MURALT WALLS: VIANE AND SCHELPHOEK, NETHERLANDS

GPR Investigation of Voiding below the Muralt Walls
for
KOAC NPC

Project Number 3067

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LIST OF REVISIONS

Date	Nature of revisions
14/12/2007	Amendment to Executive Summary to include calibration core results
14/12/2007	Amendment to Section 3.5 to include calibrated velocity used.
14/12/2007	Amendment to Section 4 to include revised findings and core results.
14/12/2007	Amendments to Section 4.4 to update conclusions and recommendations.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

An investigation using Ground Penetrating Radar (GPR) has been carried out over two sections of the Muralt Walls near Zierikzee, Netherlands to identify the presence and extent of any voiding beneath the base of the concrete which may require grouting.

The survey was carried out over three days on 7th, 8th and 9th August 2007 using a GSSI SIR10H digital radar system coupled to antennae operating at centre frequencies of 1500 MHz, 900 MHz and 400 MHz. Data were collected along a series of longitudinal profiles spaced at c.200 mm centres across the accessible width of the sloping concrete slab. Transverse profiles were also collected from both sites.

The data have been processed and analysed to highlight areas where signals of high amplitude are being reflected from the base of the slab, which may be indicative of the presence of voiding or less dense materials.

Coring information provided by KOAC NPC provided evidence for the presence of voiding in 1No. location at Viane (core 6a). No evidence of voiding was found in the cores taken from Schelphoek West.

Our results have been calibrated using the core results provided. Several areas of concern have been identified over both sites.

Areas showing high amplitude on drawings 3067-01 and 3067-02 are locations where any voiding is likely to be found. High amplitude may also be caused by interference from reinforcement, changes in ground conditions (wet clay/sand) or changes in the relative condition of the concrete.

In general the construction of both sites was very similar. Concrete slab thickness typically varied between c.100 mm and c.200 mm. Reinforcement bars were present in places as a c.200 mm mesh. Reinforcement cover was extremely variable, in places reinforcement was exposed on the surface of the slab (section 4.3 Visual Survey) and in other areas the reinforcement was located very close to the boundary at the base of the slab.

Two changes in construction were identified at Schelphoek West which corresponds to changes on the drawings sent by the client. Concrete thickness increased in these areas up to c.400 mm.

A visual survey was also conducted over both sites. The site at Schelphoek West was considerably more overgrown than the site at Viane and so a detailed inspection was not possible in many areas. In general the concrete condition of both sites seemed to be fairly good, although both sites had areas of localised spalling and cracking (mainly on the vertical section of wall) – in some cases exposing reinforcement bars.

2. INTRODUCTION

This report documents a non-destructive investigation, using Ground Penetrating Radar (GPR), of two sections along the Muralt walls; c.1500 m near Viane, and c.1300 m near Schelphoek West, both near Zierikzee, Netherlands.

2.1 Purpose

The primary purpose of the investigation was to identify locations where significant voiding exists underneath the wall structure. A secondary objective was to conduct a visual inspection of concrete condition.

The information derived from the investigation will be used to assist in determining the structural integrity of both sections of the Muralt Walls surveyed and to direct any grouting operations which may be necessary to the most appropriate locations.

2.2 Terms of Reference

This investigation was conducted by Aperio Limited for KOAC NPC and is based on data collected from site on 7th, 8th and 9th August 2007.

This investigation involved the use of non-destructive methods and therefore the majority of the findings presented here are the result of the measurement and interpretation of electrical and electromagnetic signals. This report represents the best professional opinion of the authors. Every effort has been made to ensure that the results are accurate and reliable, including reference to material calibration data from this and other sites. However, as with other indirect methods there is a possibility of localised inconsistencies and inaccuracies within the results.

This final report supersedes any previous reports, whether written or oral and completes the work currently commissioned under the KOAC NPC instruction by email dated 11th July 2007.

2.3 Background

There is a requirement for information on the condition of concrete structures (Muralt Walls) forming the crest of some dyke walls in the Netherlands. The Muralt Walls were constructed c.80 years ago.

As part of ongoing structural assessments there is a requirement to assess whether voids are present below the concrete structures. The main area of interest is on the seaward face of the walls below the sloping slabs. These slabs are c.1 m in width.

3. INVESTIGATIVE METHODS

The survey was carried out over the course of three survey sessions on 7th, 8th and 9th August 2007 using a GSSI SIR10H digital radar system coupled to antennae operating at centre frequencies of 1500 MHz, 900 MHz and 400 MHz.

3.1 Principles of Ground Penetrating Radar (GPR)

GPR is an echo sounding method where a transducer (transmitter/receiver) is passed over the surface at a controlled speed. Short duration pulses of radio energy are transmitted into the subject and reflections from material boundaries and embedded features such as metalwork or voids are detected by the receiver. Sampling is so rapid that the collected data are effectively a continuous cross section, enabling rapid assessment of thickness and condition over large areas. By assessing the strength, phase and the scatter of signals it is often possible to find cracking and changes in compaction, bond and moisture content.

This method inevitably involves the collection of a large body of information - not all of which is of engineering significance. Analysis involves identifying the main elements of the structure under investigation and establishing the characteristics of its base condition. Variations in construction and condition can then be identified and compared with other similar structures investigated elsewhere enabling significant features to be mapped.

The arrangement and condition of structural components can be identified by analysing a combination of three main variables in the GPR data:

- the **amplitude, phase and velocity** of the signals from within the material and from the material boundaries which give an idea of material type
- the **continuity** of the signal which gives an idea of the shape of the component
- the **travel time** of radio pulses though the material gives an indication of the layer thickness or depth to embedded features

3.2 Survey Rationale

GPR can effectively detect voids and separation within or between material layers by mapping changes in the level of radio energy reflected from a material boundary or from within an otherwise homogeneous material. However, variations in the level of reflected radio energy can occur for other reasons: a general increase in moisture content or micro-cracking may cause absorption or scattering of the radar energy and therefore a reduction in signal strength, whilst water at a material boundary, significant variation in materials or the presence of metalwork may give rise to stronger reflections.

This process relies on a degree of subjective interpretation and direct exposure is normally required to verify findings.

GPR can be very effective at mapping the extent of voids but cannot generally be used to determine the depth of a void.

3.3 Survey Methodology

The survey involved the collection of data along a series of longitudinal profiles spaced at c.200 mm centres. Transverse profiles were also surveyed at c.5 m centres. The location and extent of all survey lines are shown in green on the accompanying drawings.

Figure 1: *Survey Setup.*

Access to all areas was from a Land Rover. The survey equipment was installed in a sledge which was attached to the survey vehicle by means of a fixed scaffold frame (figure 1). This allowed the sledge to be kept at a fixed position for the duration of each profile. The GPR recording equipment was operated and powered from the Land Rover and connected to each of the antennae by 9 m cables enabling access to all required areas.

The Muralt Walls near Viane was surveyed on 7th and 8th August, and the second location of Muralt Walls at Schelphoek West was surveyed on 9th August.

3.4 Data Processing

To assist in analysis of the recorded data, the digital GPR data were processed in the following stages:

- Declipping
- Start-time correction
- Dynamic correction
- Noise removal
- Pick Straight Correct

For a more detailed description of these processing stages see Appendix B at the rear of this report.

3.5 Calibration and Relocation

The measurement of thickness or depth relies on multiplying the measured two-way travel time by the velocity of the radio signals passing through the materials under investigation.

For the purposes of this investigation the velocity of the GPR pulses through the concrete have been calibrated by direct measurement of the thickness from cores taken by KOAC NPC. A velocity of 0.09 m/ns has been calculated and used for all depth calculations.

No allowance has been made for variations in included moisture content or void ratio and therefore depth values in this report are likely to be accurate to within ±10% of the quoted value for thickness greater than 50 mm. For thickness less than 50 mm measurements are likely to be a accurate to better than ±5 mm. The location of all collected data was referenced to fixed physical features such as Dijkpaal markers and also to chainage marked on the wall with paint. With this system, longitudinal relocation of any detected features can be expected to be accurate to ±300 mm or better and transverse relocation of features can be expected to be accurate to ±100 mm.

4. FINDINGS

The results arising from the non-destructive investigation have been presented on two A1 drawings: drawing number 3067-01 provides the results for the section of wall near Viane and drawing number 3067-02, provides results for the section of wall near Schelphoek West. The method of analysis and presentation and the findings of the investigation are described below.

4.1 Method of Analysis and Presentation

In order to determine the location of any areas of voiding or lack of integrity beneath the Muralt Walls, GPR data have been analysed to highlight locations where signals of high amplitude are being reflected from the base of the slab. Such high amplitude signals from what should be a fairly uniform boundary can be, but not always, associated with the presence of voiding or generally loose materials. Signals of similar amplitude may also be generated by buried metallic objects, trapped water or significant variations in construction materials.

The method of analysis reports upon the total amount of radio energy which is reflected from within a particular time/depth window for each of the survey lines profiled. This information is then presented as a plan of the survey area with a coloured scale representing variations in the amplitude of the reflections.

It is worth noting that the interpolation of this information to either side of the survey line positions to produce a meaningful plan can lead to information apparently ‘spilling’ out slightly into areas where surveying may not actually have been possible. All data interpolation is square to the survey grid inducing a minor distortion in the shape of any features identified that are not orthogonal to this grid.

Each site has been split into sections on the accompanying drawings. The data from each section have been processed and presented in exactly the same way and therefore a direct comparison of the amount of energy reflected from beneath the slab is possible between all sections of each site. Note that it is not possible to compare directly between the two sites, but direct comparisons can be made between different sections in the same site.

The results provide an indication of the relative condition of the structure. Following comparison with the core information provided the areas shown in grey/white/yellow probably do not represent areas of significant levels of voiding over and above what might be typical for this type of structure. It is likely to be the areas highlighted by red or magenta where possible voiding exists and where grouting should be directed. However, areas highlighted in red or magenta may also relate to areas variations in concrete condition or construction materials rather that voiding.

Along parts of the wall in each site, reinforcement bars were located very close to the base of the concrete. This produced spurious high amplitude areas due to the effects of the steel. In both drawings these anomalous high amplitude areas have been hatched out and should be ignored.

Cores have been taken at 11No. locations along the both survey areas. The locations and results have been presented in the table below.

Core No.	Location from Dijkpaal	Distance from Wall (m)	Depth of Reinforcement (top and bottom of bar) mm	Notes
Viane				
1	324 + 29 m	0.65	120-127 / 124-133	Lots of Vegetation
2	325 + 16 m	0.7	65-78 / 78-93	
3	326 + 48 m	0.7	108-118	Vegetation
4	328 + 29 m	0.7	95-104 / 80-89 / 78-88 / 82-93	
5	332 + 34.5 m	0.5	94-104 / 102-109	Lots of Vegetation
6	337 – 18.5 m	0.4	85-95	
6a	337 + 18.5 m	0.4	No reinforcement present	c. 20mm Void
Schelphoek West				
7	55 – 33.5 m	0.5	No reinforcement present	
8	55 + 85.5 m	0.5	55-68	
9	55 + 550 m	0.5	No reinforcement present	
10	55 + 1163 m	0.5	55-68 / 45-58	

4.2 Viane (Ouwerkerk)

Due to obstructions and vegetation covering parts of the wall, it was not possible to survey a segment of the wall between Dijkpaal 335 and Dijkpaal 336. This site therefore, has been split into two sections.

Six continuous areas of potential voiding were originally identified; three in section 2 and three in section 1. With the available calibration cores it is likely that the majority of high amplitude areas in section 1 are associated with either the presence of reinforcement, or clay rich ground conditions and not with the presence of voiding. The only core which exposed a void was extracted from section 2. In general it appears that this section (between dijkpall 336 and dijkpaal 338) is in poorer condition than section 1.

4.2.1 Construction Information

Concrete slab thickness typically varied between c.100 mm and c.200 mm. Reinforcement bars were present in places as a c.200 mm mesh. Reinforcement cover was extremely variable, in places reinforcement was exposed on the surface of the slab (Appendix C Visual Survey Photographs) and in other areas the reinforcement was located very close to the boundary at the base of the slab.

4.2.2 Areas of Concern

In general, section 1 appears to be in good condition with a number of smaller areas of potential voiding. Section 2 generally appears to show more evidence of voiding throughout.

The only location where voiding has been identified by coring is at 337 + 18.5 m, however similar areas of high amplitude response persist along much of section 2. Several large areas of concern exist along section 2 and it is recommended that any further intrusive testing should be concentrated in these areas. In addition to the areas in section 2, 3No. large areas of concern exist in section 1.

Dijkpaal Start + m	Dijkpaal End + m	Approximate length of voiding (m)
324 - 30	324 + 0	30
329 + 0	329 + 50	5
331 - 55	331 + 0	55
336 – 50	336 – 22	28
337 +18	337 + 24	6
338 – 12	338 + 0	12
337 + 36.5	337 +45.5	9

It is possible that other small areas of voiding may exist within high amplitude areas of this site. Data confidence over much of this site is fairly low due to the positioning of the reinforcement very close to the base of the slab. This increases the amplitude of the reflection produced at the base of the slab leading to high amplitude areas which can be then interpreted as areas of potential voiding.

4.2.3 Visual Inspection
For the majority of the survey area the concrete appeared to be in good condition. In several places, particularly around Dijkpaal No. 329 there was cracking and/or spalling of the concrete and in some places reinforcement bars were exposed on the surface (Appendix C, Plates 1-4).

4.3 Schelphoek West

All locations are referenced from Dijkpaal marker post No.55. Due to the slab being covered in grass and vegetation along most of the mid-portion of the survey area, no data were collected from these areas.

Two continuous areas of potential voiding were originally identified. 4No. cores have been taken over the site, two within the areas of potential voiding described by Aperio. None of the cores taken revealed voiding underneath the slab. An additional 'control' core (number 9) was taken along the mid-portion of the survey area where we were unable to collect data. No voiding was indicated by this core.

Smaller areas of similar high amplitude occurred throughout the site which may also indicate further areas of relatively poorer condition or possible locations of voiding.

4.3.1 Construction Information
Concrete slab thickness typically varied between c.100 mm and c.200 mm. Reinforcement bars were present in places as a c.200 mm mesh. Reinforcement cover was extremely variable, in places reinforcement was exposed on the surface of the slab (section 4.3 Visual Survey) and in other areas the reinforcement was located very close to the boundary at the base of the slab. This typical construction was not uniform throughout. In at least two areas the construction changed to a deeper slab (up to c.400 mm thick). These changes persisted for c.10 m. The change in construction at Dijkpaal 55+c.200-225 m consisted of two c.10 m sections separated by c.5 m. This has been identified as one construction change.

The drawing supplied by the client shows three changes in construction along the length of the survey area. Due to heavy vegetation on site, only two of these construction changes were surveyed, and changes in data were identified over both. It is therefore likely that the remaining unsurveyed construction change will be of similar construction to those already surveyed (Appendix A Figure 2). Plate 6, Appendix C shows an example of the surveyed construction change at Dijkpaal 55 +c.1327 m which was also visible on the surface.

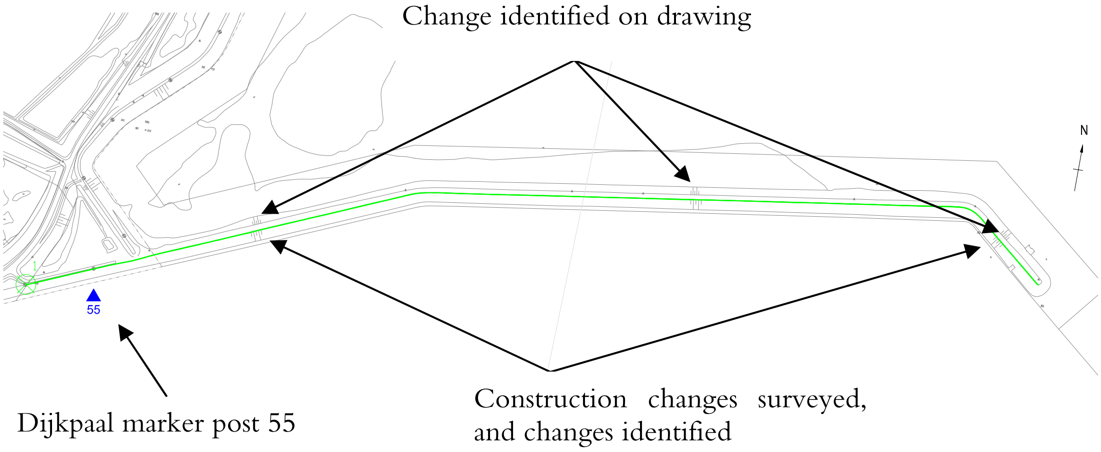


Figure 3: *Location plan of Schelphoek West showing locations of construction changes. Green line represents survey area.*

4.3.2 Areas of Concern

No areas of voiding were discovered during the intrusive investigation. It has been noted however, that core 8 may have missed the area of high amplitude at which it was targeted, it is therefore not clear if this area of high amplitude relates to voiding or changing ground conditions / poor concrete condition.

Two areas of concern have been identified over the site.

Dijkpaal Start + m	Dijkpaal End + m	Approximate length of voiding (m)
55 - 50	55 - 15	35
55 + 75	55 + 95	20

It is likely that these higher amplitude areas are either indicative of changes in material below the slab (sand to clay) or areas of relatively poorer concrete condition, although areas of potential voiding are much more likely to exist within the areas of higher amplitude. It is in these areas that future intrusive investigations should be targeted.

4.3.3 Visual Inspection

Large areas of concrete were obscured by vegetation which compromised the visual survey. However several of areas near the start of the survey (Dijkpaal 55) appeared to be in poorer condition (Appendix C, Plates 5-7).

4.4 Conclusions and Recommendations

10No. cores were taken across both sites. 6No. of these were in locations recommended by Aperio. Calibration information has been taken from these cores and our results adjusted accordingly.

Some areas of potential voiding have been identified behind the wall at both locations. Areas showing high amplitude on drawings 3067-01 and 3067-02 are locations where any voiding is likely to be found. High amplitude may also be caused by interference from reinforcement, changes in ground conditions (wet clay/sand) or changes in the relative condition of the concrete

5. APPENDIX A: EXAMPLES OF GPR DATA

Figure 1: Longitudinal Profile (0.5m) at Viane (Ouwerkerk) near Dijkpaal 324, 900MHz antenna

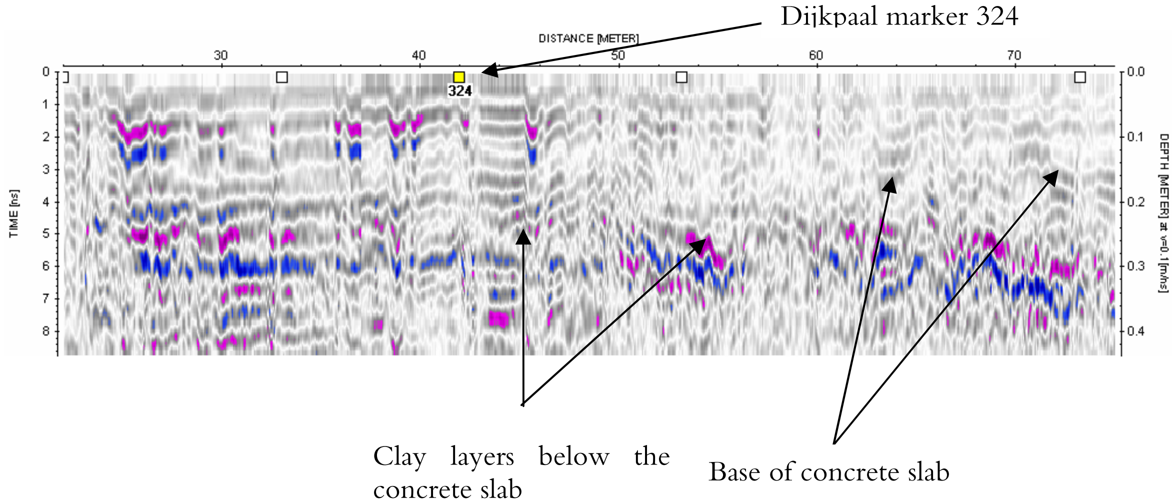
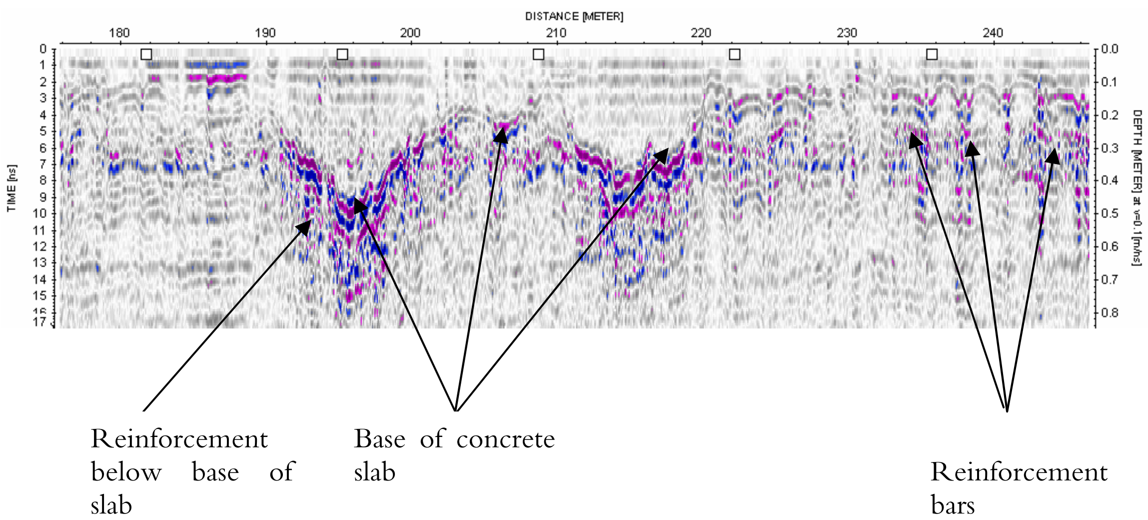


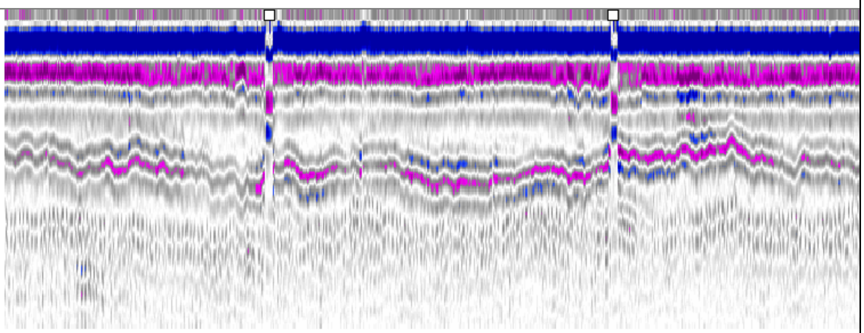
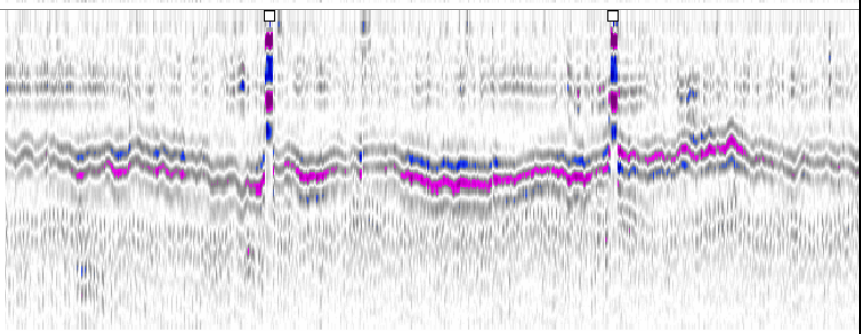
Figure 2: Longitudinal Profile (0.5m) at Schelphoek West over Construction Changes between Dijkpaal 55+c.175m and c.245m, 900MHz antenna

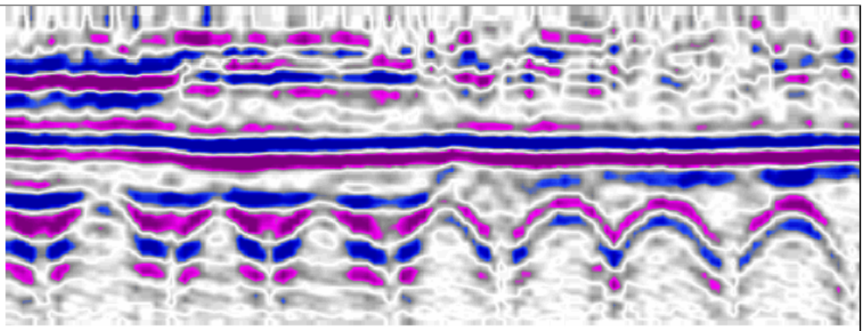
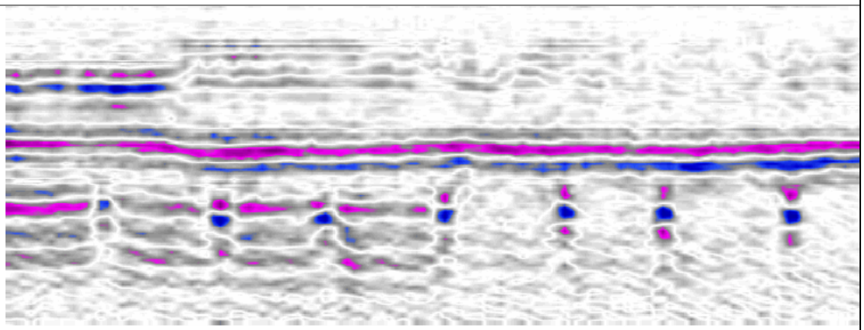
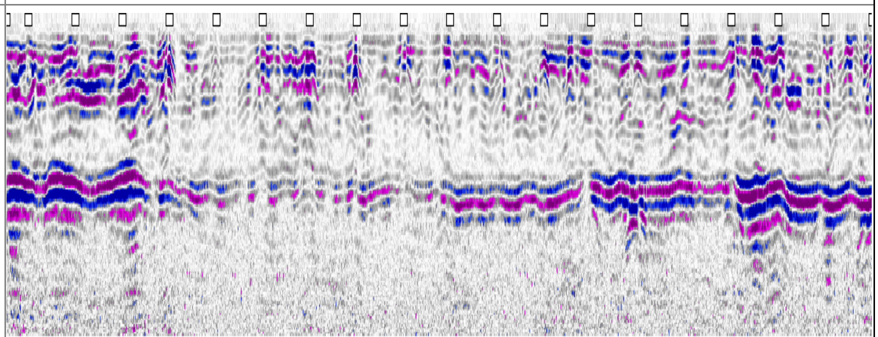
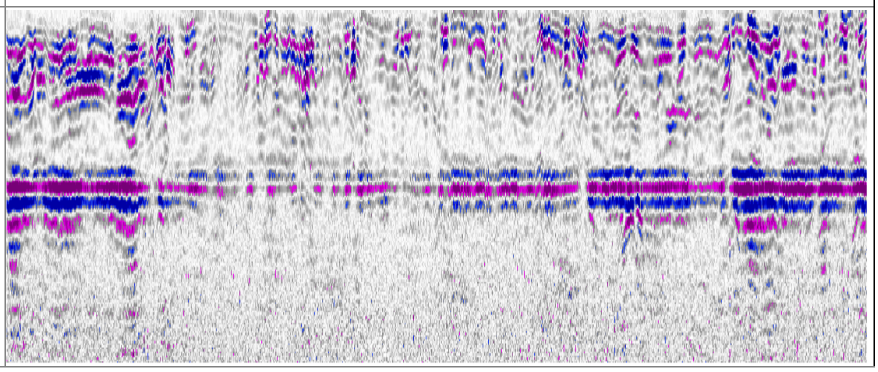


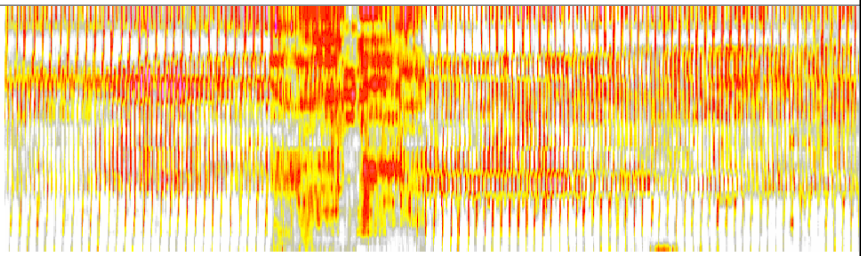
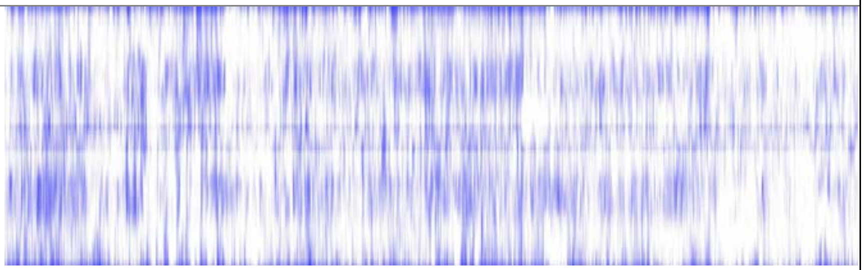
6. APPENDIX B: GPR PROCESSING STAGES

Table 1: Explanation of GPR Processing Stages

Data examples shown are from various sources:

Processing Stages	Explanation & Example
1	**Start -time Correction.** The effect of the transmitter elevated above the road surface and small variations in surface moisture are corrected.
2	**De-clipping.** Keeping the signal amplitude the same for each survey line is essential for comparative reasons, but this means that some signals are too large to be recorded (for example steel in PQC). This correction reshapes the over-gained signals to allow it to fall within workable thresholds.
3	**Dynamic Correction.** The effect of the separation between transmitter and receiver is corrected.
4	**Noise Removal.** System noise is removed.
Before	
After	
5	**Migration.** Migration shifts dipping data to its true position below the transducer. In the case of hyperbolic signals such as reinforcement, migration collapses the signal to give an accurate point location for each feature.

Before	
After	
6	**Pick Straight Correct.** When analysis of the amplitude and/or nature of reflected GPR signals from a specific boundary is required (such as the base of a slab), the data is adjusted such that the signal from this boundary becomes flat. This enables only data from the selected interface to be analysed without introducing spurious signals/noise into the analysis window.
Before	
After	

7	**Energy/Amplitude Plots.** All GPR profiles are spatially relocated with each trace being given an X,Y coordinate. This enables the energy reflected from certain depth ranges to be analysed in order to give a full spatial representation of various condition features such as delamination and voiding of the area under investigation.
	
8	**Frequency Plots.** In order to analyse the frequency content of GPR profiles a Fast Fourier Transform (FFT) is carried out on the spatially relocated profiles. This enables the frequency content of energy reflected from certain depth ranges to be analysed in order to give a full spatial representation of various condition features such as moisture content of the area under investigation.
	

7. APPENDIX C: VISUAL INSPECTION PHOTOGRAPHS

Plate 1: Viane, Dijkpaal No. 329 + c.63m:
Spalling evident in wall. Reinforcement bars visible.

Plate 2: Viane, Dijkpaal No. 329 + c.55.5m:
Reinforcement bars visible along top of wall.

Plate 3: Viane, Dijkpaal No. 333 + c.54m:
Large area of spalling in wall. Reinforcement visible. Approximate dimensions marked on wall.

Plate 4: Viane, Dijkpaal No. 329 + 36.85m:
Cracking in post.

Plate 5: Schelphoek, Dijkpaal No. 55 – c.67m:
Reinforcement visible on concrete slope.

Plate 6: Schelphoek, Dijkpaal No. 55 +c.1327m
Change in construction at end of dyke (near survey limit) at Schelphoek West.

	
Plate 7: Schelphoek, Dijkpaal No. 55 – c.90m: Reinforcement visible on post.	

8. APPENDIX D: DRAWINGS

List of Drawings:

- Dwg. No. 3067-01: Voiding Below Muralt Walls at Viane
- Dwg. No. 3067-02: Voiding Below Muralt Walls at Schelphoek

Note: copies of A1 size drawings reduced to A3 size should not be scaled from.

FIGURE 1: SCHELPHOEK WEST DIJKPAAL 55-100m TO DIJKPAAL 55+650m

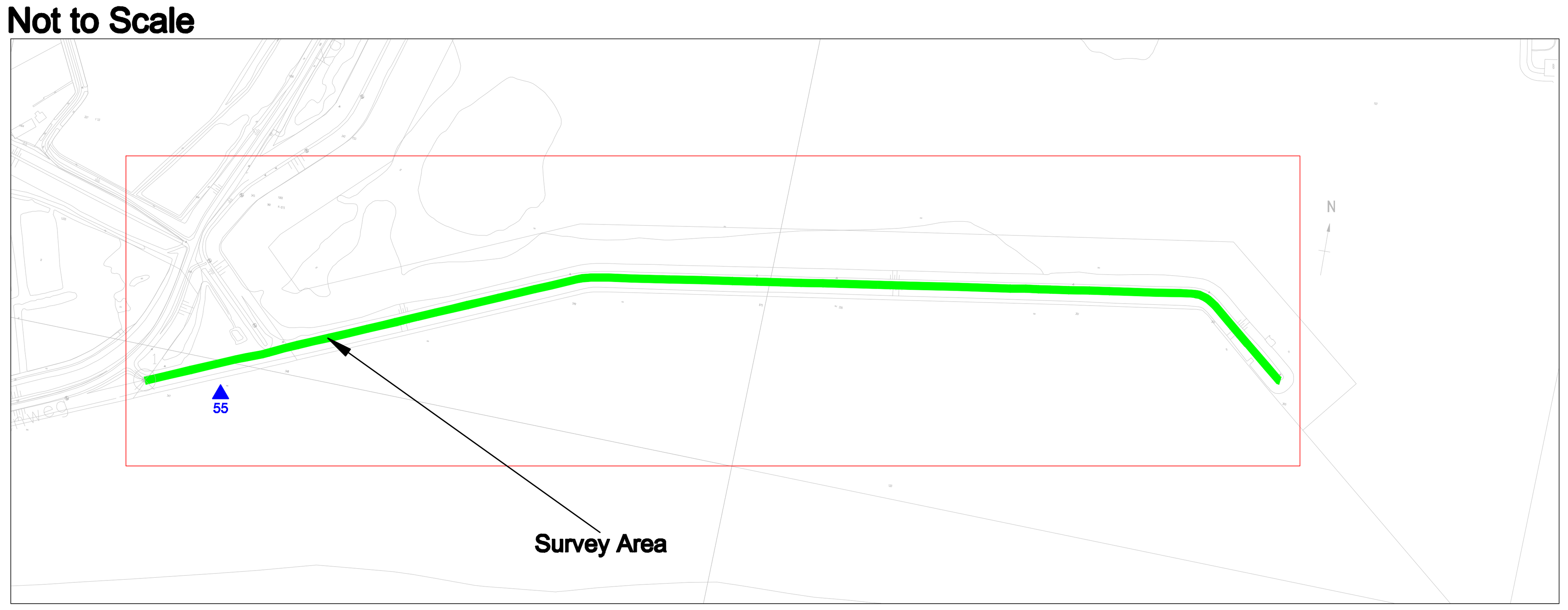
Scale- H - 1:1000, V - 1:10

FIGURE 2: SCHELPHOEK WEST DIJKPAAL 55+650m TO DIJKPAAL 55+1400m

Scale- H - 1:1000, V - 1:10

LOCATION PLAN

Not to Scale



KEY

- GPR Datum
- GPR Survey lines
- 55 Dijkpaal reference marker
- Increasing levels of radar energy reflected from within Muralt wall structure indicating increasing probability of voiding. (See Fugro Aperio Report 3067).
- Area of high amplitude caused by change in construction (See Fugor Aperio report 3067)
- Area of high amplitude caused by reinforcement
- KOAC Core location (with reference number)

The information shown on this drawing has been derived from an investigation carried out using Ground Penetrating Radar (GPR) andcoring. This drawing should be read in conjunction with Fugro Aperio Report number 3067. All dimensions on this drawing have the following accuracies:

- ± 300mm in plan
- ± 10% in depth/thickness.

Please see the associated report for a more detailed description of the accuracies.

Revised Drawing

Drawing elements	Updated by	Date
Added KOAC NPC core loactions.	EB	DEC 07
Changed boundary analysis to correspond with KOAC NPC core results.	EB	DEC 07
Re-evaluated areas of high amplitude caused by reinforcement.	EB	DEC 07

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Project	MURALT WALLS: VIANE AND SCHELPHOEK, NETHERLANDS
Client	KOAC NPC
Title	VOIDING BELOW MURALT WALLS AT SCHELPHOEK

Date	Dec 2007	Scale	AS SHOWN
Drawn	AS	Dwg No	3067-02
Project Engineer Checked	EB	Technical Support Approved	AT

FIGURE 1: VIANE SECTION 1 DIJKPAAL 324 to DIJKPAAL 330
Scale- H - 1:1000, V - 1:10

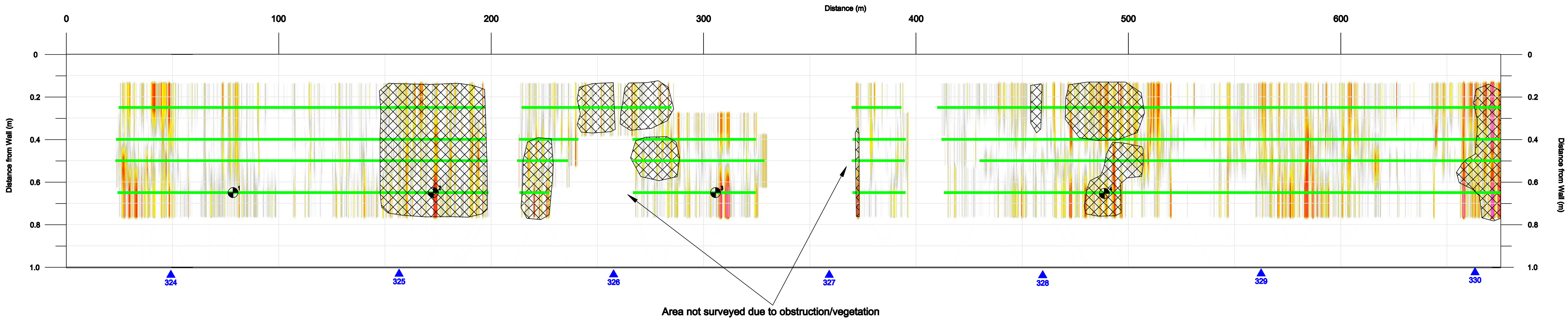


FIGURE 2: VIANE SECTION 1 DIJKPAAL 330 to DIJKPAAL 335
Scale- H - 1:1000, V - 1:10

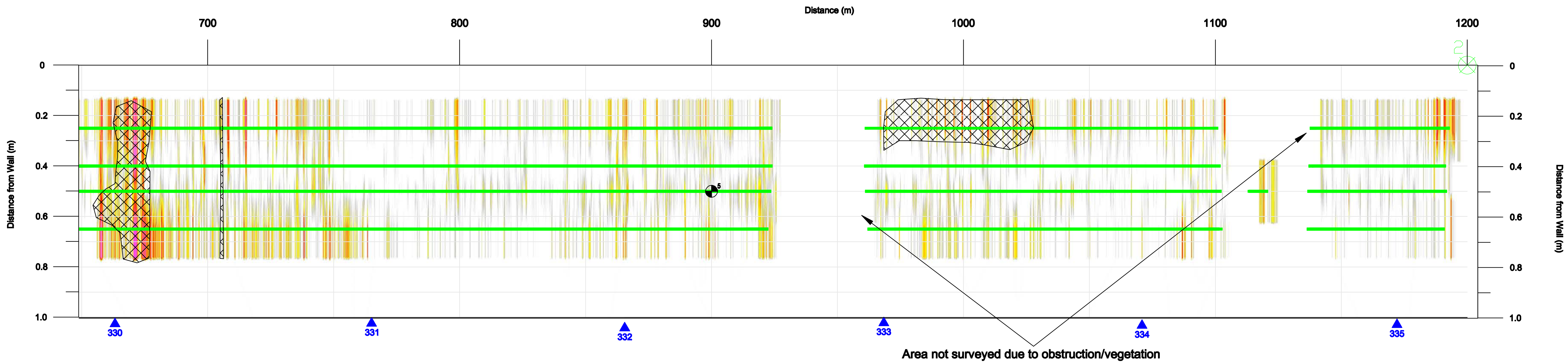
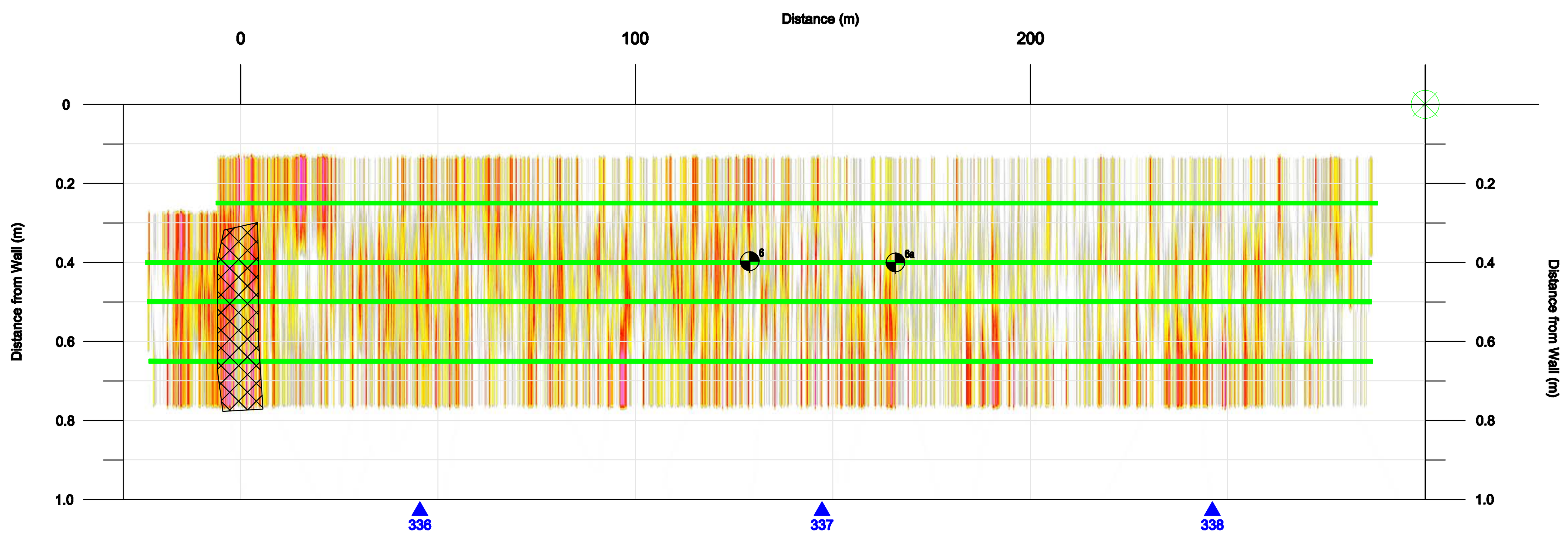
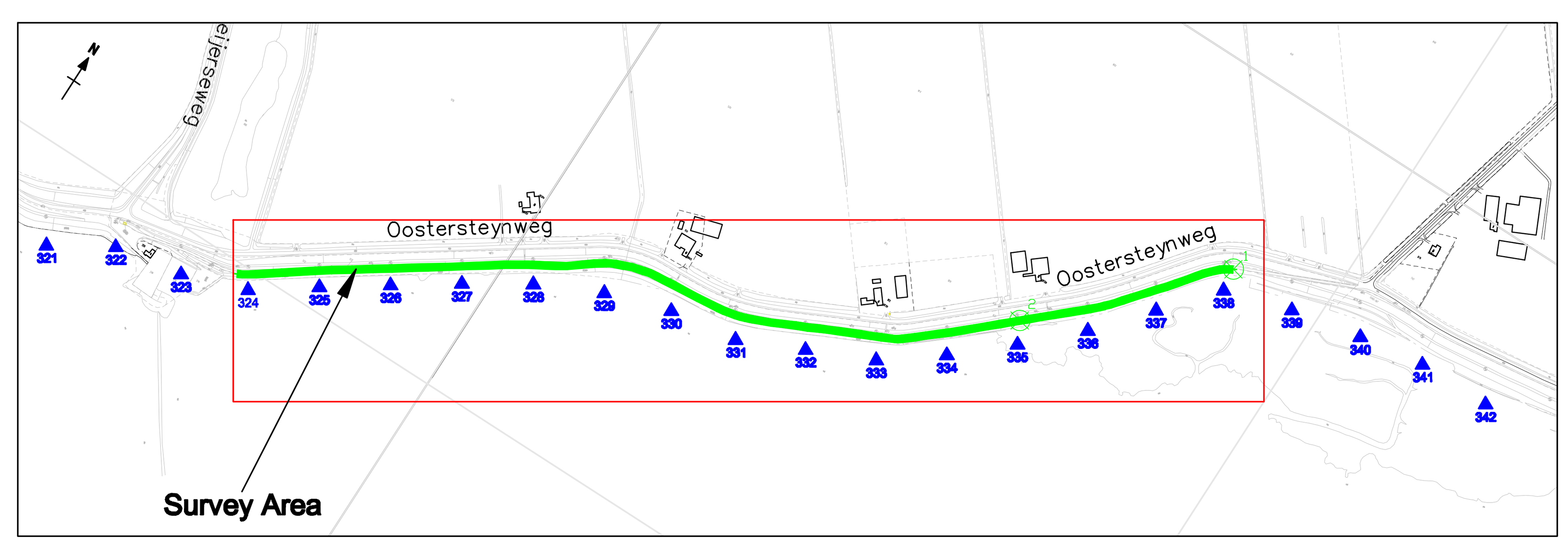


FIGURE 3: VIANE SECTION 2 DIJKPAAL 336 to DIJKPAAL 338
Scale- H - 1:1000, V - 1:10



LOCATION PLAN
Not to Scale



Revised Drawing		
Drawing elements	Updated by	Date
Added KOAC NPC core loactions.	EB	DEC 07
Changed boundary analysis to correspond with KOAC NPC core results.	EB	DEC 07
Re-evaluated areas of high amplitude caused by reinforcement.	EB	DEC 07

KEY

- GPR Datum (with reference number)
- GPR Survey lines
- 330 Dijkpaal reference marker
- Area of high amplitude caused by reinforcement
- Increasing levels of radar energy reflected from within Muralt wall structure indicating increasing probability of voiding. (See Fugro Aperio Report 3067).
- KOAC Core location (with reference number)

The information shown on this drawing has been derived from an investigation carried out using Ground Penetrating Radar (GPR) and coring. This drawing should be read in conjunction with Fugro Aperio Report number 3067. All dimensions on this drawing have the following accuracies:

- ± 300mm in plan
- ± 10% in depth/thickness.

Please see the associated report for a more detailed description of the accuracies.

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Project	MURALT WALLS: VIANE AND SCHELPHOEK, NETHERLANDS		
Client	KOAC NPC		
Title	VOIDING BELOW MURALT WALLS AT VIANE		
Date	DEC 2007	Scale	AS SHOWN
Drawn	AS	Dwg No	3067-01
Project Engineer	EB	Technical Support	AT
Checked		Approved	