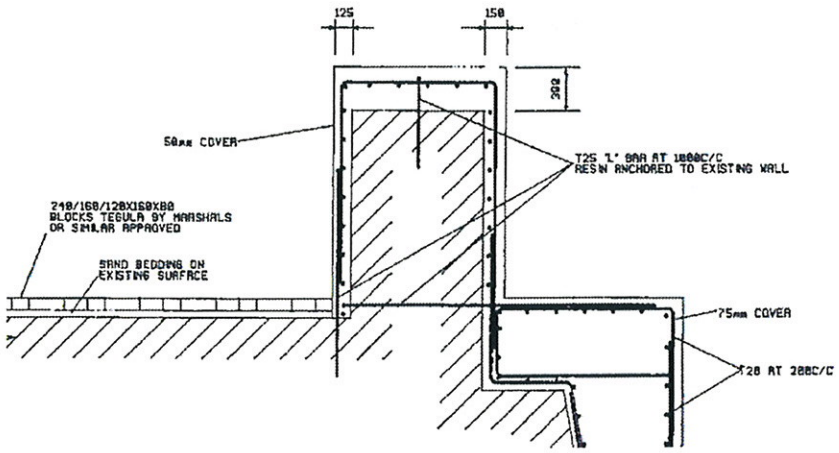


Figure 2: St. Mary's Wave Wall 1993 Improvements

As part of the 1993 improvement works a reinforced concrete plinth was added to the seaward side of the wall. There is also rubble mound armour at the wall base for wave and scour protection which is approximately 1.5m deep extending an unknown distance away from the quall wall. The depth of the rubble mound armour reduces as the wall extends north into deeper water and more exposed conditions. The following Beckett Rankine Drawings have been provided, detailing the 1993 improvement works;

- Drawing 90/017/53 - St. Mary's Quay Improvement: Sheet Piling and Anchor Walls – May 1993, [1].
- Drawing 90/017/59 - St. Mary's Quay Improvement: Pile Painting – October 1993, [2].
- Drawing 90/017/55 - St. Mary's Quay Improvement: Panel Details – June 1993, [3].
- Drawing 90/017/54 - St. Mary's Quay Improvement: Fenders and Bollards – May 1993, [4].
- Drawing 90/017/15 - St. Mary's Quay Improvement: Land Requirements – March 1993, [5].

It is understood that there are no existing documents commenting on the condition of the existing masonry wall at the time of writing this report.

The leeward side of the wave wall on plan measures 23.5m from the start of 1993 works at the south end to the corner on a straight path with the second section measuring 38.5m from the corner to the north end of the wall on the leeward side. The transition angle between the two straight sections is approximately 20 degrees.

3 INSPECTION SCOPE AND METHOD

3.1 General

The inspection work described in this report was carried out on 02/09/2013 with test results produced by 30/09/2013.

3.2 Scope of Work

All inspection and testing was required to cover the total length of the existing wave wall on the leeward side of the wall only (due to health and safety considerations regarding access on the seaward side).

During the inspection no accidents, injuries or near misses were recorded.

A brief scope and methodology of each survey method is given below;

3.2.1 Photographic and Visual Inspection

Visual and photographic inspections were carried out and documented for the total length of the leeward side of the wave wall. The wall was marked with chainages with all photographic evidence referencing a chainage point to ascertain the location on the wall. The datum point was the south end of the wall.

3.2.2 Crack Mapping

Crack mapping was conducted over all leeward facing surfaces which identified and quantified the location and width of all cracks and crack patterns on the existing wave wall.

3.2.3 Tactile and Hammer Sounding Survey

A hammer sounding survey was conducted on all leeward facing surfaces to ascertain any delamination of concrete and weakened or hollow material. The hammer sounding survey was carried out at 5m centres with closer inspection conducted of any areas of concern, particularly cracked and stapled zones.

3.2.4 Cover Meter Survey

A cover meter survey was conducted on all leeward facing surfaces to ascertain the cover to reinforcement at positions along the length of the wall. This cover survey was carried out at 5m centres with closer inspection of any areas where the cover was less than that stated on the drawings. The design cover stated on the original drawings is 50mm (refer Figure 2).

3.2.5 Chloride Testing

Chloride testing was conducted on dust samples extracted from the leeward face of the wall to ascertain the chloride content at depth indicating the risk of corrosion of reinforcement. Dust samples were extracted from penetration depths; 0mm – 25mm, 25mm – 50mm and 50 – 75mm into the wave wall on the leeward side using a 25mm diameter hole. The samples were taken at 10m intervals along the wall length.

3.2.6 **Carbonation Testing**

Carbonation testing was conducted within the holes created when taking the chloride dust samples by spraying phenolphthalein into each hole. Phenolphthalein is an indicator that will turn pink when in contact with normal concrete but remains colourless if the concrete has been subjected to carbonation. The carbonation levels were measured for CO_2 penetration into the existing concrete creating calcites ($CaCO_3$). These penetration levels were measured at increasing depths highlighting potential corrosion of reinforcement. Carbonation testing was conducted at 10m intervals along the length of the wall as well as any areas of concern, particularly cracked zones. The tests were carried out in areas away from any cracking to ascertain the condition of the concrete not affected by cracking.

The areas omitted from the survey (excluding visual) were the seaward side of the wave wall as well as 3m at the north end due to restrictions on access and health and safety considerations. A visual and photographic survey was completed to assess the condition of these areas.

4 OBSERVATIONS AND RESULTS

4.1 Photographic and Visual Inspection

In general the structural condition of the wave wall is seriously deteriorated along the length of the leeward and seaward sides. There is considerable cracking in both the vertical and horizontal directions with crack widths ranging in sizes, examples are shown in Figure 3.

Evidence of remedial works to rectify zones of concentrated cracking is visible through large staples driven into the leeward and top of the wave wall. Areas where staples are present show concentrated cracking which is notably worse than other areas of the wall. It is unclear whether the staples are acting as a catalyst for further cracking by introducing discontinuities but it should be noted that cracking is evident which is discontinuous from the staples edges.

It is worth noting that in zones of concentrated cracking, evidence of spalling concrete is visible. The spalling of concrete ranges in sizes and is dependent on the magnitude of cracking at that location. Spalling is most notable in areas which are of a close proximity to staples from recent remedial works that coincide with the worst cracking, shown in Figure 3.

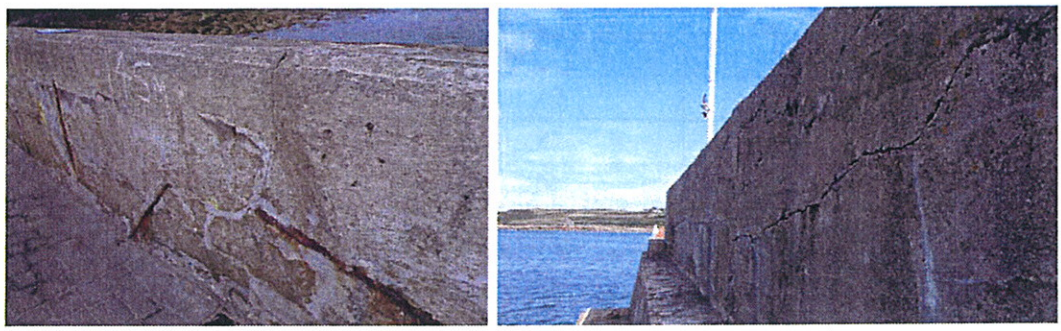


Figure 3: Evidence of Spalling and Cracking on Leeward Side (Left) and Seaward Side (Right)

The intensity of cracking increases as the wall extends away from the shore, with the worst cracking occurring at the more exposed north end. This trend occurs on both the leeward and seaward sides of the wall. It is evident that the magnitude of cracking on the seaward side of the wall is worse than the leeward side with crack widths and depths being much larger in all locations surveyed. This is evidently due to the exposure of the seaward face of the wall to the environmental conditions.

At chainage 36.5m there is a discontinuity the full wave wall height which spans 2.5m in length. Within this discontinuity a 140mm masonry block work wall has been constructed that extends the full height of the wall. The wall appears to be a more recent construction than the 1993 works and appears to use standard concrete blocks and mortar.

The finish of the wave wall is severely deteriorated along all exposed faces. The verticality and finish of the wall is therefore severely affected with many sections showing signs of delamination.

A summary of images has been provided within Appendix 1 to represent the leeward and seaward visual inspection.

4.2 Tactile and Hammer Sounding Survey

The hammer sounding survey suggested significant proportions of the leeward side of the wall to be delaminated by presenting hollow sounding results. It appears that the reinforced concrete placed during the 1993 works has delaminated from the original masonry wall. The areas which presented the worst hollow sounding results coincided with the most concentrated cracking generally at higher elevations on the wall face. Lower levels presented denser, sound concrete at southern ends of the wall with the area of dense sounding material becoming reduced at greater chainages to the north.

4.3 Cover meter Survey

Throughout the leeward side of the wave wall, cover was found to be generally greater than 50mm (design cover shown on the drawings) with the exception of chainage point 40m where cover was shown as 49mm. Cover meter survey results are repeated in Table 1.

Table 1: Wave Wall Cover Relative to Chainages

Chainage (m)	Cover (mm)
0	61
5	58
10	56
15	56
20	55
25	52
30	51
35	53
40	49
45	52
50	55
55	54
60	Inaccessible
Note: For datum point refer to Figure 1	

4.4 Wall Dimension Survey

A dimensions survey was undertaken through hand measurements to determine wave wall heights and widths along its length from chainages 0m to 55m relative to the datum shown in Figure 1.

The height of the wall from deck level increased by 390mm from the southern end to chainage point 35m and dropped by 180mm to chainage point 55m. The high point coincided with the masonry infill section of the wave wall and it should therefore be noted that this increase is more likely due to movement of the wall rather than by design due to the drop from the high point to the north end of the wall. The width of the wall (at the top of the wall) remained approximately constant, with a tolerance of +/- 50mm, through the total length of the wall. The results of the dimensional survey are given in Table 2 below.

Table 2: Wave Wall Dimensions Relative to Chainages

Chainage (m)	Wall Width (mm)	Wall Height (mm)
0	900	990
5	880	1070
10	900	1150
15	900	1170
20	850	1170
25	900	1200
30	870	1240
35	900	1300
40	880	1380
45	900	1350
50	890	1300
55	890	1200
60	Inaccessible	
Note: For datum point refer to Figure 1		

4.5 Crack Mapping

The crack regimes described in Section 4.1 have been visually shown through crack mapping conducted on the leeward side of the wave wall from chainages 0m to 55m relative to the datum shown in Figure 1. All crack widths, locations and extents are shown in Figures 4 to 14. Due to access issues data from chainages 55m to 60m was not obtained but reflected that of chainages 50m to 55m.

4.5.1 Chainage 0m to 5m

The following in Figure 4 shows the wall height, crack locations and sizes for chainages 0m to 5m from the south end of the wave wall on the leeward side only. Crack widths are averages.

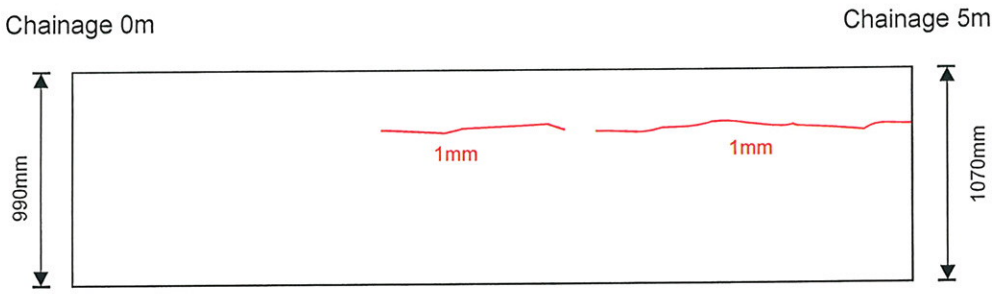


Figure 4: Wall Height, Crack Locations and Sizes for Chainages 0m to 5m

4.5.2 Chainage 5m to 10m

The following in Figure 5 shows the wall height, crack locations and sizes for chainages 5m to 10m from the south end of the wave wall on the leeward side only. Crack widths are averages.

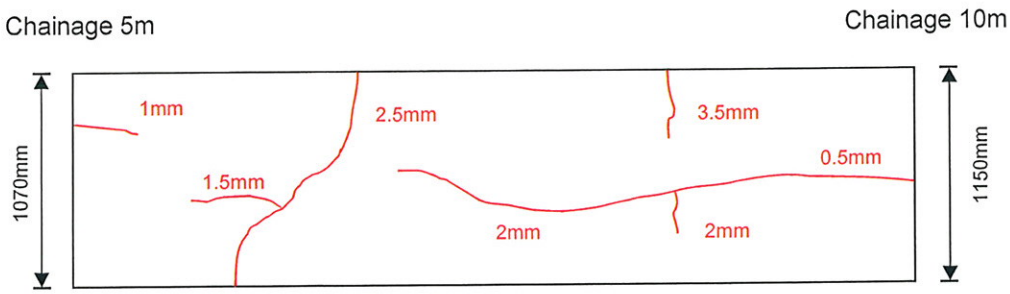


Figure 5: Wall Height, Crack Locations and Sizes for Chainages 5m to 10m

4.5.3 **Chainage 10m to 15m**

The following in Figure 6 shows the wall height, crack locations and sizes for chainages 10m to 15m from the south end of the wave wall on the leeward side. Crack widths are averages.

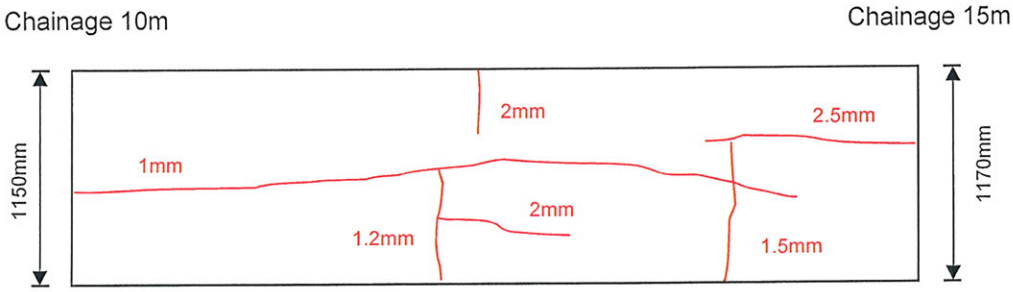


Figure 6: Wall Height, Crack Locations and Sizes for Chainages 10m to 15m

4.5.4 **Chainage 15m to 20m**

The following in Figure 7 shows the wall height, crack locations and sizes for chainages 15m to 20m from the south end of the wave wall on the leeward side. Crack widths are averages.

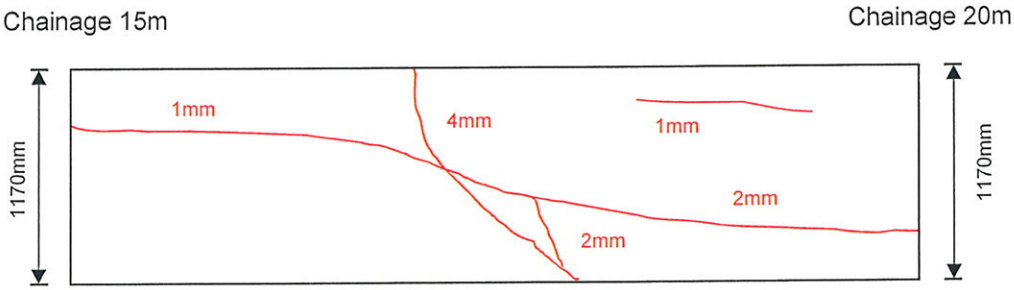


Figure 7: Wall Height, Crack Locations and Sizes for Chainages 15m to 20m

4.5.5 **Chainage 20m to 25m**

The following in Figure 8 shows the wall height, crack locations and sizes for chainages 20m to 25m from the south end of the wave wall on the leeward side. Crack widths are averages.

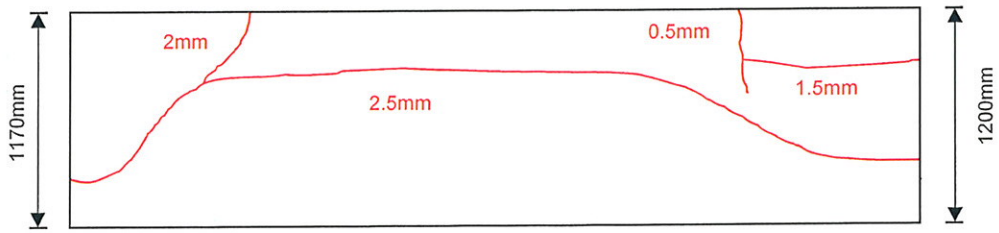


Figure 8: Wall Height, Crack Locations and Sizes for Chainages 20m to 25m

4.5.6 **Chainage 25m to 30m**

The following in Figure 9 shows the wall height, crack locations and sizes for chainages 25m to 30m from the south end of the wave wall on the leeward side. Crack widths are averages.

Figure 9: Wall Height, Crack Locations and Sizes for Chainages 25m to 30m

4.5.7 **Chainage 30m to 35m**

The following in Figure 10 shows the wall height, crack locations and sizes for chainages 30m to 35m from the south end of the wave wall on the leeward side. Crack widths are averages.

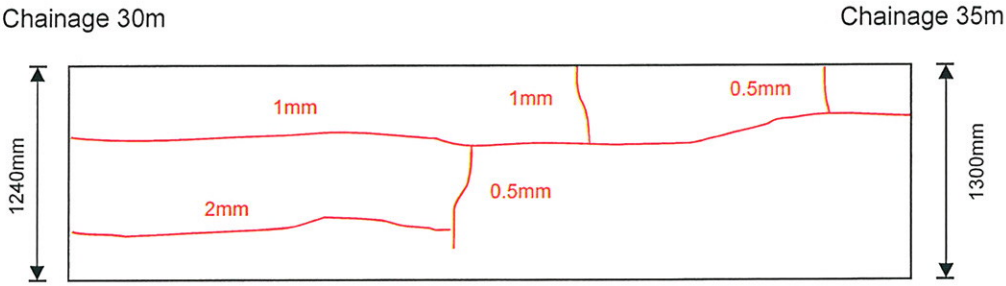


Figure 10: Wall Height, Crack Locations and Sizes for Chainages 30m to 35m

4.5.8 **Chainage 35m to 40m**

The following in Figure 11 shows the wall height, crack locations and sizes for chainages 35m to 40m from the south end of the wave wall on the leeward side. Crack widths are averages.

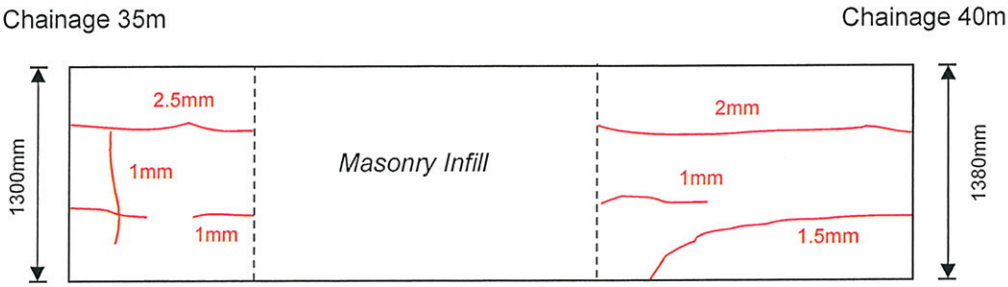


Figure 11: Wall Height, Crack Locations and Sizes for Chainages 35m to 40m

4.5.9 **Chainage 40m to 45m**

The following in Figure 12 shows the wall height, crack locations and sizes for chainages 40m to 45m from the south end of the wave wall on the leeward side. Crack widths are averages.

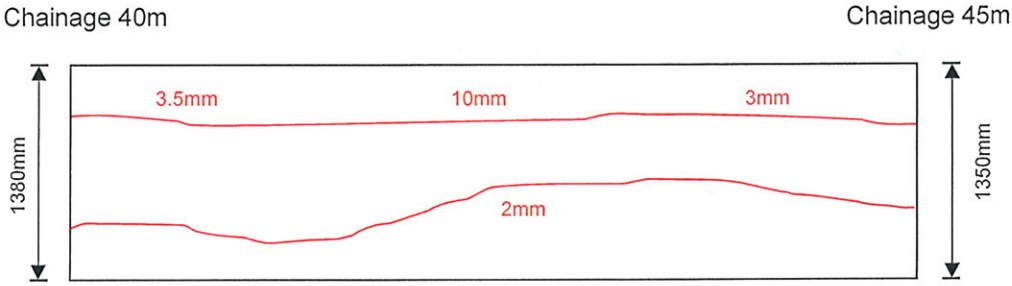


Figure 12: Wall Height, Crack Locations and Sizes for Chainages 40m to 45m

4.5.10 **Chainage 45m to 50m**

The following in Figure 13 shows the wall height, crack locations and sizes for chainages 45m to 50m from the south end of the wave wall on the leeward side. Crack widths are averages.

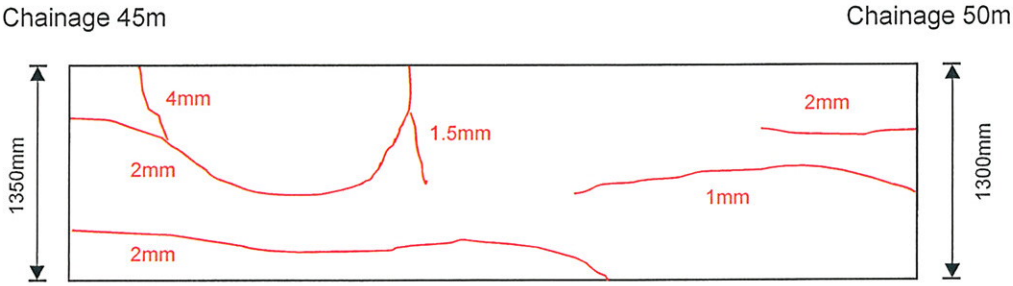


Figure 13: Wall Height, Crack Locations and Sizes for Chainages 45m to 50m

4.5.11 **Chainage 50m to 55m**

The following in Figure 14 shows the wall height, crack locations and sizes for chainages 50m to 55m from the south end of the wave wall on the leeward side. Crack widths are averages.

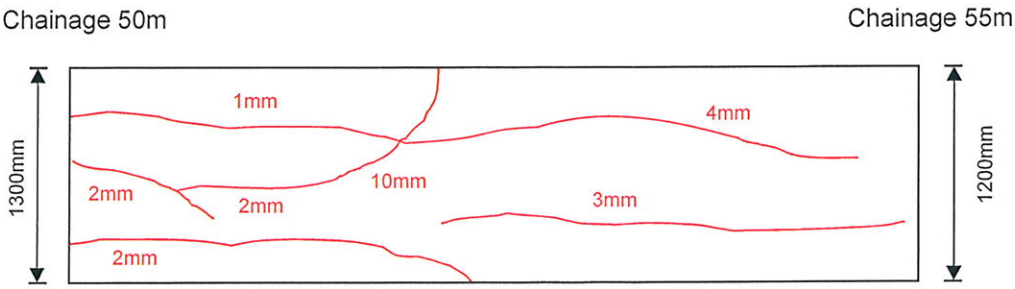


Figure 14: Wall Height, Crack Locations and Sizes for Chainages 50m to 55m

4.6 Carbonation Testing

Carbonation testing was conducted at 10m intervals along the length of the wall. The primary tests were carried out in areas away from any cracking to ascertain the condition of the concrete not affected by cracking.

Generally the carbonation depths into the concrete was small, showing good protection in areas where no cracking was visible.

Table 3: Carbonation Depths Relative to Chainages

Chainage (m)	Carbonation Depth (mm)
0	5
10	4
20	4
30	5
40	6
50	10
60	Inaccessible

4.7 Chloride Testing

Chloride testing was conducted on dust samples extracted from the leeward face of the wall at penetration depths; 0mm – 25mm, 25mm – 50mm and 50 – 75mm into the wave wall on the leeward side at 10m intervals along the wall length. The chloride content laboratory tests were undertaken by RSK Environment Ltd in accordance with BS1881-124:1988, [7].

The chloride content has been given as a % mass of cement. The results show that in all locations the chloride content is significantly greater than the allowable from BS EN 206-1:2000, [6] Table 10 as 0.4% for reinforced concrete. It is also generally expected that chloride content reduces with depth. Results have been given in Table 4.

Table 4: Chloride Test Results Relative to Chainages and Penetration Depths

Chainage (m)	Sample Depth into Wall (mm)	Chloride (as Cl ion) by Mass of Cement (%)
0m	0mm-25mm	4.32
	25mm-50mm	4.37
	50mm-75mm	4.74
10m	0mm-25mm	2.09
	25mm-50mm	2.89
	50mm-75mm	3.50
20m	0mm-25mm	1.94
	25mm-50mm	3.59
	50mm-75mm	3.52
30m	0mm-25mm	5.55
	25mm-50mm	3.34
	50mm-75mm	2.89
40m	0mm-25mm	2.69
	25mm-50mm	3.55
	50mm-75mm	3.19
50m	0mm-25mm	6.49
	25mm-50mm	5.37
	50mm-75mm	5.58
60m	Inaccessible	

5 DISCUSSION

Only the new concrete construction of the wave wall could be usefully investigated under this inspection work.

The condition of the original masonry wave wall (underlying the reinforced concrete) is unknown at this time as no documentation is available to substantiate the condition of the existing section at the time of the 1993 concrete works.

5.1 Visual Inspection

The level of cracking presented within both the leeward and seaward sides of the wave wall is significant. In general, there is a tendency for the cracking to be in the vertical and horizontal directions (although this is not the case for all cracks) and therefore the cracking is following the principal directions of the reinforcement.

Causes of cracking could be attributed to one or a combination of a number of causes including differential movement between the two forms of construction, shrinkage cracking, wave and other loading, corrosion of reinforcement and the like.

Discontinuous cracking from the introduction of staples gives evidence that water ingress from these remedial works has led to the corrosion of reinforcement and further cracking.

The increase in cracking concentration as the wall extends north is most likely attributed to the more exposed location and the wall being subjected to larger wave forces.

It is unknown whether the cracking extends into the original masonry wall as this would require further intrusive investigations.

5.2 Cover Survey

Cover meter readings showed consistent values compared to the construction issue drawings [1] of 50mm with results having a tolerance of +/- 6mm. It appears that the reinforcement was accurately placed during construction. This implies that the reinforcement would have been provided with the level of concrete cover, and hence protection, that was intended by the designer.

5.3 Tactile Hammer Sounding Survey

Hammer sounding surveys highlighted large sections of hollow sounding concrete showing possible delamination throughout the leeward side of the wall. Areas of intense cracking coincided with hollow sounding concrete giving rise to the possibility of water ingress behind the 1993 remedial works and existing masonry wall. In order to determine whether water has penetrated behind the reinforced concrete, further test tests would be required.

5.4 Carbonation Testing

Carbonation testing was conducted in areas where no cracking was present to eliminate erroneous results occurring from crack penetration. In general the carbonation penetration showed good results; with the maximum penetration being only 10mm. The maximum penetration is significantly less than the concrete cover and therefore the risk of corrosion of the reinforcing steel as a result of carbonation is low.

5.5 Chloride Testing

The chloride levels from all results show evidence of a continual splash zone exposure. Structures of this type usually present chloride content levels which have higher content at surfaces, reducing with depth. However, results show significant penetration into the wall in all locations, in most instances the highest content does not occur at the surface, outlining the potential corrosion to reinforcement. This factor also points to the possibility of water ingress behind the reinforced concrete, showing chloride penetration from both sides. This may well be as a result of the original masonry wall containing significant quantities of chlorides that have since leached back in to the concrete.

The samples show significantly greater chloride content than the maximum recommendation of 0.4% stated in BS EN 206-1:2000, [6]. Therefore there is a high risk that the reinforcement is corroding or at a high risk of corroding.

5.6 Wall Construction

The existing wall has a large discontinuity located at chainage 36.5m extending the full height of the wall which is filled with 140 masonry block. The position of this masonry infill section is at the exposed north end of the wall and therefore subjected to the more onerous conditions. It is expected that the resistance of the masonry panel is not suitable for a significant wave impact and failure may occur.

6 CONCLUSIONS

6.1 General

The condition of the original underlying masonry wave wall section remains unknown due to a lack of documentation, whilst the inspection and testing work undertaken identifying the condition of the improvement works conducted in 1993.

The condition of the reinforced concrete works are heavily cracked and potentially delaminated from the existing masonry leading to the probability that the reinforcement within the section is either corroding or likely to commence corroding in the near future. These findings are substantiated from large areas of hollow sounding concrete and crack measurements from hammer sounding surveys and visual inspections respectively together with evidence of spalled concrete.

Chloride tests have shown that chloride content is significantly higher than the maximum recommended in BS EN 206-1, chloride ingress arising as a result of airborne salts. This is a further indicator that the reinforcement is at a high risk of corrosion.

6.2 Recommendations

The condition of the wave wall has been found to be in a poor condition and repair work is not recommended given the extent of cracking and the high levels of corrosion throughout the full tested depth of the concrete. Although repairs could be undertaken, it is anticipated that they would offer little benefit in extending the longevity of the structure.

Although the wall would currently appear to be adequate to resist general wave loading, further deterioration is to be expected until its replacement becomes necessary.

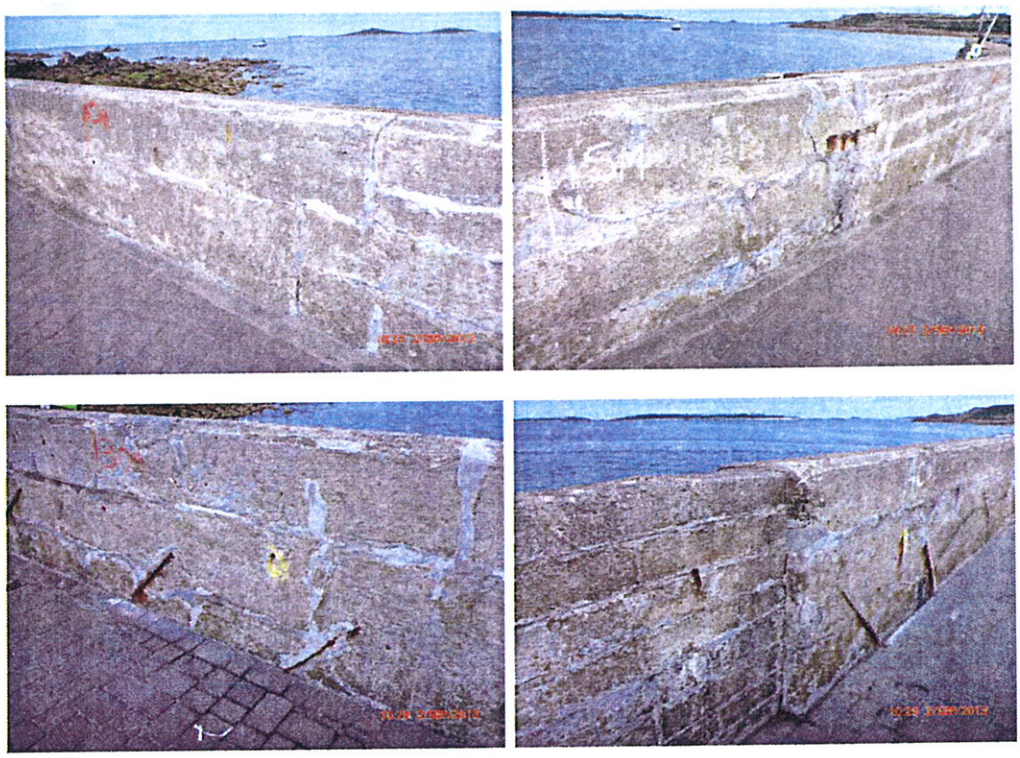
It is understood that a higher wave wall is proposed by the Duchy to improve overtopping resistance and, if this to be implemented, it is recommended that the existing wall is removed and a complete new wave wall is constructed.

REFERENCES

Ref	Doc	Issue	Date	Title	Reference Category
1	Beckett Rankine Drawing 90/017/53	-	May 1993	St. Mary's Quay Improvement – Sheet Piling and Anchor Walls	Primary
2	Beckett Rankine Drawing 90/017/59	-	Oct 1993	St. Mary's Quay Improvement – Pile Painting	Primary
3	Beckett Rankine Drawing 90/017/55	-	June 1993	St. Mary's Quay Improvement – Panel Details	Primary
4	Beckett Rankine Drawing 90/017/54	A	May 1993	St. Mary's Quay Improvement – Fenders and Bollards	Primary
5	Beckett Rankine Drawing 90/017/15	-	Mar 1993	St. Mary's Quay Improvement – Land Requirements	Primary
6	BS EN 206-1:2000	-	2000	Concrete - Part 1: Specification, performance, production and conformity	Primary
7	BS1181-124 11	-	1998	Testing Concrete – Methods for Analysis of Hardened Concrete	Primary

APPENDIX 1: LEEWARD AND SEAWARD SIDE WAVE WALL PHOTOS

Leeward Side



Seeward Side