AGL15247_02

Report

on the

Geophysical Investigation

For

G.D.D.P. Portmarnock Golf Course, Dublin

For

Tobin Consulting Engineers &

Irish Water

18th February 2016

APEX Geoservices Limited
Unit 6 Knockmullen Business Pk.,
Gorey,
Co. Wexford, Ireland

T: 0402 21842
F: 0402 21843
E: info@apexgeoservices.ie
W: www.apexgeoservices.com

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TONY LOMBARD, M.SC (GEOPHYSICS)	EURGEOL ANDREW TRAFFORD P.GEO., B.SC (GEOPHYSICS)	V.02	18TH FEBRUARY 2016

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1. EXECUTIVE SUMMARY

APEX Geoservices Limited was requested by Tobin Consulting Engineers acting on behalf of Irish Water to carry out a geophysical investigation as part of a ground investigation for a proposed outfall pipeline for the Greater Dublin Drainage Scheme. The investigation was conducted over part of Portmarnock Golf Club and on a section of the adjacent Velvet Strand.

The investigation consisted of Electrical Resistivity Tomography (ERT), Seismic Refraction profiling and Multichannel Analysis of Surface Waves (MASW).

The investigation was conducted following a marine geophysical investigation undertaken by APEX Geoservices Limited in 2015, **AGL15060 Greater Dublin Drainage Scheme Geophysical Investigation Report.**

The objectives of the investigation were to determine the nature and thickness of the overburden, depth to and variation within bedrock and determine engineering parameters.

The results of the investigation are displayed in a series of maps, figures, graphs and tables and are presented in **Appendix A** – **Appendix D**.

Three overburden layers have been defined by the geophysical investigation. Materials with a P-wave seismic velocity (Vp) in the range 300 – 1000m/s and 1000 – 1800m/s are interpreted (in conjunction with client borehole data) as loose – medium dense silty sand and medium dense – dense silty sand. These granular layers range in thickness from c. 7.2 – 10.7m in the southwest to c. 7.2 – 20.9m in the north and northeast.

Materials with a Vp of 1800 – 2300m/s are interpreted (in conjunction with client borehole data) as stiff – very stiff sandy gravelly clay. This layer varies in thickness from c. 1.8 – 6.7m in the southwest to c. 1.9 – 7.1m in the north and northeast.

A layer of moderately weathered bedrock ranges in thickness from c. 1.0m to > 12.5m with an average thickness of c. 4.9m. The thickness of this layer increases over localised zones in the southwest and north (see **Appendix A: Drawing No.s AGL15247_02 & AGL15247_05**).

The depth to the top of the slightly weathered – fresh competent bedrock layer ranges c. 14.2m – 21.5m in the southwest to c. 13.3 - > 28.4m below ground level (bgl) in the north. The average depth to the top of this competent bedrock layer is c. 17.6m bgl.

Zones of increased weathering / fracturing / faulting of the bedrock and possible changes in bedrock type from argillaceous limestone and subordinate shale to a bedrock with increased shale content are interpreted in the southwest and the north of the survey area (see **Appendix A: Drawing No.s AGL15247_02 – AGL15247_06**).

There is a good correlation between the results of the geophysical investigation and depth to bedrock data from two client supplied boreholes.

2. INTRODUCTION

APEX Geoservices Limited was requested by Tobin Consulting Engineers acting on behalf of Irish Water to carry out a geophysical investigation as part of a ground investigation for a proposed outfall pipeline for the Greater Dublin Drainage Scheme. The investigation consisted of Electrical Resistivity Tomography (ERT), Seismic Refraction Profiling and Multichannel Analysis of Surface Waves (MASW). The investigation was conducted over part of Portmarnack Golf Course and on a section of Velvet Strand.

The investigation was conducted following a marine geophysical investigation undertaken by Apex Geoservices Ltd in 2015, **AGL15060 Greater Dublin Drainage Scheme Geophysical Investigation Report.**

2.1 Survey Objectives

The objectives of the investigation were to:

- Map the nature of the overburden material
- Establish sediment stiffness
- Map the depth to bedrock across the survey area
- Map variation in bedrock type and rock quality
- Determine engineering parameters including dynamic moduli (Gmax)

2.2 Site Background

The site is located at Portmarnack Golf Course, Co. Dublin and also covers part of the adjacent beach, Velvet Strand. The area under investigation crosses part of the golf course and extends west through a public beach access area and car park. Elevation across the area under investigation ranges from c. 1.4 mOD to c. 9.71 mOD.

The outline location of the survey area is shown in Fig. 2.1 below.

Fig 2.1: Location map (site marked in magenta).

2.2.1 Geology

The GSI bedrock geology map (Fig. 2.2) shows the Portmarnack Golf Club and the beach / Velvet Strand area is underlain by the Malahide Formation, which is described as argillaceous bioclastic limestone and shale.

Fig 2.2: The GSI bedrock map (site marked in magenta).

2.2.2 Soils

The soil of the site consists primarily of blown sand in dunes (marked blue on Fig.2.3), with minor beach sand along the edges of the strand (marked orange on Fig.2.3).

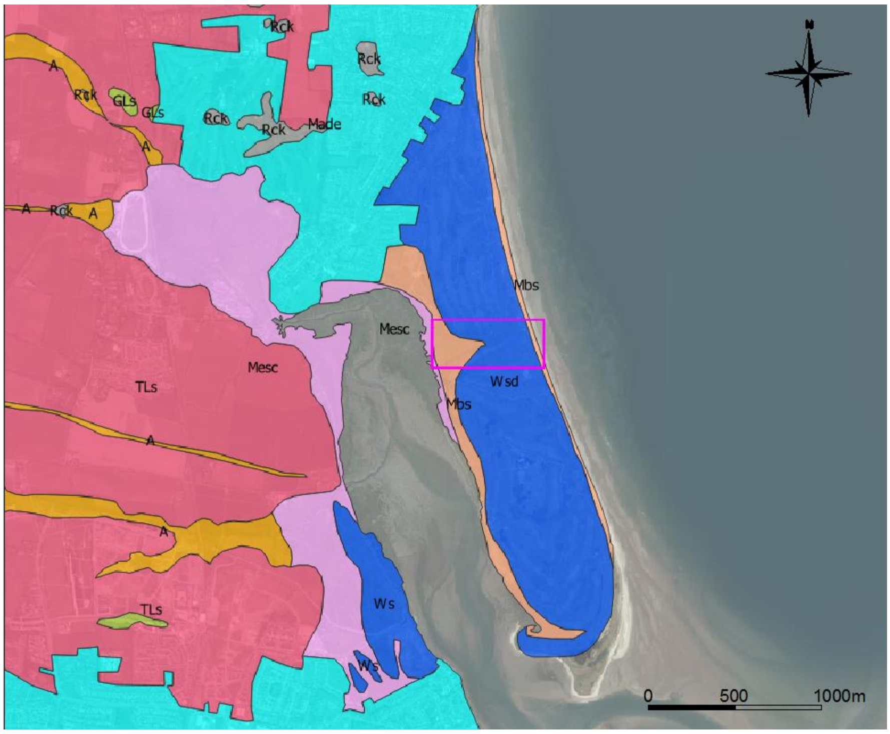

Fig 2.3: The Teagasc soil map (site marked in magenta). Blue = blown sand in dunes, orange = beach sand, purple = estuarine sediments (silts/clays).

2.2.3 Vulnerability

The survey area is located in an area of high vulnerability as shown in Fig. 2.4.

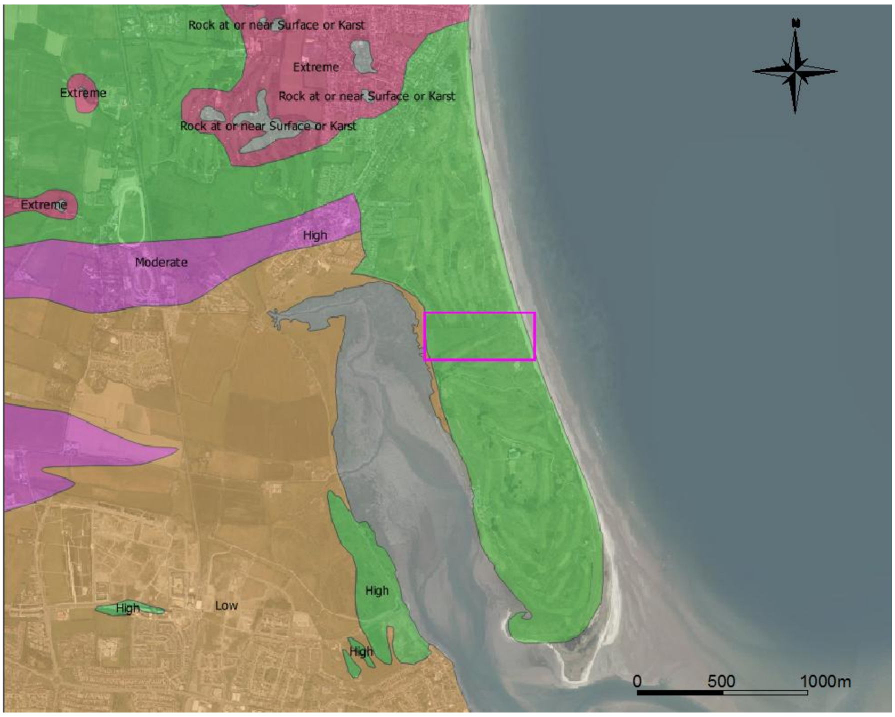

Fig 2.4: The GSI vulnerability map (site marked in magenta).

2.2.4 Aquifer Classification

The aquifer is classified as Unimportant with no local or national significance.

Fig 2.5: The GSI aquifer map (site marked in magenta).

2.2.5 Direct Investigation Data

Direct investigation data from two client supplied boreholes was available for incorporation into this report. Borehole BH-1, from a 2015 investigation, is situated at approximate ING coordinate 325063E, 242320N on Velvet Strand and is in alignment with the route of the 2015 marine geophysical investigation and c. 58m south of this 2016 investigation. This offset is as a result of an alteration to the proposed route of the terrestrial section of the pipeline route. The location of BH-1 is shown in Fig. 2.6. Borehole BH14 / BH14A dates from a 2013 investigation and is situated on the course at approximate ING coordinate 324662E, 242271N. This borehole is c. 40m offline from the acquired geophysical profiles.

Borehole, BH-1, describes medium dense to dense silty sand and gravelly sand to 12.9m below ground level (bgl) over c. 1.60m of stiff gravelly clay. Depth to bedrock is recorded as 14.50m bgl. The bedrock is described as partially weathered to unweathered argillaceous limestone. The borehole terminates in limestone described as medium strong to strong at a depth of 59.90m bgl.

Borehole BH14 / BH14A describes loose to medium dense silty sand to 5.10m bgl over c. 6.60m of stiff sandy silt over 3.70m of sandy gravelly clay, described as possible highly weathered rock. The borehole records depth to weathered bedrock at 15.40m. The borehole terminates in medium strong to strong limestone at a depth of 22.70m bgl.

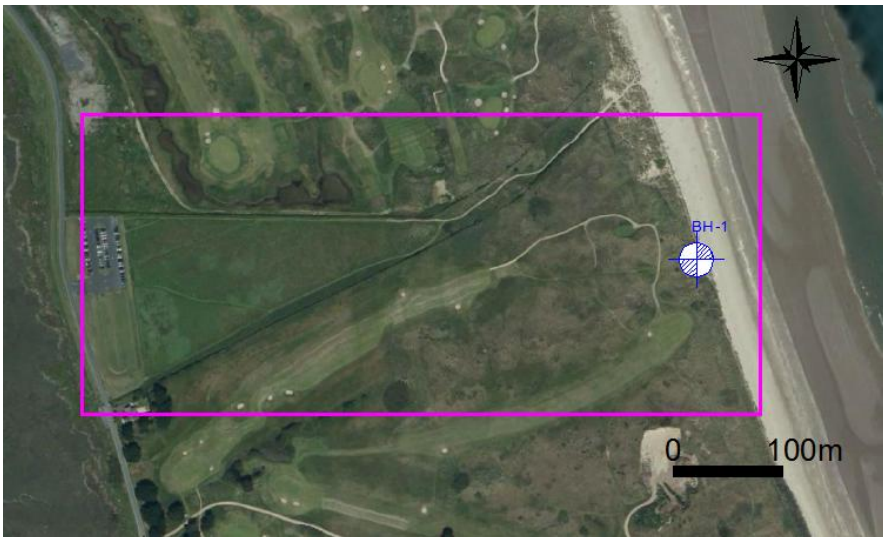

Fig 2.6: BH-1 location within survey area (site marked in magenta).

2.3 Survey Rationale

A number of geophysical surveying techniques were utilised to achieve the objectives of the survey. These methods included Electrical Resistivity Tomography (ERT), Seismic Refraction Profiling and Multi-Channel Analysis of Surface Waves (MASW).

Electrical Resistivity Tomography (ERT) soundings will image the resistivity of the materials in the subsurface along a profile to produce a pseudo-section showing the variation in resistivity to c. 40 m bgl, depending on the length of the profile. Each pseudo-section will be interpreted to determine the material type along the profile at increasing depth, based on the typical resistivities returned for Irish ground materials.

Seismic Refraction Profiling measures the velocity of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher seismic velocities while soft, loose or fractured materials have lower velocities. Readings are taken using geophones connected via multi-core cable to a seismograph. This method should allow us to profile the depth to the top of the bedrock, along profiles across the site.

The **MASW** method is used to estimate shear-wave (S-wave) velocities in the ground material. The MASW data is acquired as a series of 1D soundings to allow for determination of variation in the stiffness of sediment material and derivation of engineering parameters of the sedimentary units including dynamic moduli (Gmax).

The methodology is described in detail in **Appendix E**.

3. RESULTS

The survey was carried out over two sessions on the 6th and 7th January 2016 and involved the collection of five ERT profiles (2 x 155m, 1 x 235m and 1 x 475m (R1 & R2 combined)), fifteen seismic refraction spreads (13 x 46m and 2 x 69m) and fifteen 1D MASW soundings. The MASW data was acquired at the centre of each seismic refraction spread.

The results of the geophysical investigation are displayed in **Appendix A: Drawing No.s AGL15247_01 - AGL15247_06**).

3.1 ERT

Electrical Resistivity Tomography (ERT) Profiles (R1 to R5) were acquired across the site. The model resistivity data ranges from 30 – 500 Ohm.m and can be interpreted as overburden and bedrock layers. Due to the saline environment encountered across the area under investigation the model resistivity intervals for overburden and bedrock layers are lower than would normally be expected and therefore a detail interpretation of individual overburden layers based on the ERT data alone is not possible. A generalised interpretation of the model resistivity data is as follows.

Layer	*Resistivity (Ohm.m)*	*Interpretation*
1	30 - 50	Overburden – areas of increased conductivity
2	50 - 170	Overburden
3	170 - 510	Overburden
4	85 - 170	Moderately Weathered Bedrock
5	170 - 500	Slightly Weathered – Fresh Bedrock

3.2 Seismic Refraction Profiling

Fifteen seismic refraction spreads were recorded across the site (S1-15). The recorded data was processed using a tomographic inversion to produce smoothly varying models which resulted in model Vp velocities in the range 300 – 5040m/s. The seismic refraction data at the Portmarnack Golf Course (**Appendix A: Drawing No. AGL15247_01**) has been interpreted on the following basis:

Layer	*P-Wave Seismic Velocity (m/s)*	*Interpretation*	*Stiffness/Rock Quality*	*Excavatibility*
1	300 - 1000	Overburden – Silty Sand	Loose – Medium Dense	Diggable
2	1000 - 1800	Overburden – Silty Sand	Medium Dense - Dense	Diggable
3	1800 - 2300	Overburden – Sandy Gravelly Clay	Stiff – Very Stiff	Diggable / Rippable
4	2300 - 2700	Moderately Weathered Bedrock	Very Poor - Poor	Break / Blast
5	2700 - 5040	Slightly Weathered - Fresh Bedrock	Poor	Break / Blast

3.3 MASW

MASW data was recorded along the seismic refraction spreads across the site. The shear wave (S-wave) velocity recorded above top of competent bedrock at the 1D locations ranges from 131-510m/s.

The shear wave velocity, Vs, and the Gmax values at each of the fifteen MASW locations are shown in Figs. 3.1 and 3.2 below. Shear wave velocity and corresponding soil cohesion and generalised bedrock interpretation is displayed in Fig. 3.3.

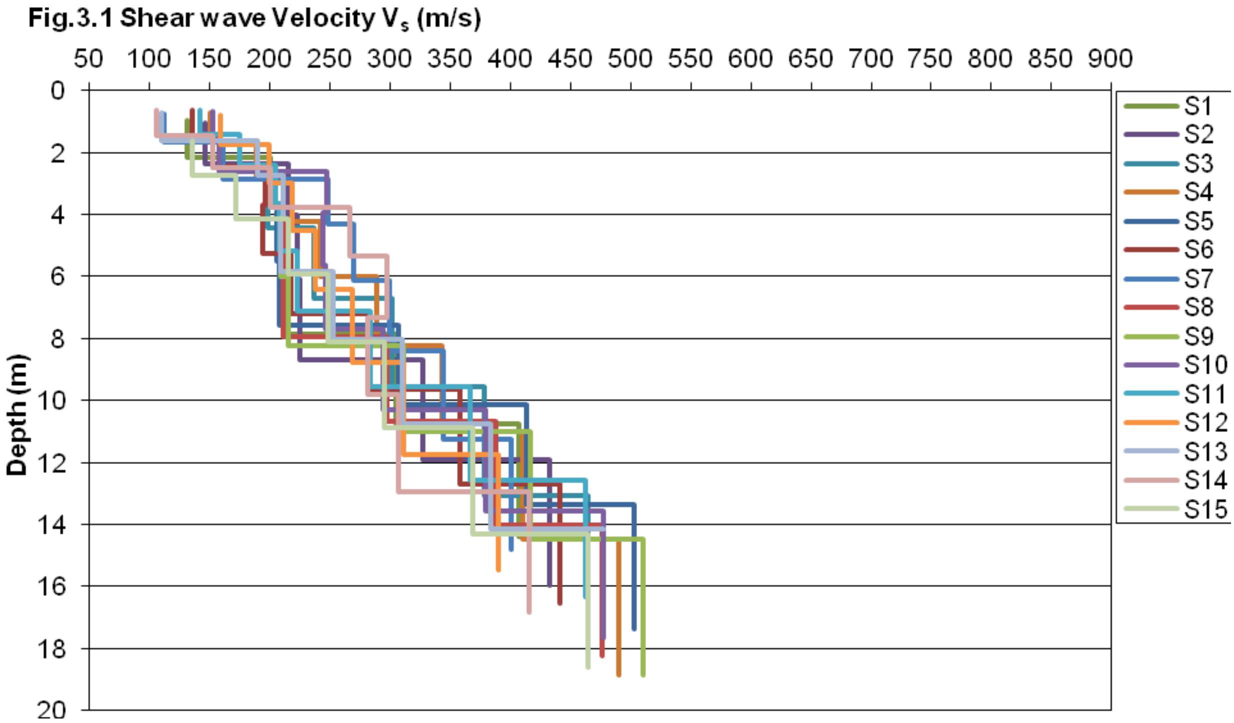
Fig.3.1 Shear wave Velocity V_s (m/s)
50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900
0 2 4 6 8 10 12 14 16 18 20
Depth (m)
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15

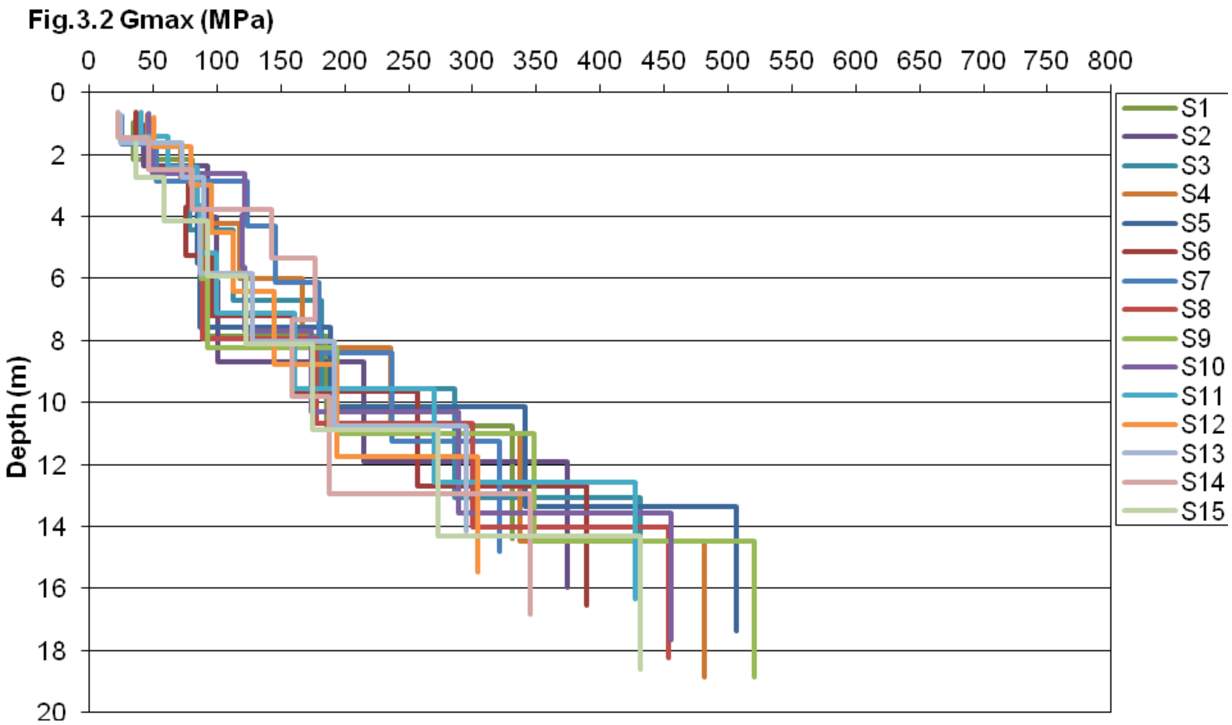
Fig.3.2 Gmax (MPa)
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800
0 2 4 6 8 10 12 14 16 18 20
Depth (m)
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15

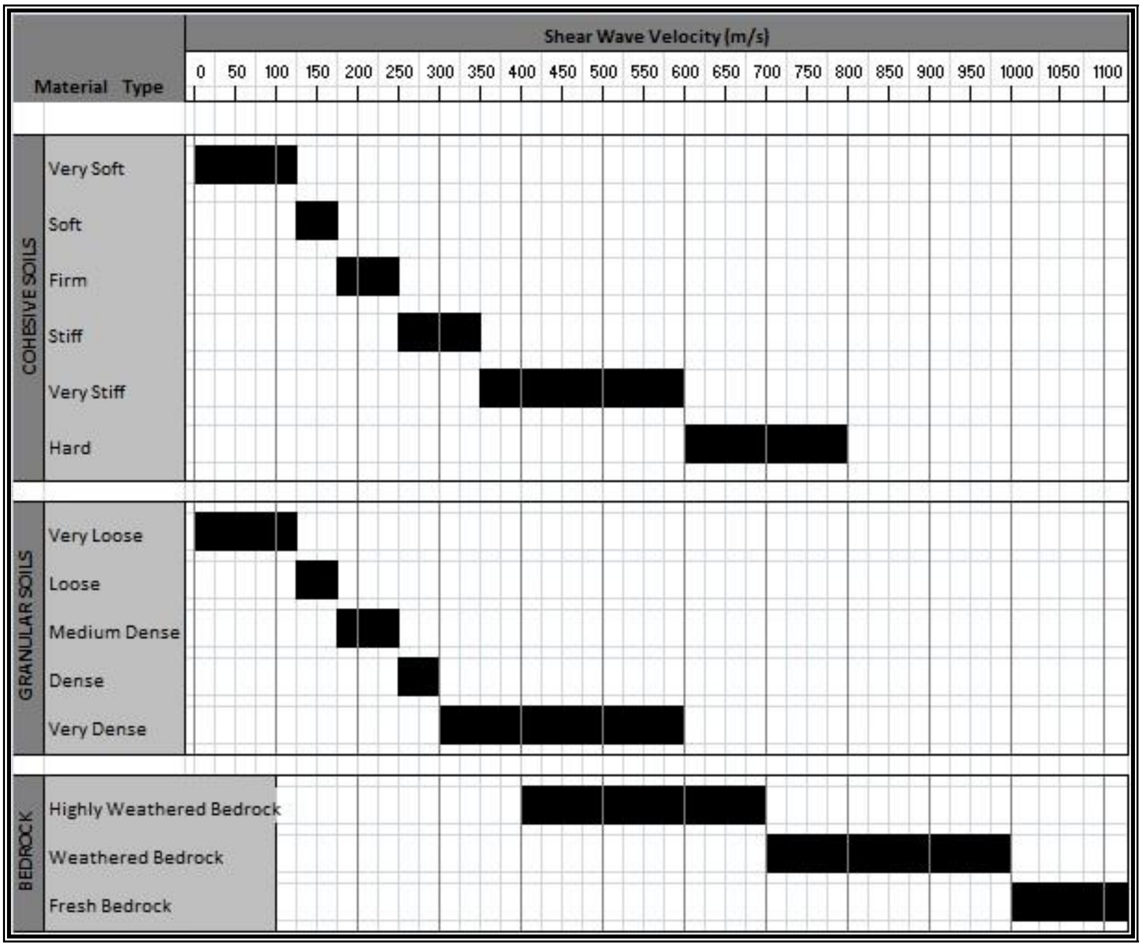

Fig.3.3. Shear-wave velocity and corresponding soil cohesion and generalised bedrock interpretation.

4. DISCUSSION

The geophysical datasets, in conjunction with client supplied borehole information, were used to generate an integrated geological model for determination of overburden layer thickness, stiffness and engineering parameters. The combined methodology also gives information on bedrock topography, depth, lithology, quality, excavatability and faulting / fracturing. Combining several techniques maximises the advantages and minimises the limitations of each individual method.

Due to the saline environment it was not possible to differentiate between granular and cohesive overburden layers using the ERT model resistivity data. It was not possible to delineate saturated saline water in the overburden layers.

For this reason the interpretation of the overburden type was primarily based on the mechanical parameters derived from the seismic refraction and MASW surveys, as well as correlation to the two client supplied borehole datasets.

Where no seismic refraction and MASW data exists the model resistivity data from the ERT investigation is used to guide the interpretation of the layer boundaries.

4.1 Overburden

Materials with a P-wave seismic velocity (Vp) from the tomographic inversions in the range 300 – 1000m/s, 1000 – 1800m/s and 1800 – 2300m/s were interpreted as overburden layers. Based on the velocities and the 2013 client supplied borehole data (BH14 / BH14A) these layers were interpreted as loose – medium dense silty sand, medium dense – dense silty sand and stiff – very stiff sandy gravelly clay respectively. Based on the geophysical results it was not possible to differentiate between the silty sand and sandy silt layers as described in the borehole data.

The loose – medium dense and medium dense – dense silty sand layers vary in thickness from c. 7.2 – 10.7m in the southwest to c. 7.2 – 20.9m in the north and northeast (see **Appendix A: Drawing No.s AGL15247_02 - AGL15247_04**).

The underlying stiff – very stiff sandy gravelly clay varies in thickness from c. 1.8 – 6.7m in the southwest to c. 1.9 – 7.1m in the north and northeast (see **Appendix A: Drawing No.s AGL15247_02 - AGL15247_04**).

4.2 Bedrock

Bedrock material with Vp, from the tomographic inversions, in the range 2300 – 2700m/s and 2700m/s – 5040m/s were interpreted as moderately weathered bedrock and slightly weathered – fresh bedrock respectively. The bedrock type was interpreted as argillaceous limestone and shale.

Across the survey area the depth to top of the moderately weathered bedrock ranged from c. 8.9 – 14.8m bgl in the southwest to c. 10.4 – 25.3m bgl in the north and northeast. This layer ranged in thickness from c. 1m to > 12.5m with an average thickness of c. 4.9m. The thickness of this layer increased over localised zones in the southwest and north (see **Appendix A: Drawing No.s AGL15247_02 - AGL15247_05**).

The depth to the top of the slightly weathered – fresh competent bedrock layer ranged c. 14.2m – 21.5m in the southwest to c. 13.3 - > 28.4m bgl in the north. The average depth to the top of this competent bedrock layer was c. 17.6m bgl.

In the client supplied borehole BH01, on Velvet Strand, the depth to bedrock was recorded as 14.5m bgl. At the closest point on the geophysical profiles, seismic refraction spread S4, the depth was interpreted as 14.4m bgl (see **Appendix A: Drawing No.s AGL15247_05**).

Borehole BH14 / BH14A records very gravelly clay, described as possible weathered rock, at 13.5m bgl and highly weathered rock at 15.40m. While this borehole was offset from the geophysical profile ERT R5 by c. 40m it correlated well with the geophysical interpretation which indicated weathered rock at c. 12.4m bgl and competent bedrock at c. 17.1m bgl (see **Appendix A: Drawing No.s AGL15247_02**).

Lateral variation in bedrock velocities and in the relative model resistivity values represented possible changes in bedrock competency, reflecting areas of weakness or increased weathering / fracturing / faulting of the bedrock and possible changes in bedrock type from argillaceous limestone and subordinate shale to bedrock with increased shale content. These areas, including possible fault / fracture zones are highlighted in **Appendix A: Drawing No.s AGL15247_02 – AGL15247_06.**

In the northern part of the survey area, on west – east oriented ERT profiles R1/R2, two possible fault / fracture zones are highlighted. The orientation of these zones is in general agreement with the northwest – southeast regional faulting trend.

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6. APPENDIX A: DRAWINGS

The information derived from the geophysical investigation as well as correlation with the available direct investigation is presented in the following drawings:

AGL15247_01

Figure.1	Geophysical Investigation Location Map	Scale1:2000 @A3

AGL15247_02

Figure.1	Geophysical Investigation Location R5	Scale1:4000 @A3
Figure.2	Geophysical Results & Interpretation R5	Scale1:1000 @A3

AGL15247_03

Figure.1	Geophysical Investigation Location R1/R2	Scale1:4000 @A3
Figure.2	Geophysical Results & Interpretation R1/R2	Scale1:1000 @A3

AGL15247_04

Figure.1	Geophysical Investigation Location R1/R2	Scale1:4000 @A3
Figure.2	Geophysical Results & Interpretation R1/R2	Scale1:1000 @A3

AGL15247_05

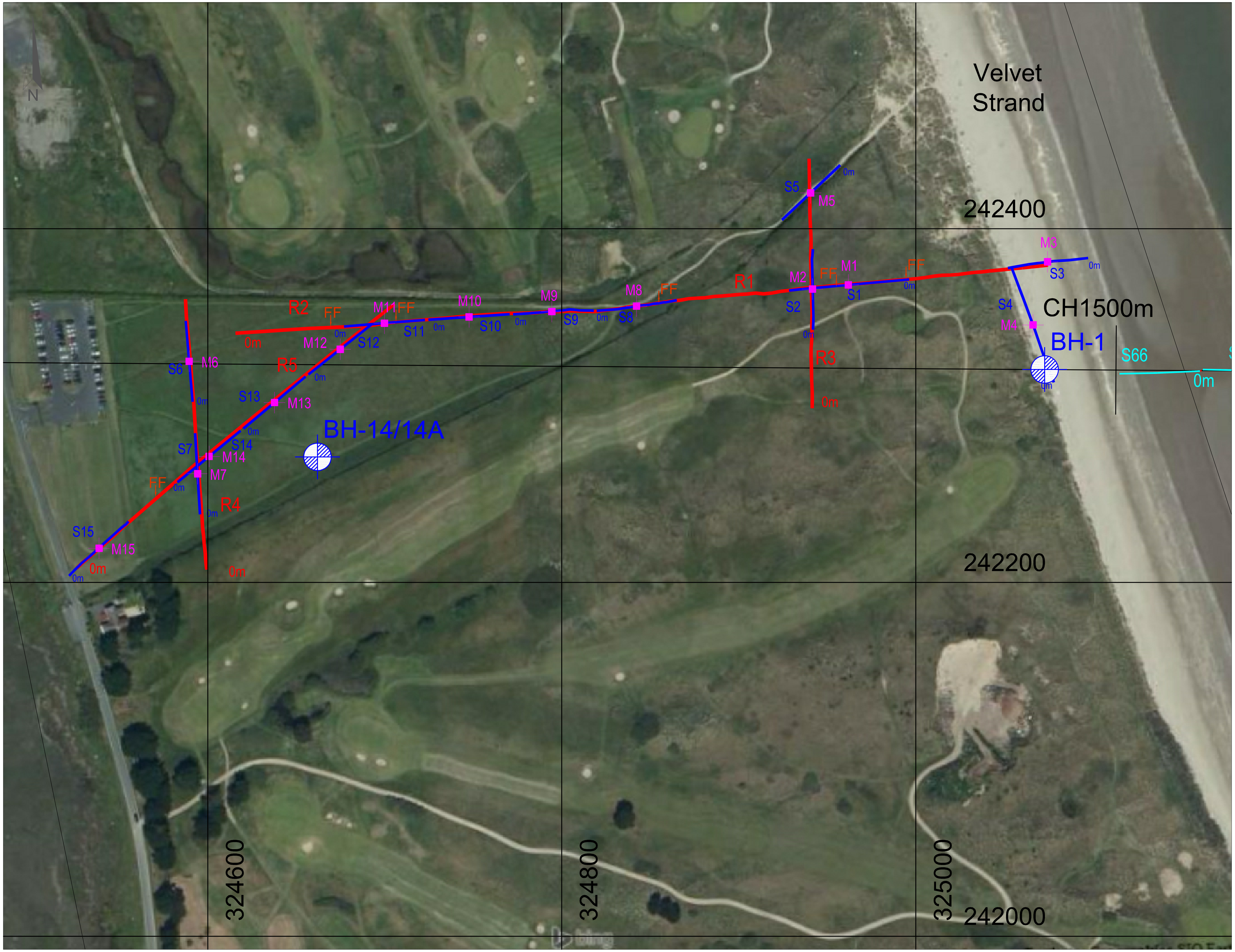
Figure.1	Geophysical Investigation Location R4	Scale1:4000 @A3
Figure.2	Geophysical Results & Interpretation S4	Scale1:1000 @A3
Figure.3	Geophysical Results & Interpretation R4	Scale1:1000 @A3

AGL15247_06

Figure.1	Geophysical Investigation Location R3 & S5	Scale1:4000 @A3
Figure.2	Geophysical Results & Interpretation R3	Scale1:1000 @A3
Figure.3	Geophysical Results & Interpretation S5	Scale1:1000 @A3

FIGURE 1: GEOPHYSICAL INVESTIGATION LOCATION MAP

SCALE 1:2000



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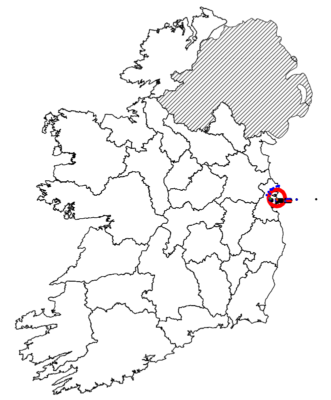
INDEX MAP:



LEGEND:

R1 (red line)	ERT Profile
S1 (blue line)	Seismic Refraction Spread
M1	MASW Location on Seismic Refraction Spread
BH-1	Client Borehole Data
325000 242000	ING Coordinate
(dashed line)	Possible Fault / Fracture
FF	Possible Fault / Fracture

apex geoservices

6 Knockmullen Business Park
Gorey
Co. Wexford
Ireland.
T +353 (0)402-21842
F +353 (0)402-21843
E info@apexgeoservices.ie
www.apexgeoservices.ie

Regus House, Herald Way
Pegasus Business Park
Castle Donington
Derby DE74 2TZ
UK
T +44 (0)844 8700 692
E info@apexgeoservices.co.uk
www.apexgeoservices.co.uk

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DRAWING NO:	AGL15247_01
SCALE:	AS INDICATED @ A3
DATE:	27/01/2016

Version:	Date:	Drawn By:	Checked:
01	27/01/2016	TL	SOR
02	11/02/2016	TL	SOR

FIGURE 1: GEOPHYSICAL INVESTIGATION LOCATION R5

SCALE 1:4000

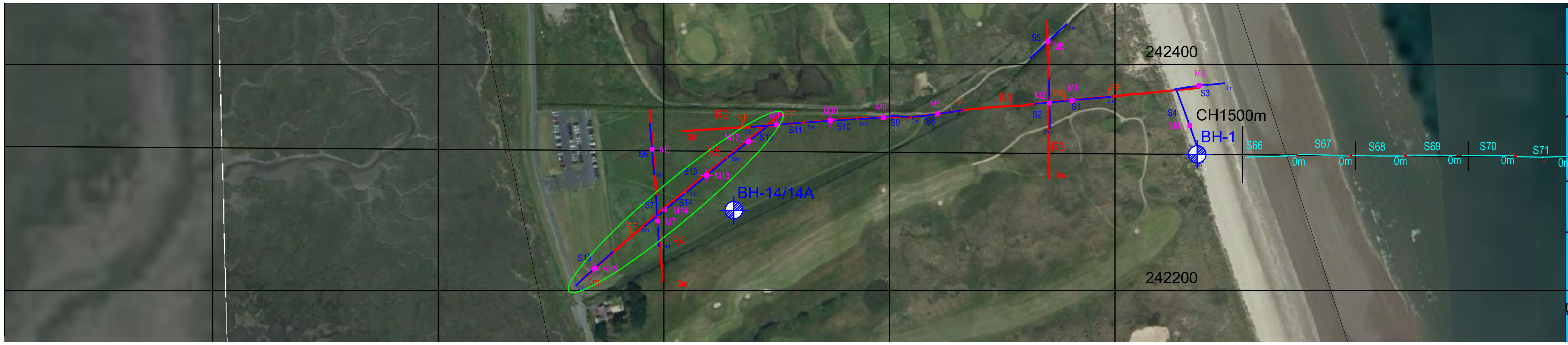
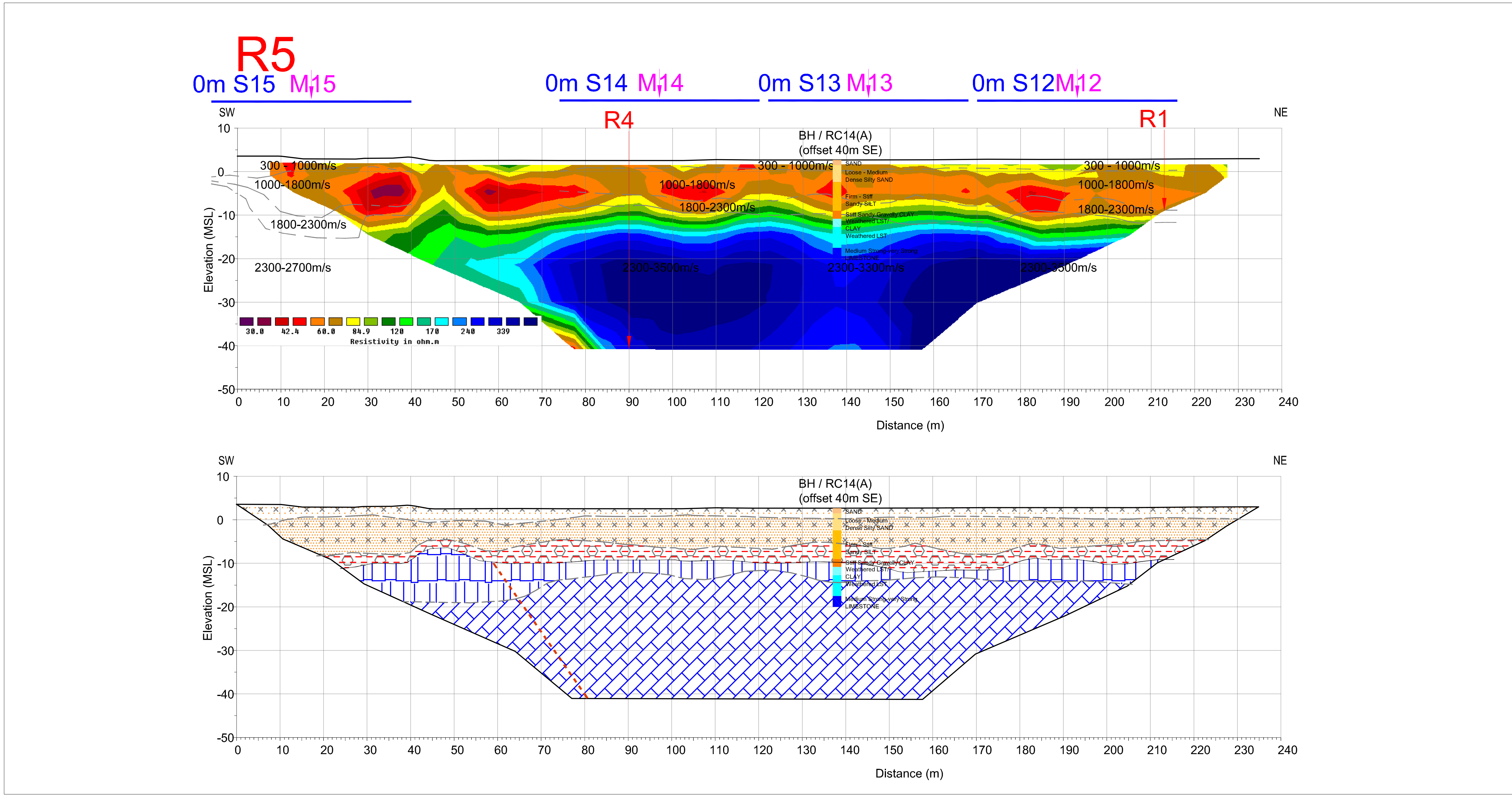
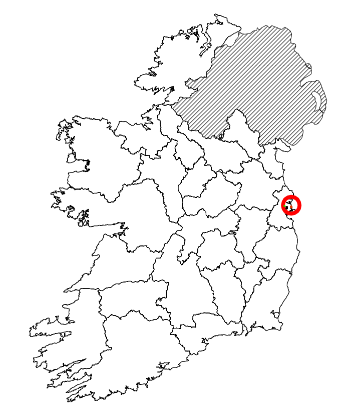


FIGURE 2: GEOPHYSICAL RESULTS & INTERPRETATION R5

SCALE 1:1000



INDEX MAP:



LEGEND:

- ERT Profile
- Seismic Refraction Spread
- Seismic Refraction Spread Marine Investigation 2015
- Area of Interpretation Display
- MASW Location on Seismic Refraction Spread
- Client Borehole Data
- ING Coordinate
- Overburden Thickness from Borehole
- Seismic Layer Boundary
- Internal Overburden Layer Boundary
- Top of Bedrock
- Possible Fault / Fracture Zone
- Very Loose - Medium Dense Silty Sand
- Medium Dense - Dense Silty Sand
- Stiff - Very Stiff Sandy Gravelly CLAY
- Moderately Weathered Limestone & Shale
- Slightly Weathered - Fresh Limestone & Shale

apex geoservices

6 Knockmullen Business Park, Gorey, Co. Wexford, Ireland.
T +353 (0)402-21842
F +353 (0)402-21843
E info@apexgeoservices.ie
www.apexgeoservices.ie

Regus House, Herald Way, Pegasus Business Park, Castle Donington, Derby DE74 2TZ, UK
T +44 (0)844 8700 692
E info@apexgeoservices.co.uk
www.apexgeoservices.co.uk

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01	27/01/2016	TL	SOR
02	11/02/2016	TL	SOR

FIGURE 1: GEOPHYSICAL INVESTIGATION LOCATION R1/R2

SCALE 1:4000

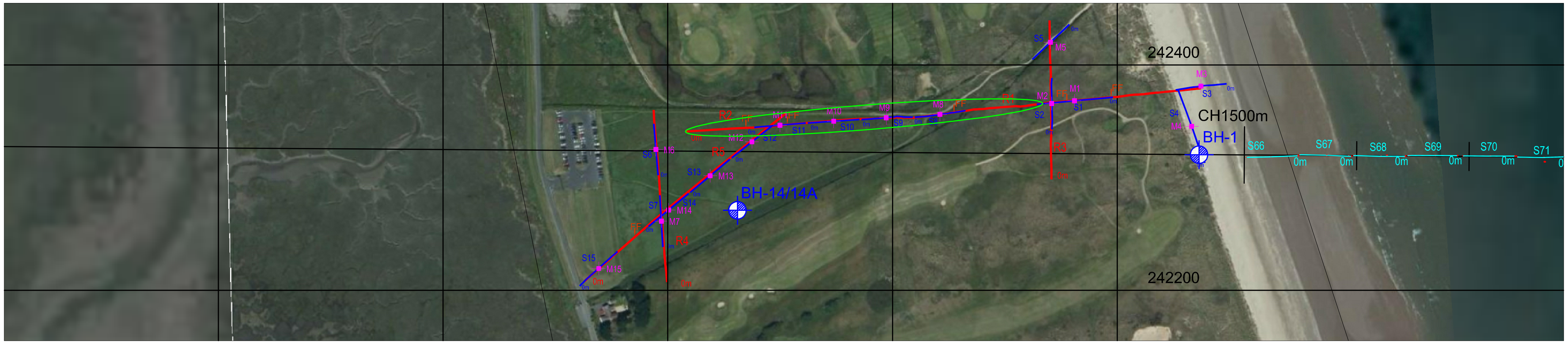
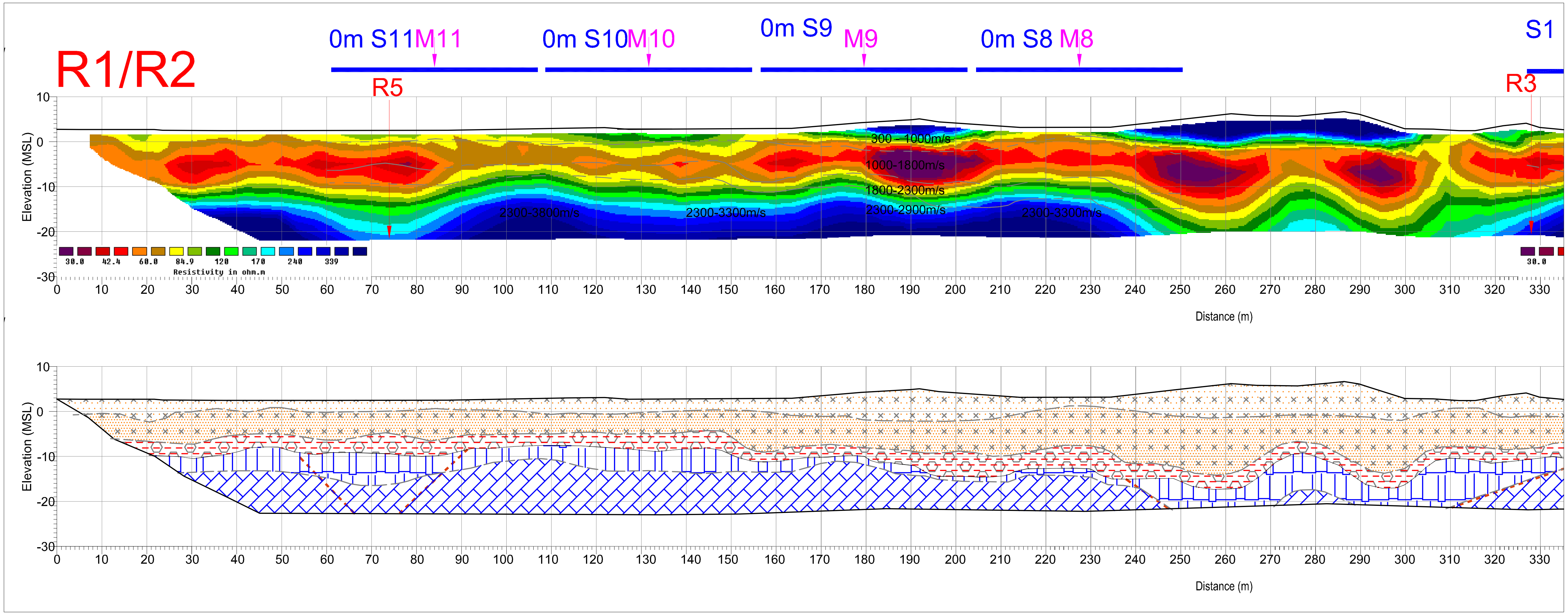
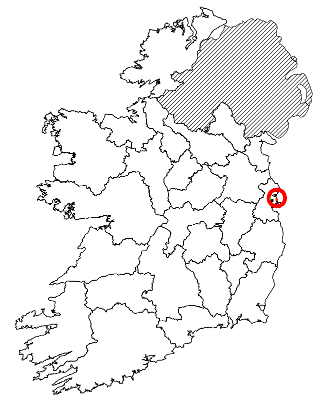


FIGURE 2: GEOPHYSICAL RESULTS & INTERPRETATION R1/R2

SCALE 1:1000



INDEX MAP:



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Co. Wexford
Ireland.
T +353 (0)402-21842
F +353 (0)402-21843
E info@apexgeoservices.ie
www.apexgeoservices.ie

Regus House, Herald Way
Pegasus Business Park
Castle Donington
Derby DE74 2TZ
UK
T +44 (0)844 8700 692
E info@apexgeoservices.co.uk
www.apexgeoservices.co.uk

PROJECT:	G.D.D.P PORTMARNOCK GOLF COURSE GEOPHYSICAL INVESTIGATION
CLIENT:	TOBIN CONSULTING ENGINEERS
DRAWING NO:	AGL15247_03
SCALE:	AS INDICATED @ A3
DATE:	27/01/2016

Version:	Date:	Drawn By:	Checked:
01	27/01/2016	TL	SOR
02	11/02/2016	TL	SOR

FIGURE 1: GEOPHYSICAL INVESTIGATION LOCATION R1/R2

SCALE 1:4000

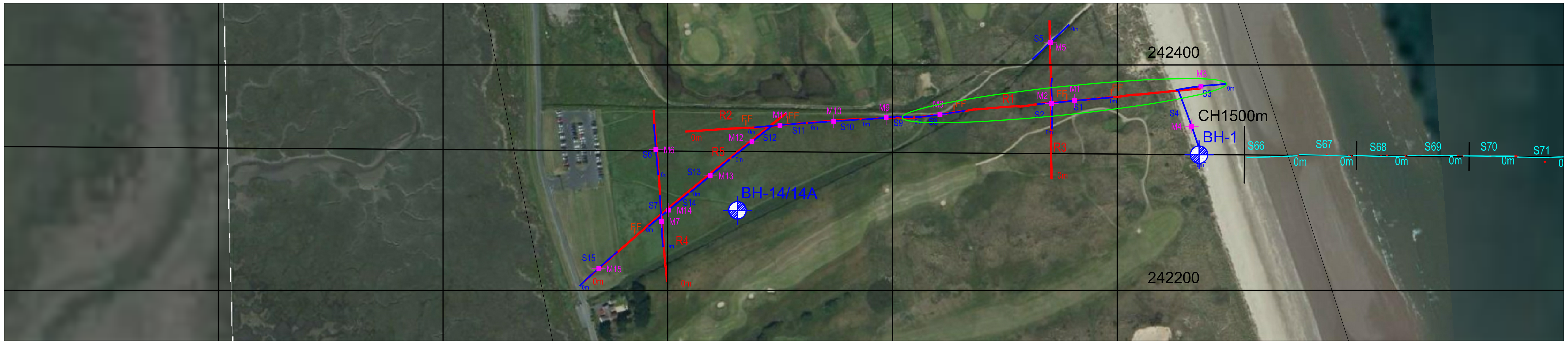
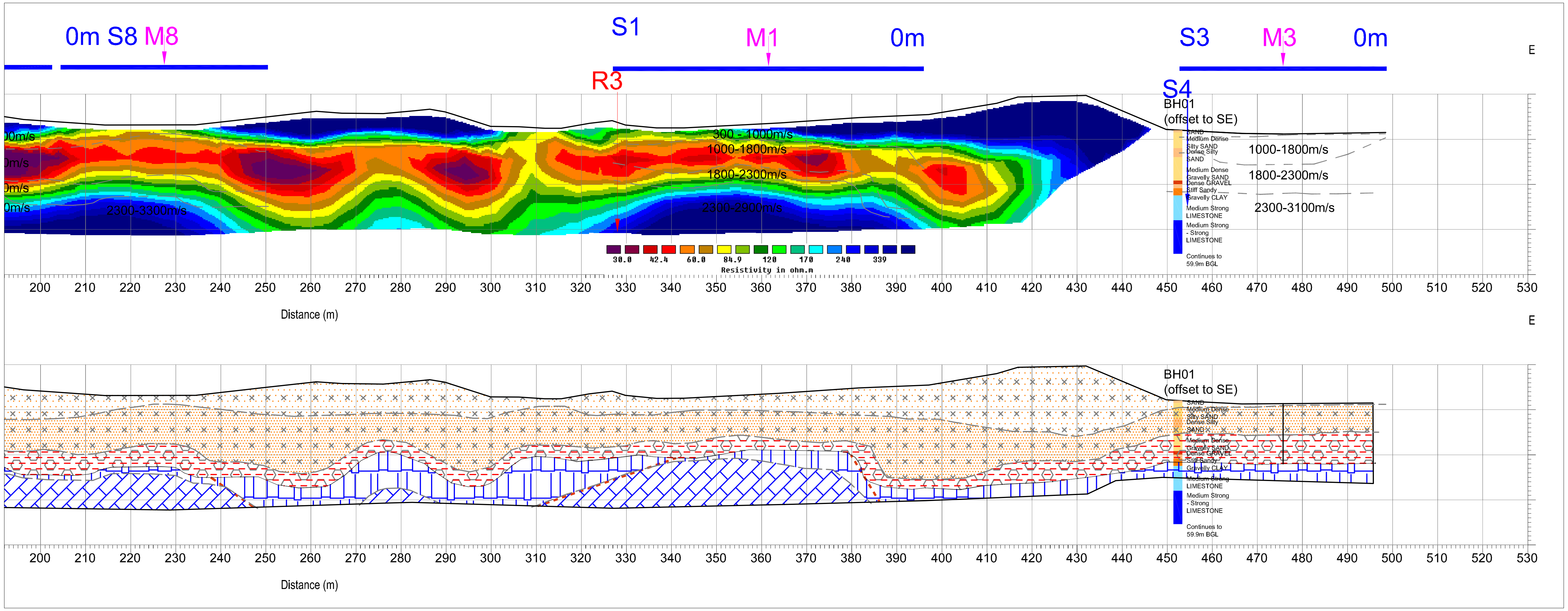
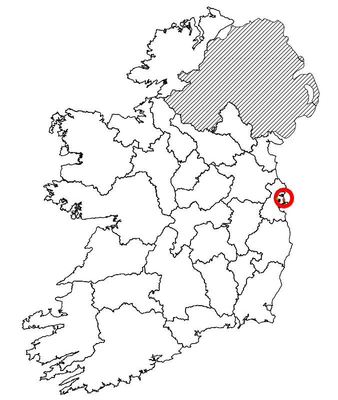


FIGURE 2: GEOPHYSICAL RESULTS & INTERPRETATION R1/R2

SCALE 1:1000



INDEX MAP:



LEGEND:

- ERT Profile
- Seismic Refraction Spread
- Seismic Refraction Spread Marine Investigation 2015
- Area of Interpretation Display
- MASW Location on Seismic Refraction Spread
- Client Borehole Data
- ING Coordinate
- Overburden Thickness from Borehole
- Seismic Layer Boundary
- Internal Overburden Layer Boundary
- Top of Bedrock
- Possible Fault / Fracture Zone
- Very Loose - Medium Dense Silty Sand
- Medium Dense - Dense Silty Sand
- Stiff - Very Stiff Sandy Gravelly CLAY
- Moderately Weathered Limestone & Shale
- Slightly Weathered - Fresh Limestone & Shale

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F +353 (0)402-21843
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E info@apexgeoservices.co.uk
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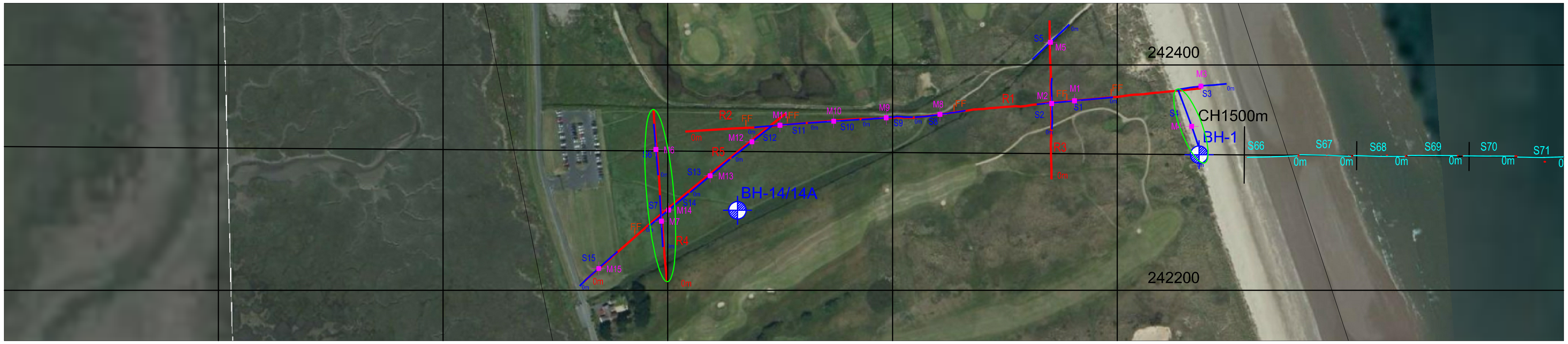
PROJECT:	G.D.D.P PORTMARNOCK GOLF COURSE GEOPHYSICAL INVESTIGATION
CLIENT:	TOBIN CONSULTING ENGINEERS
DRAWING NO:	AGL15247_04
SCALE:	AS INDICATED @ A3
DATE:	27/01/2016

Version:	Date:	Drawn By:	Checked:
01	27/01/2016	TL	SOR
02	11/02/2016	TL	SOR

FIGURE 1: GEOPHYSICAL INVESTIGATION LOCATION R4

SCALE 1:4000



INDEX MAP:

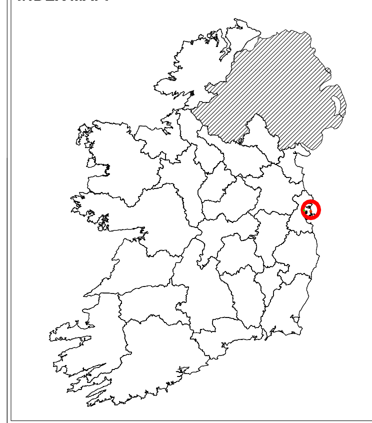


FIGURE 2: GEOPHYSICAL RESULTS & INTERPRETATIONS4

SCALE 1:1000

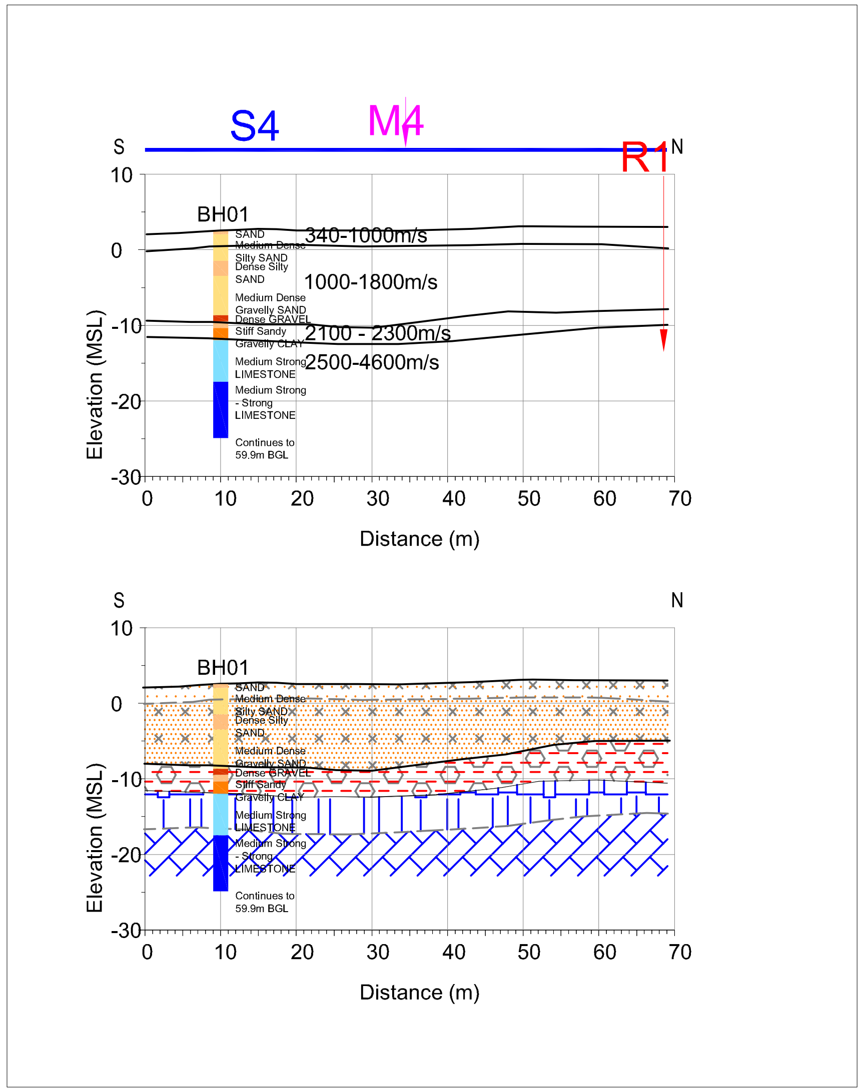
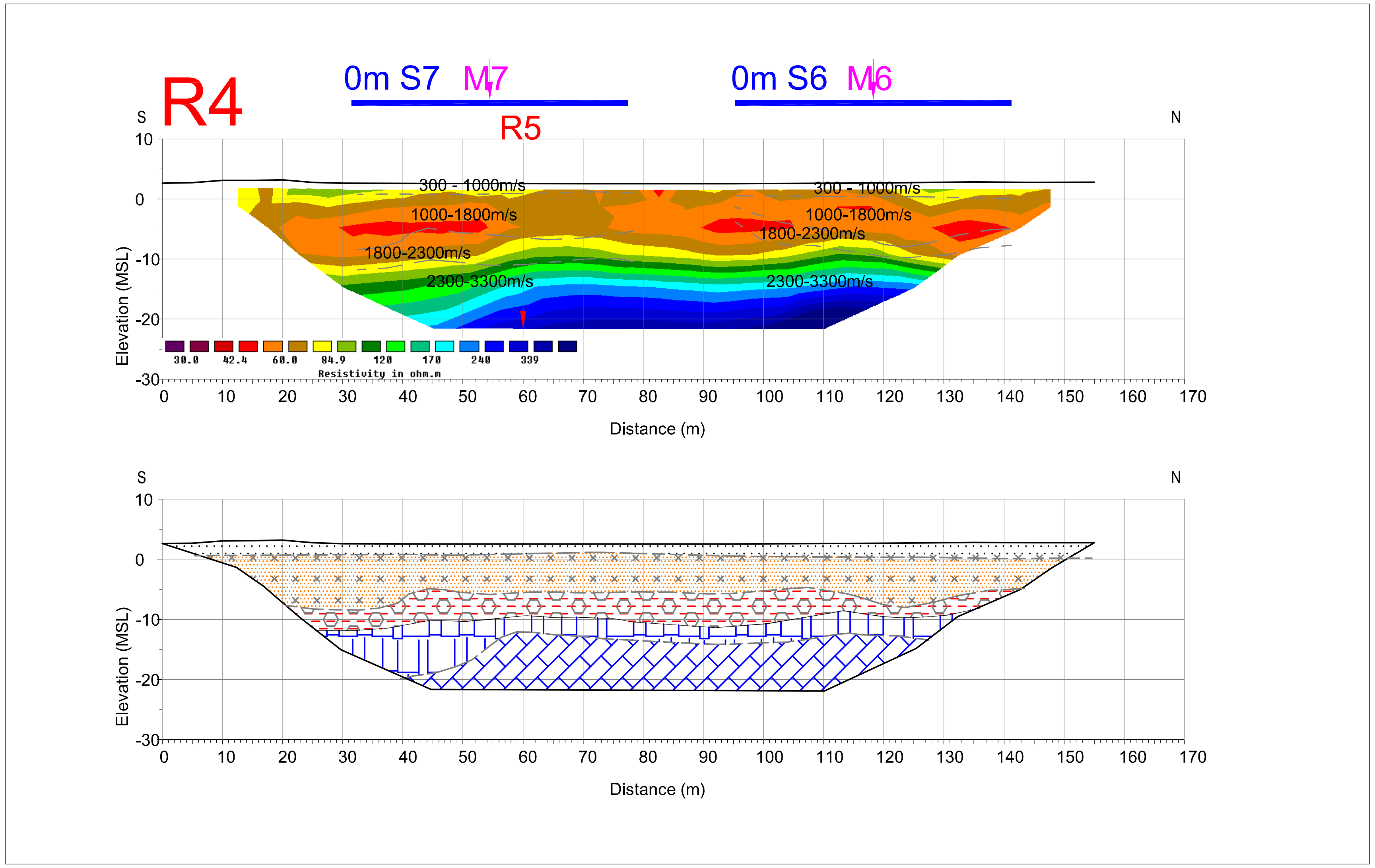


FIGURE 3: GEOPHYSICAL RESULTS & INTERPRETATION R4

SCALE 1:1000



LEGEND:

- ERT Profile
- Seismic Refraction Spread
- Seismic Refraction Spread Marine Investigation 2015
- Area of Interpretation Display
- MASW Location on Seismic Refraction Spread
- Client Borehole Data
- ING Coordinate
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- Seismic Layer Boundary
- Internal Overburden Layer Boundary
- Top of Bedrock
- Possible Fault / Fracture Zone
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- Slightly Weathered - Fresh Limestone & Shale

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F +353 (0)402-21843
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T +44 (0)844 8700 692
E info@apexgeoservices.co.uk
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PROJECT:	G.D.D.P PORTMARNOCK GOLF COURSE GEOPHYSICAL INVESTIGATION
CLIENT:	TOBIN CONSULTING ENGINEERS
DRAWING NO:	AGL15247_05
SCALE:	AS INDICATED @ A3
DATE:	27/01/2016

Version:	Date:	Drawn By:	Checked:
01	27/01/2016	TL	SOR
02	11/02/2016	TL	SOR

FIGURE 1: GEOPHYSICAL INVESTIGATION LOCATION R3 & S5
SCALE 1:4000

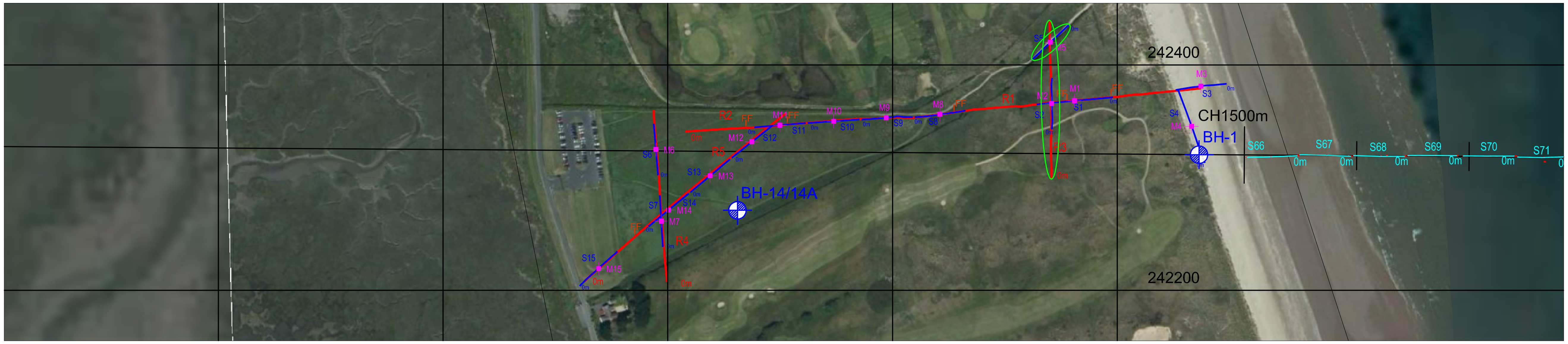


FIGURE 2: GEOPHYSICAL RESULTS & INTERPRETATION R3
SCALE 1:1000

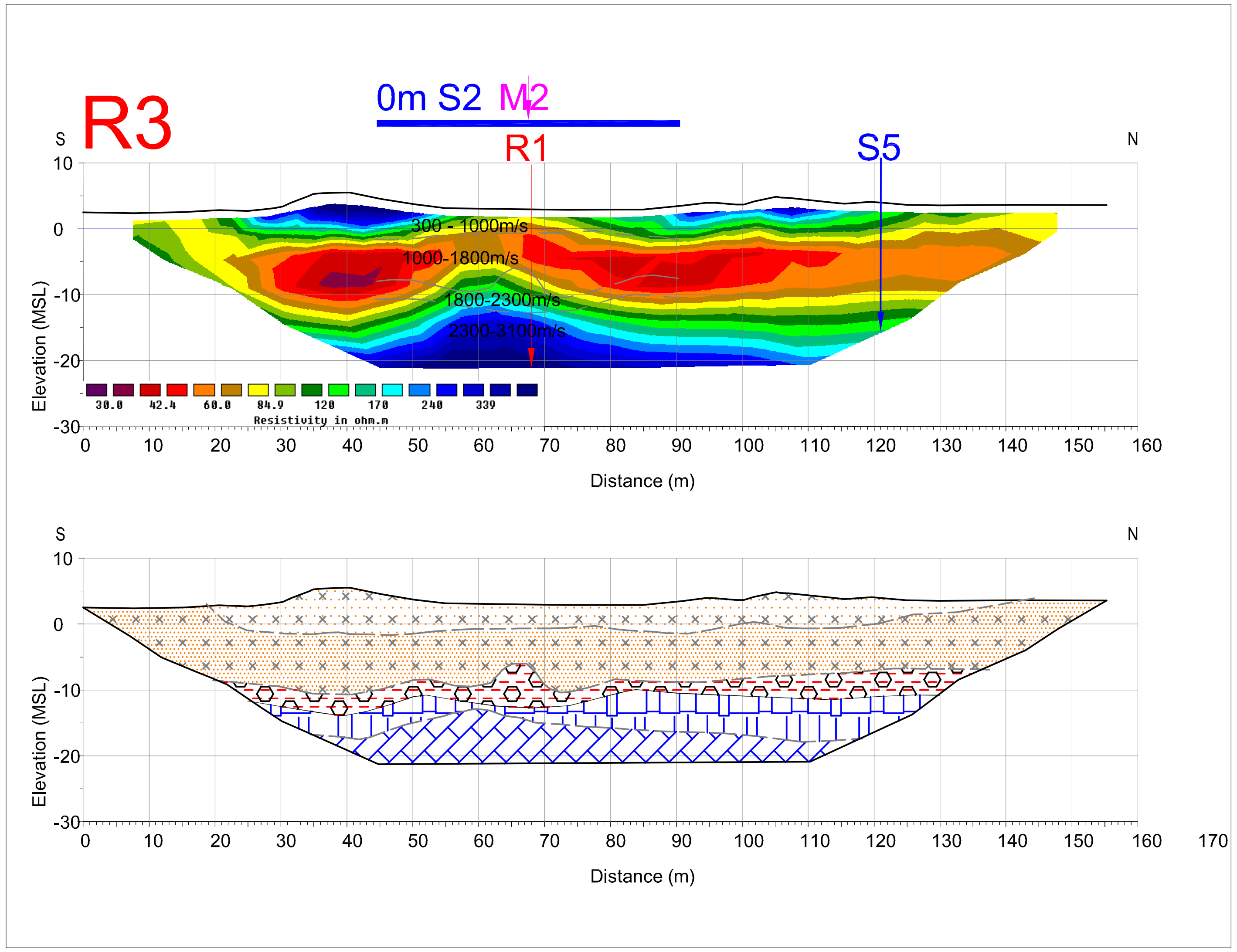
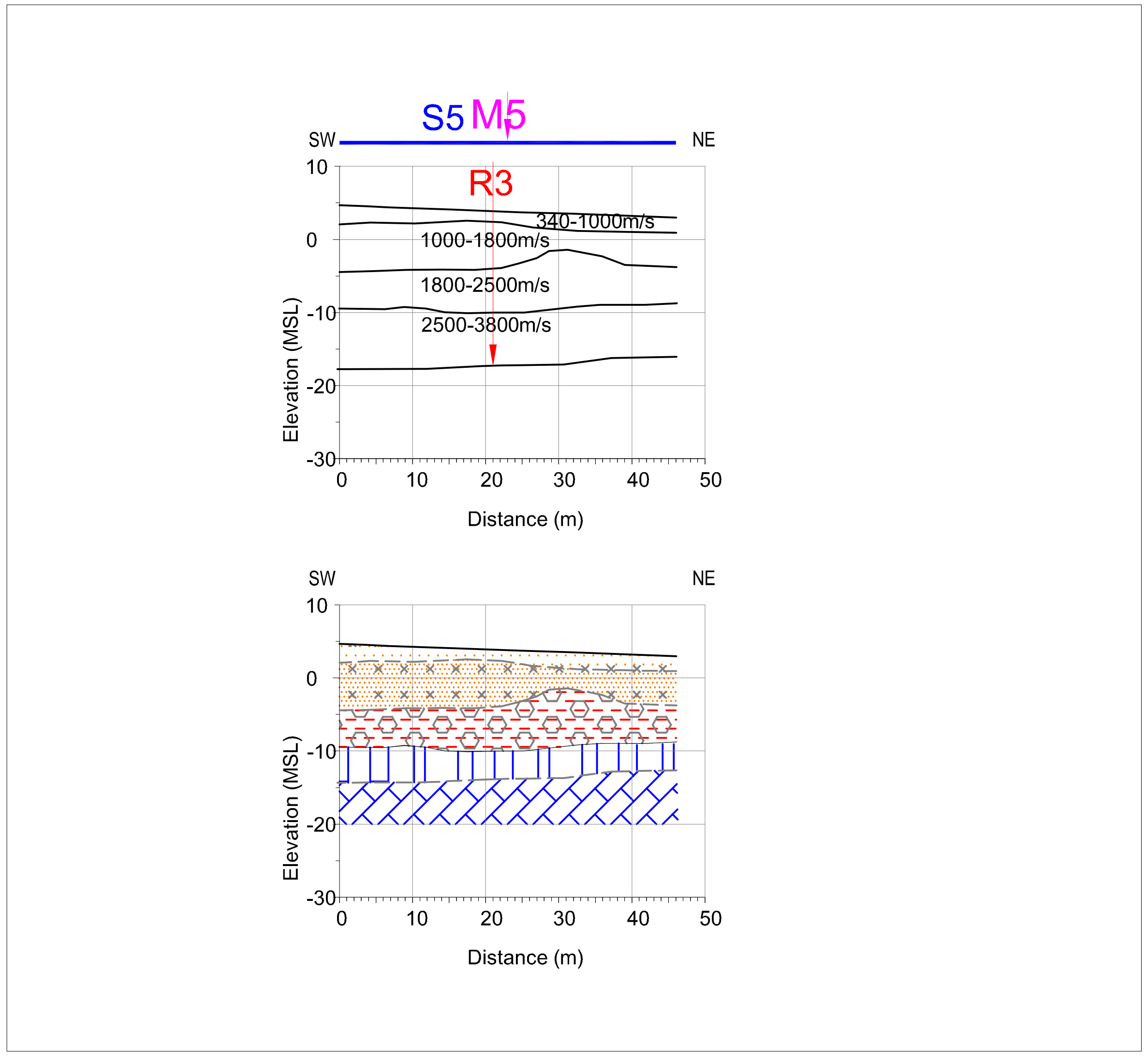
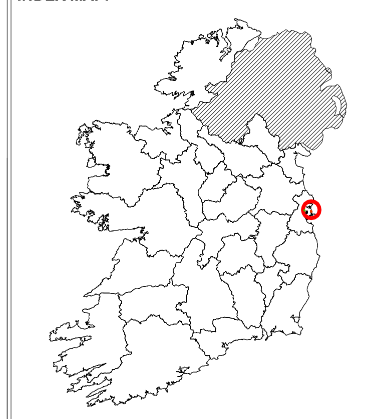


FIGURE 3: GEOPHYSICAL RESULTS & INTERPRETATION S5
SCALE 1:1000



INDEX MAP:



LEGEND:

- ERT Profile
- Seismic Refraction Spread
- Seismic Refraction Spread Marine Investigation 2015
- Area of Interpretation Display
- MASW Location on Seismic Refraction Spread
- Client Borehole Data
- ING Coordinate
- Overburden Thickness from Borehole
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F +353 (0)402-21843
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E info@apexgeoservices.co.uk
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PROJECT:	G.D.D.P PORTMARNOCK GOLF COURSE GEOPHYSICAL INVESTIGATION
CLIENT:	TOBIN CONSULTING ENGINEERS
DRAWING NO:	AGL15247_06
SCALE:	AS INDICATED @ A3
DATE:	27/01/2016

Version:	Date:	Drawn By:	Checked:
01	27/01/2016	TL	SOR
02	11/02/2016	TL	SOR

7. APPENDIX B: SEISMIC REFRACTION PLATES

The tomographic inversions for seismic refraction spreads S1 – S15 are shown below.

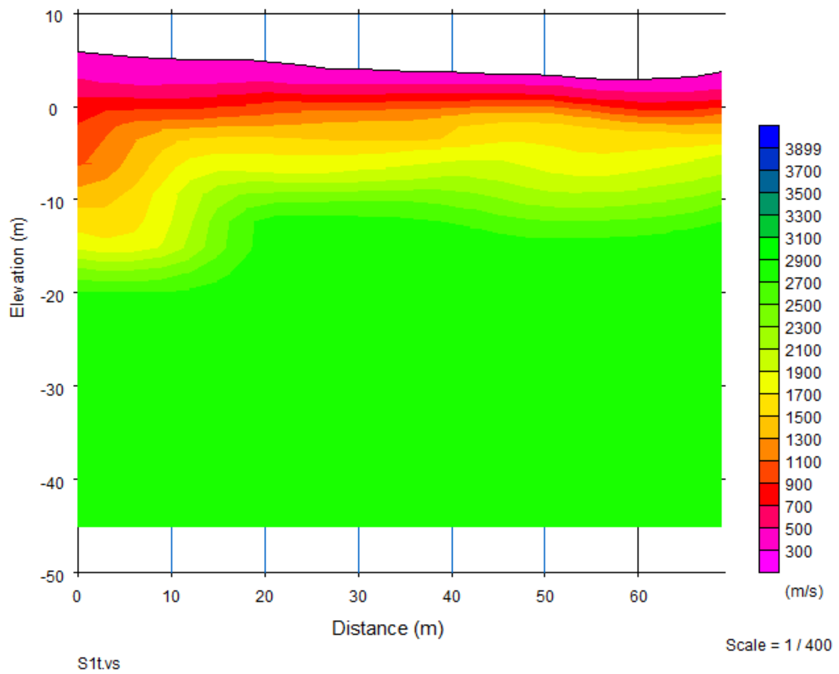


Figure 8.1. Tomographic inversion for S1, plotted E-W.

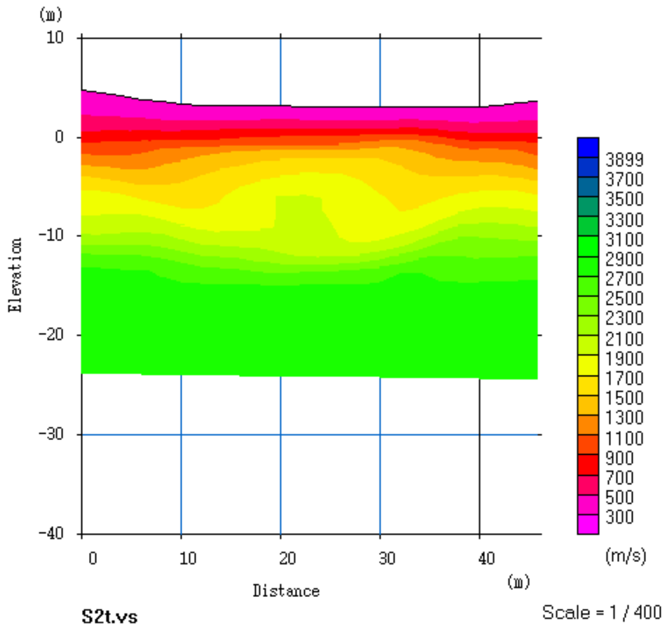


Figure 8.2. Tomographic inversion for S2, plotted S-N.

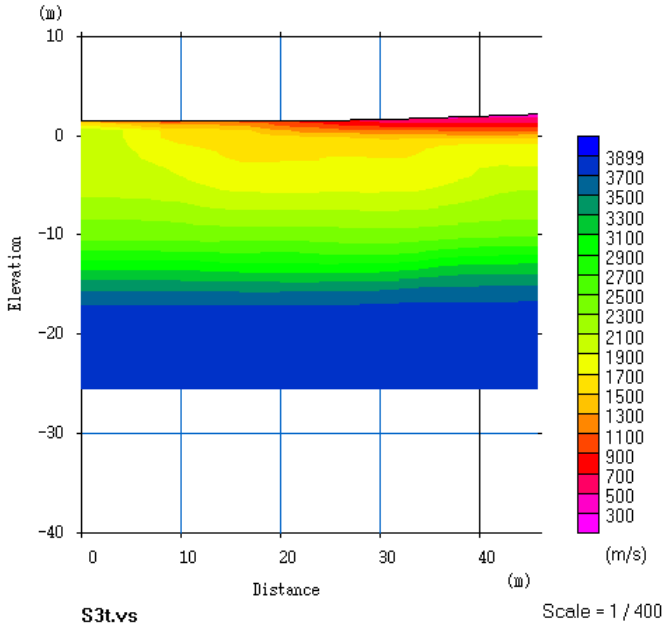


Figure 8.3. Tomographic inversion for S3, plotted E-W.

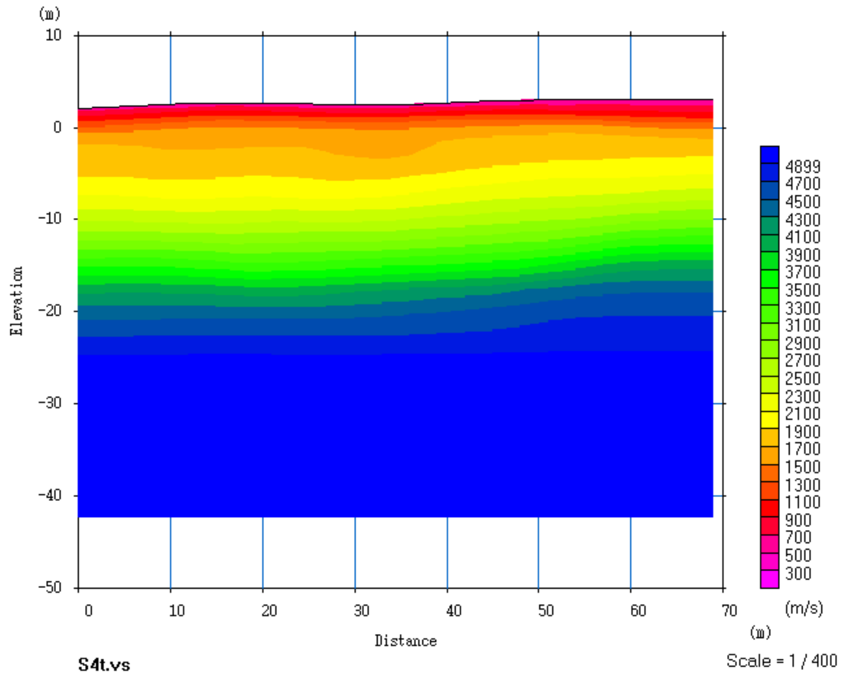


Figure 8.4. Tomographic inversion for S4, plotted S-N.

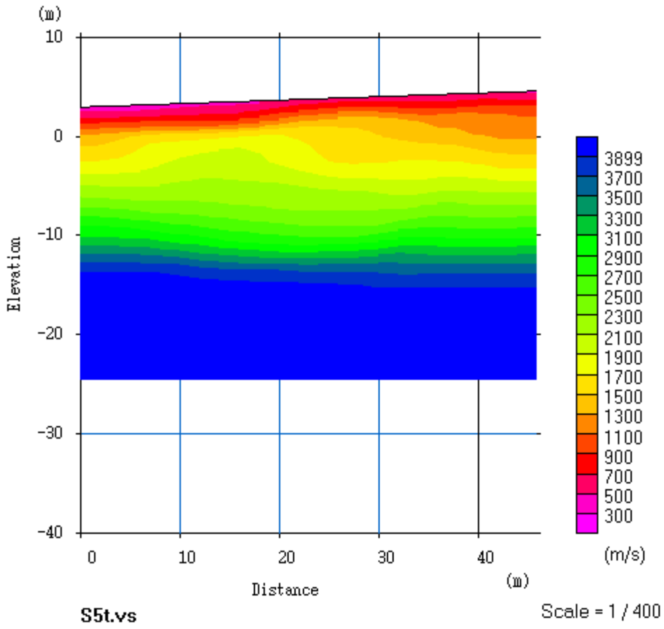


Figure 8.5. Tomographic inversion for S5, plotted NE-SW.

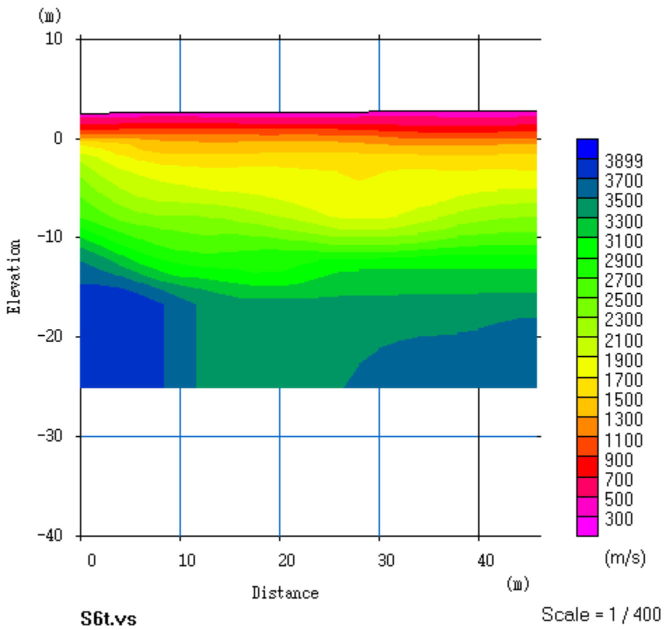


Figure 8.6. Tomographic inversion for S6, plotted S-N.

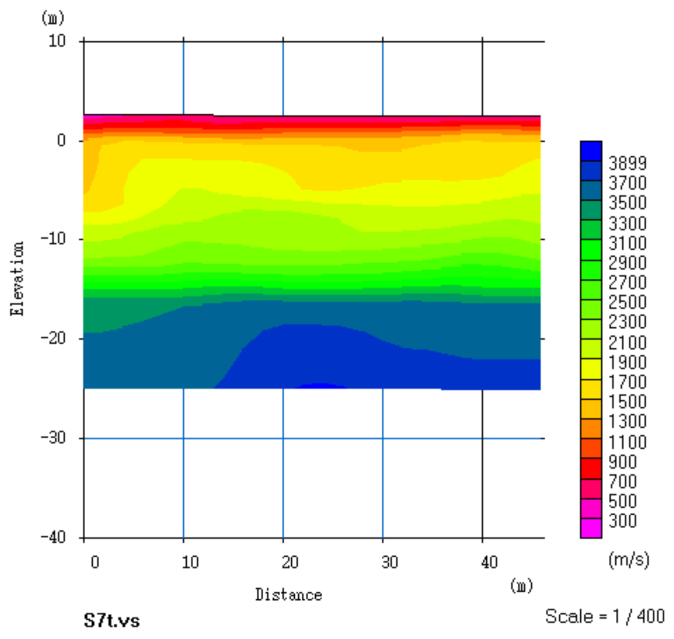


Figure 8.7. Tomographic inversion for S7, plotted S-N.

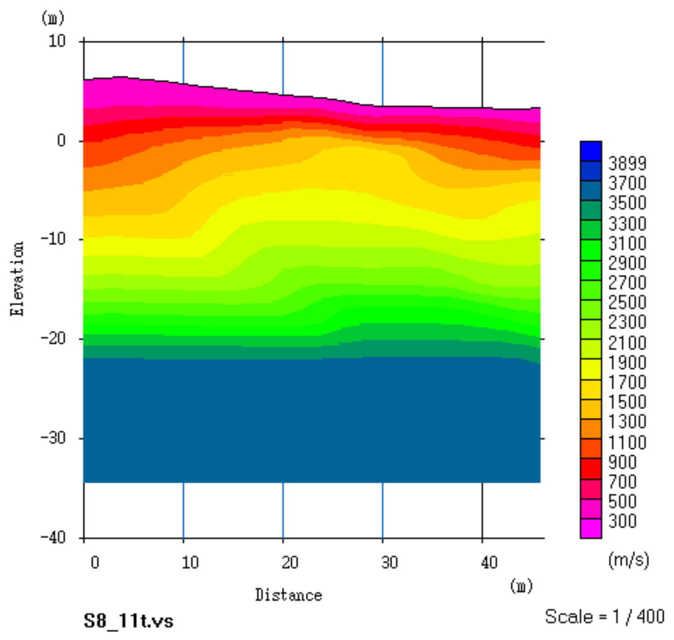


Figure 8.8. Tomographic inversion for S8, plotted W-E.

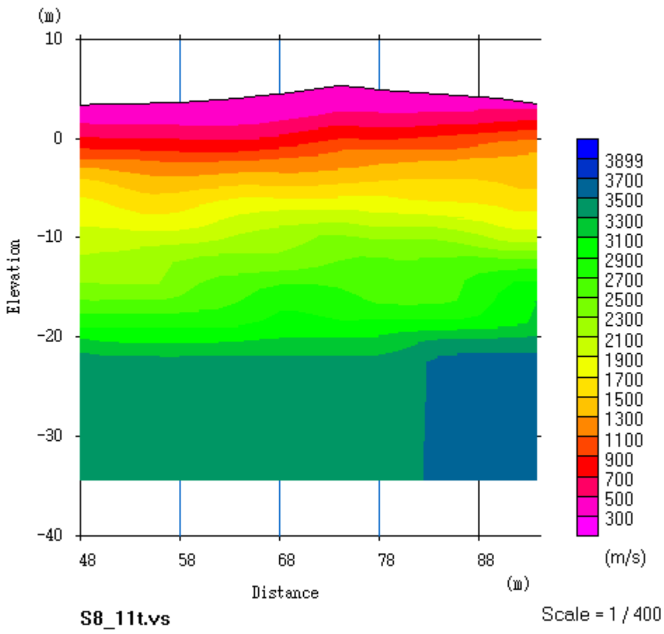


Figure 8.9. Tomographic inversion for S9, plotted W-E.

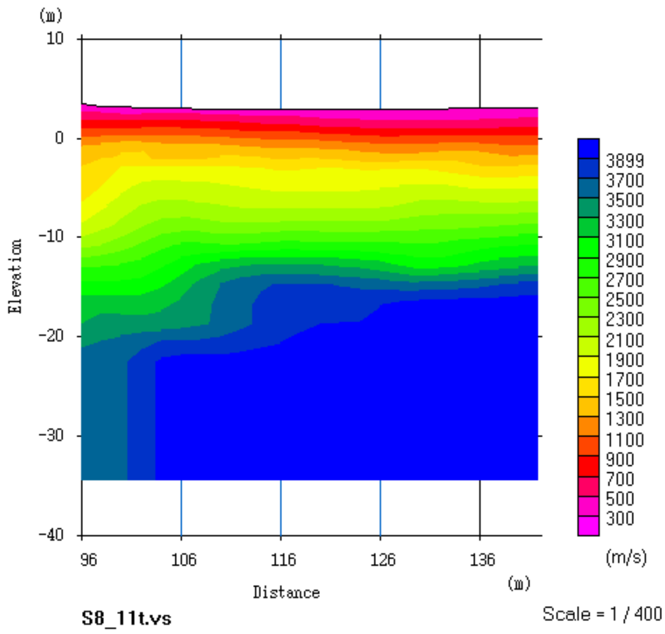


Figure 8.10. Tomographic inversion for S10, plotted W-E.

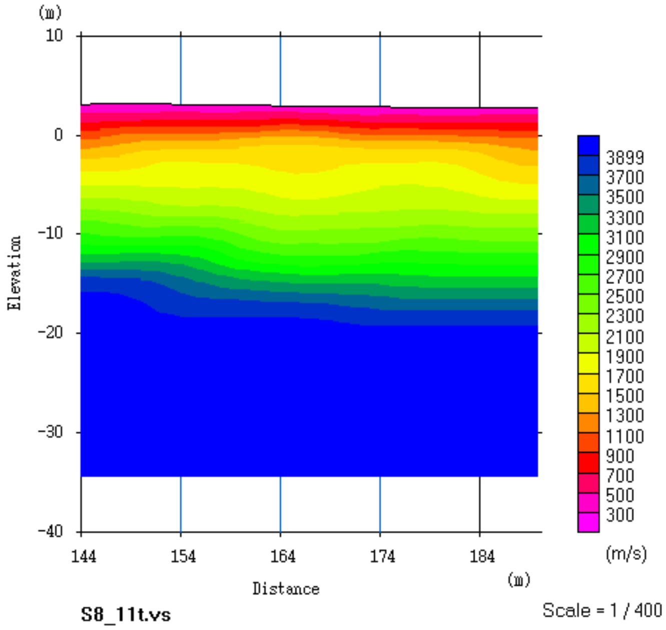


Figure 8.11. Tomographic inversion for S11, plotted W-E.

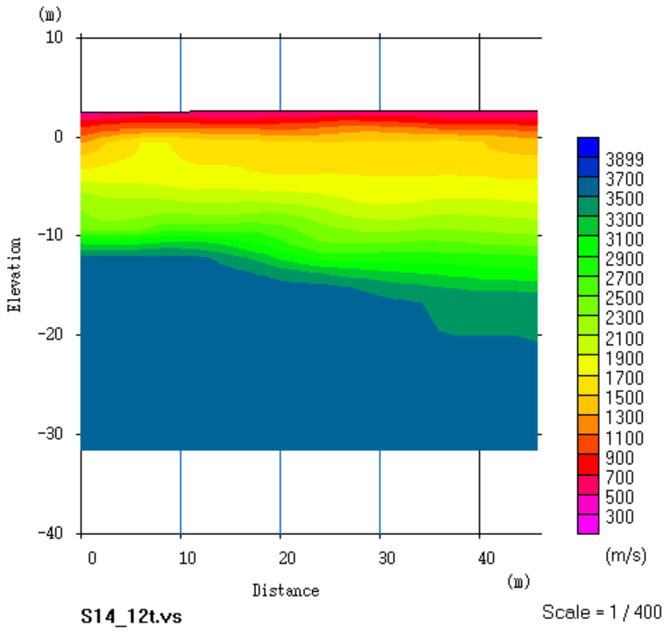


Figure 8.12. Tomographic inversion for S12, plotted SW-NE.

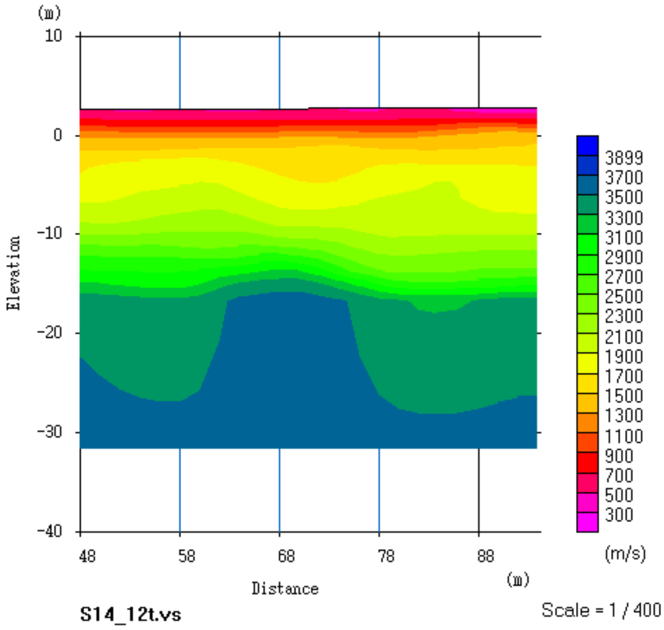


Figure 8.13. Tomographic inversion for S13, plotted SW-NE.

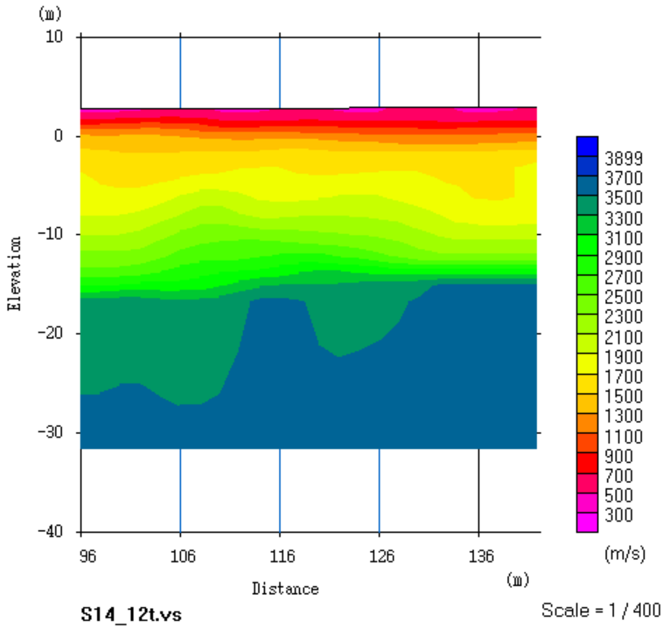


Figure 8.14. Tomographic inversion for S14, plotted SW-NE.

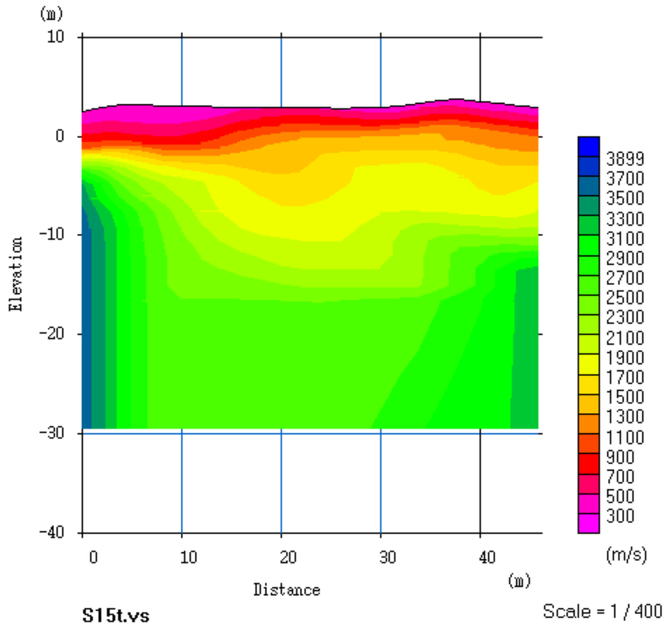


Figure 8.15. Tomographic inversion for S15, plotted SW-NE.

8. APPENDIX C: SHEAR WAVE VELOCITY, Vs, AND Gmax GRAPHS

Shear Wave velocity, Vs and Gmax results are shown below for each MASW location on each spread, (**Appendix A: Drawing No. AGL15247_01** for individual locations). Data is not displayed for competent bedrock.

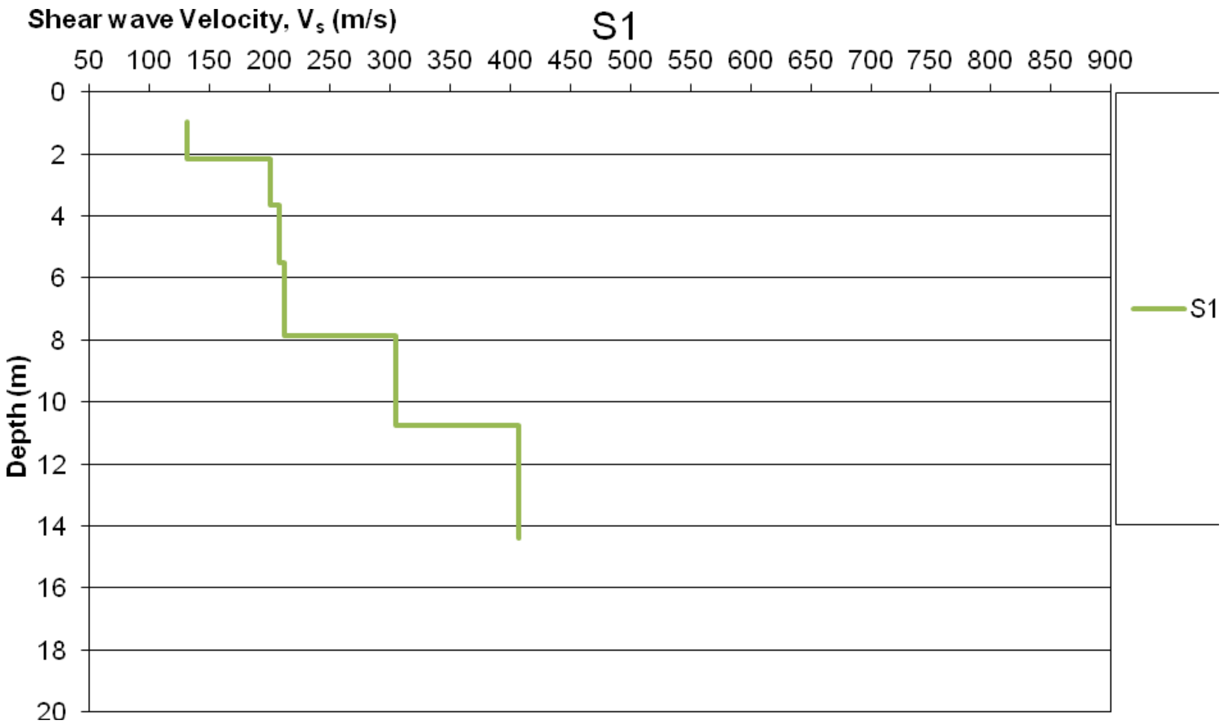


Figure 9.1. Shear wave velocity, Vs for spread S1 / M1

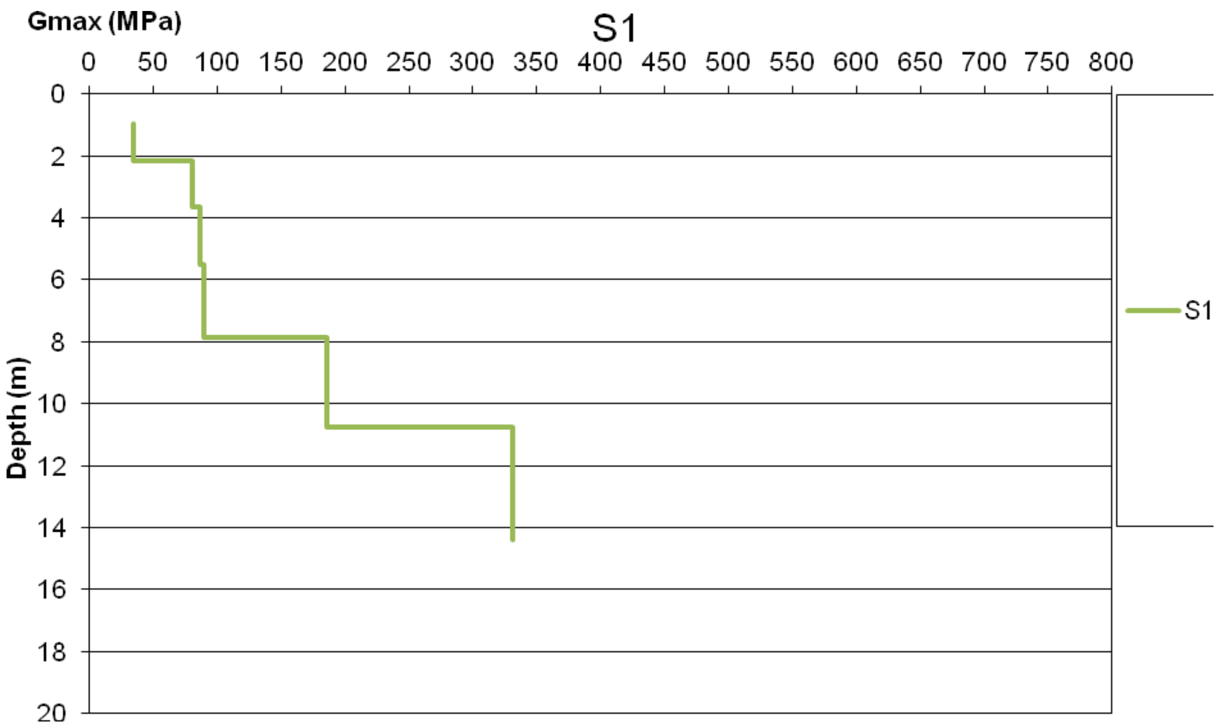


Figure 9.2. Gmax for spread S1 / M1.

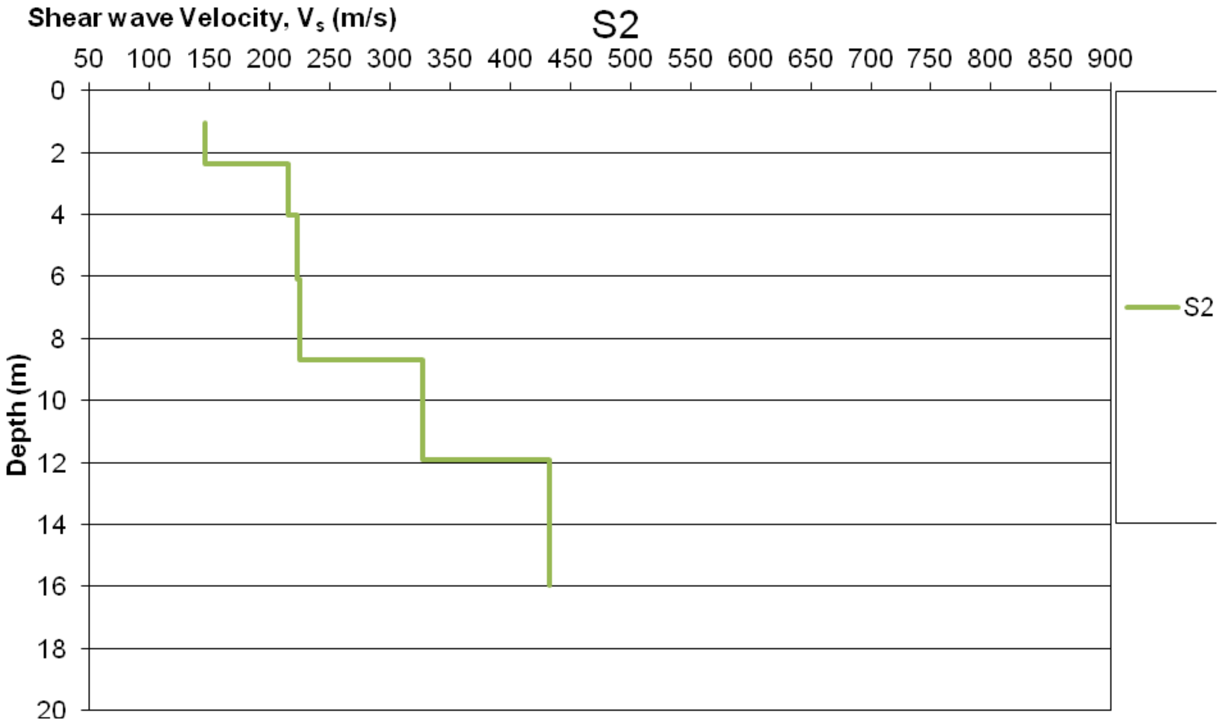


Figure 9.3. Shear wave velocity, Vs for spread S2 / M2.

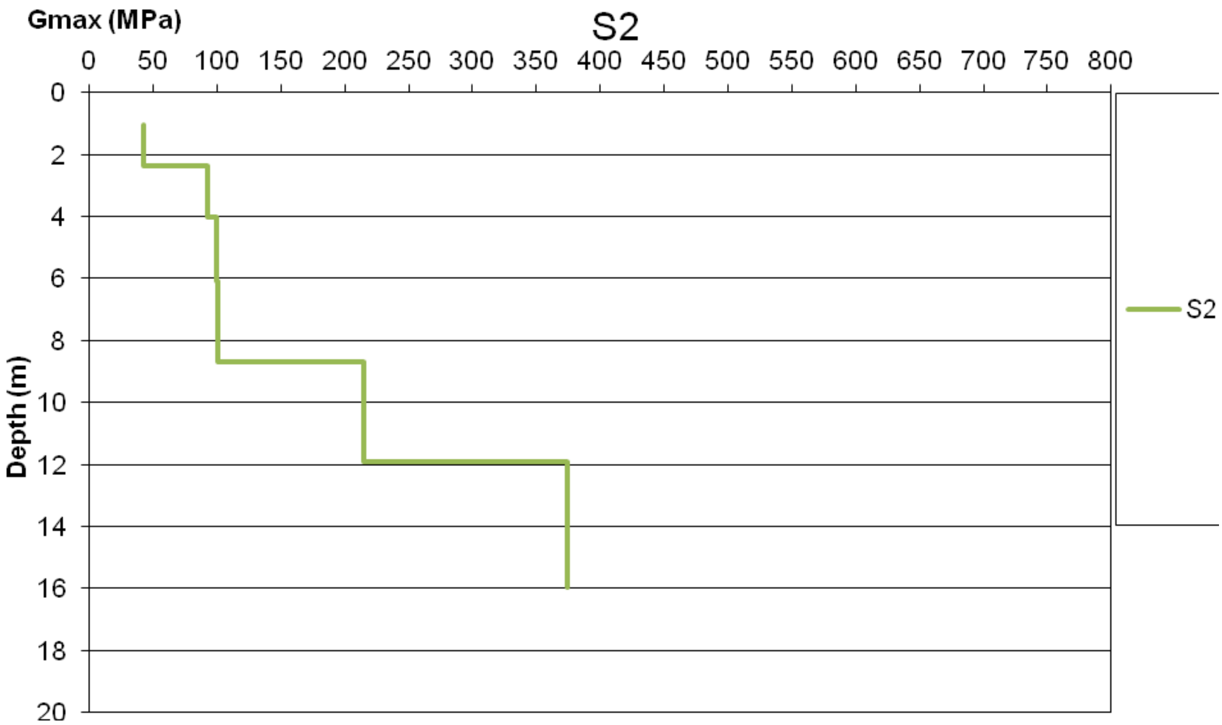


Figure 9.4. Gmax for spread S2 / M2.

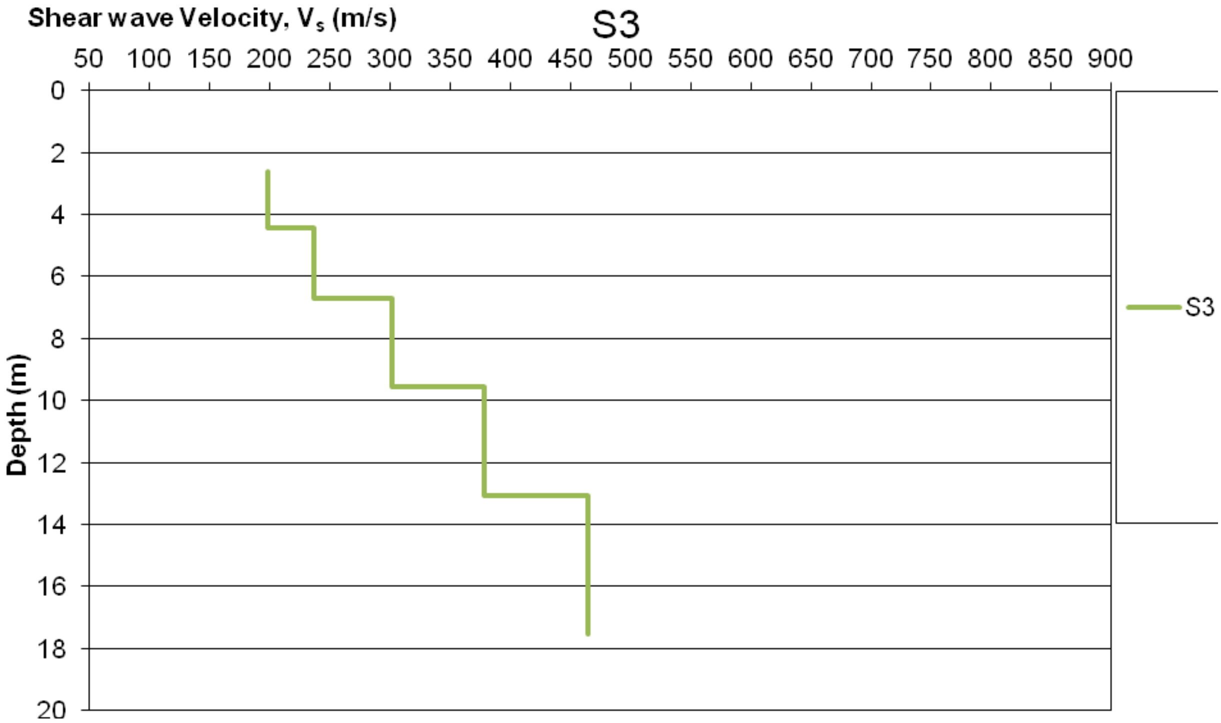


Figure 9.5. Shear wave velocity, Vs for spread S3 / M3.

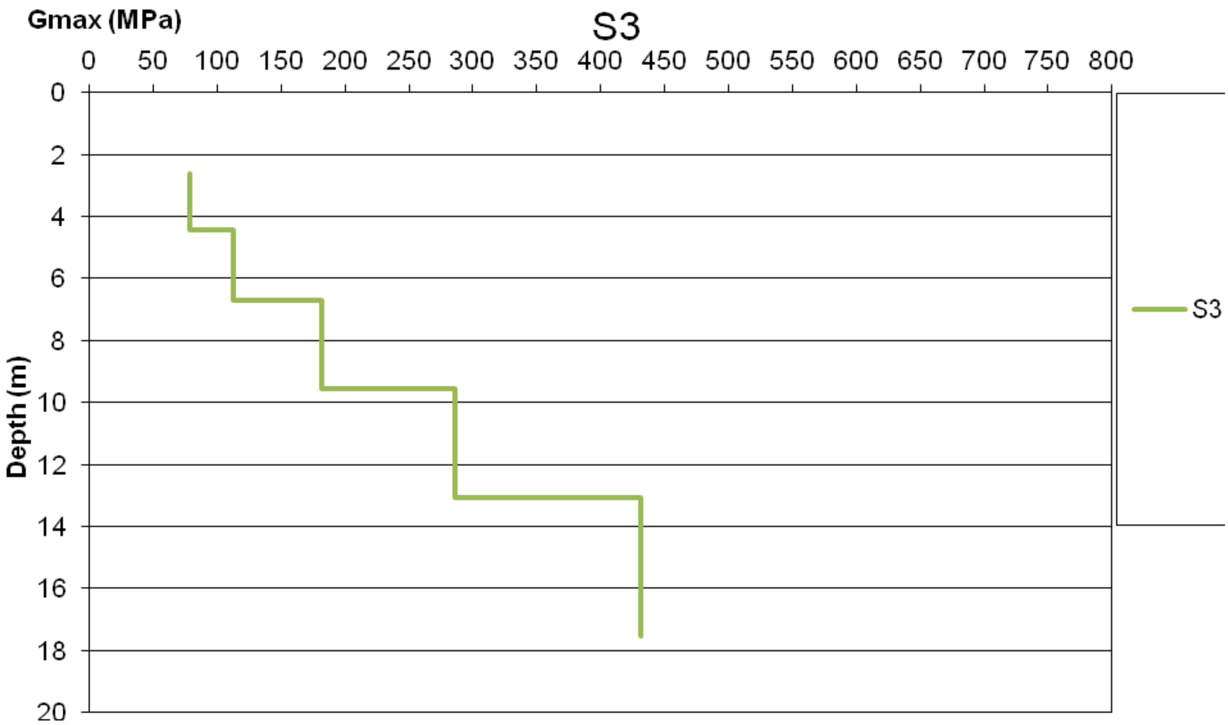


Figure 9.6. Gmax for spread S3 / M3.

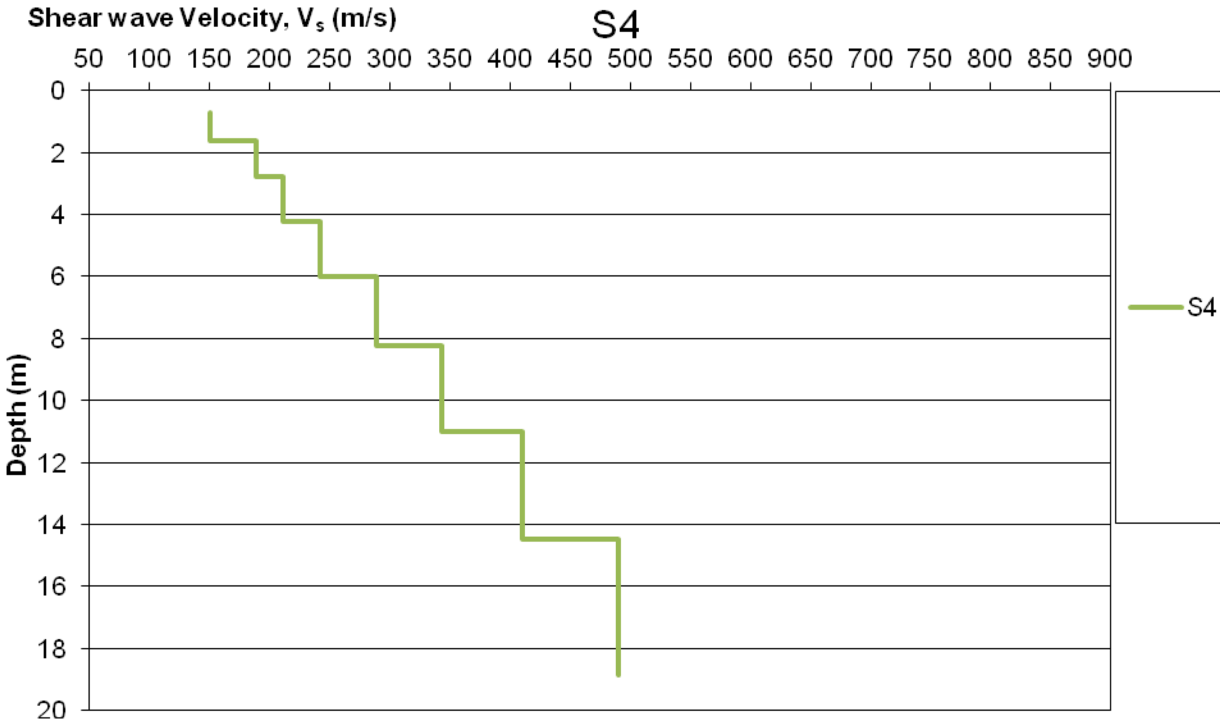


Figure 9.7. Shear wave velocity, Vs for spread S4 / M4.

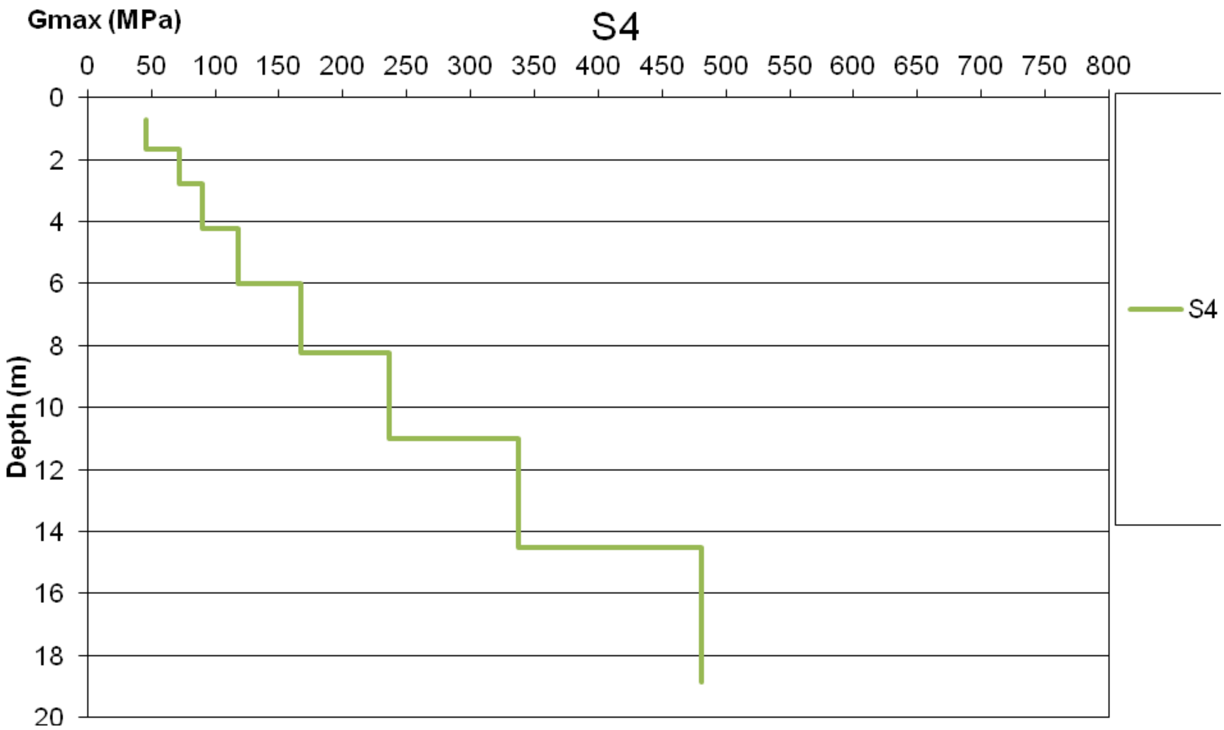


Figure 9.8. Gmax for spread S4 / M4.

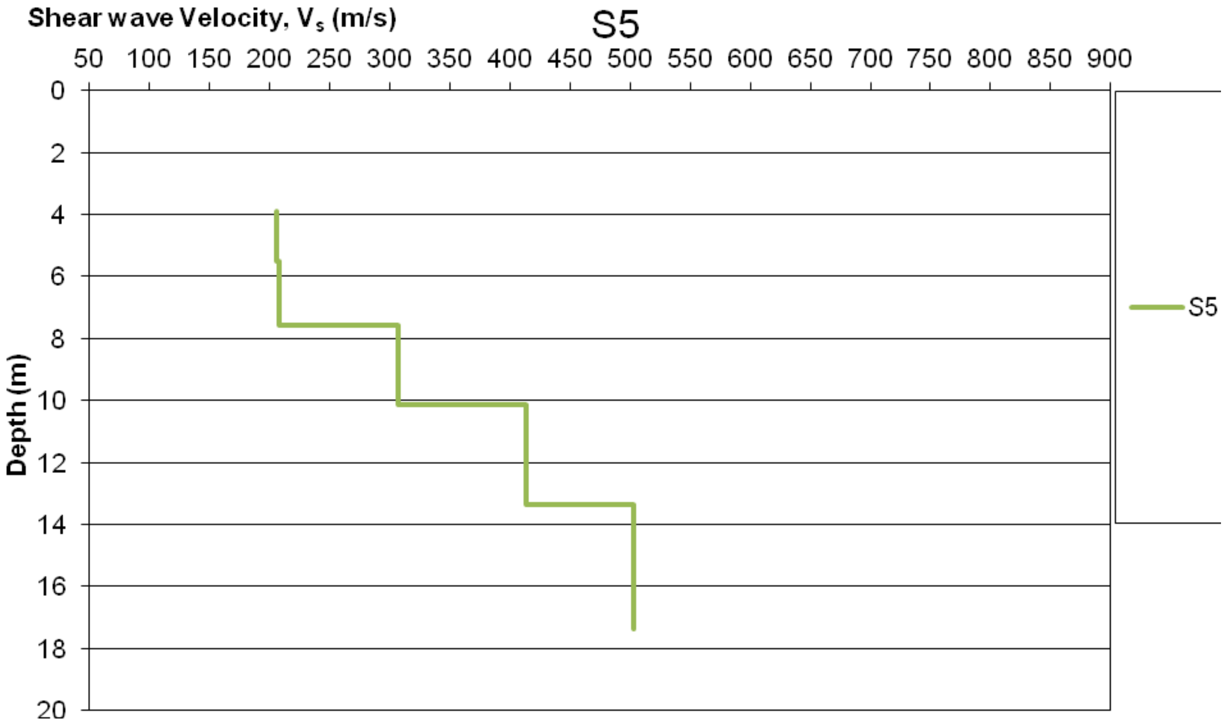


Figure 9.9. Shear wave velocity, Vs for spread S5 / M5

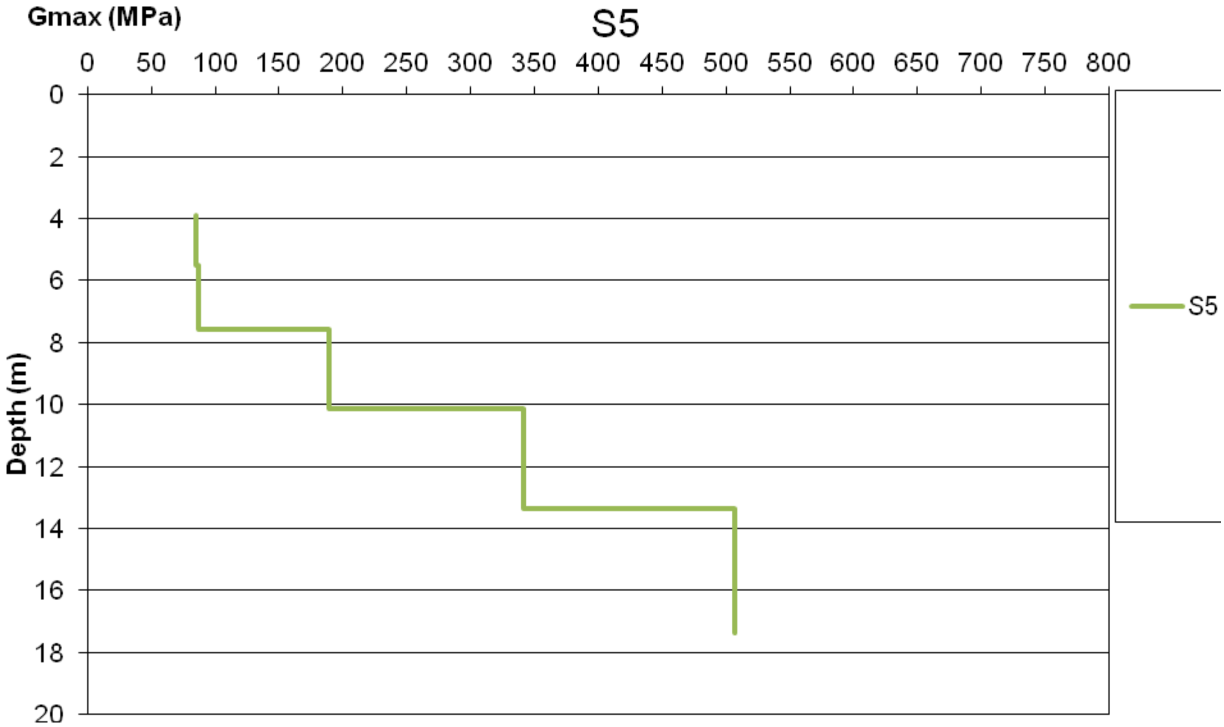


Figure 9.10. Gmax for spread S5 / M5.

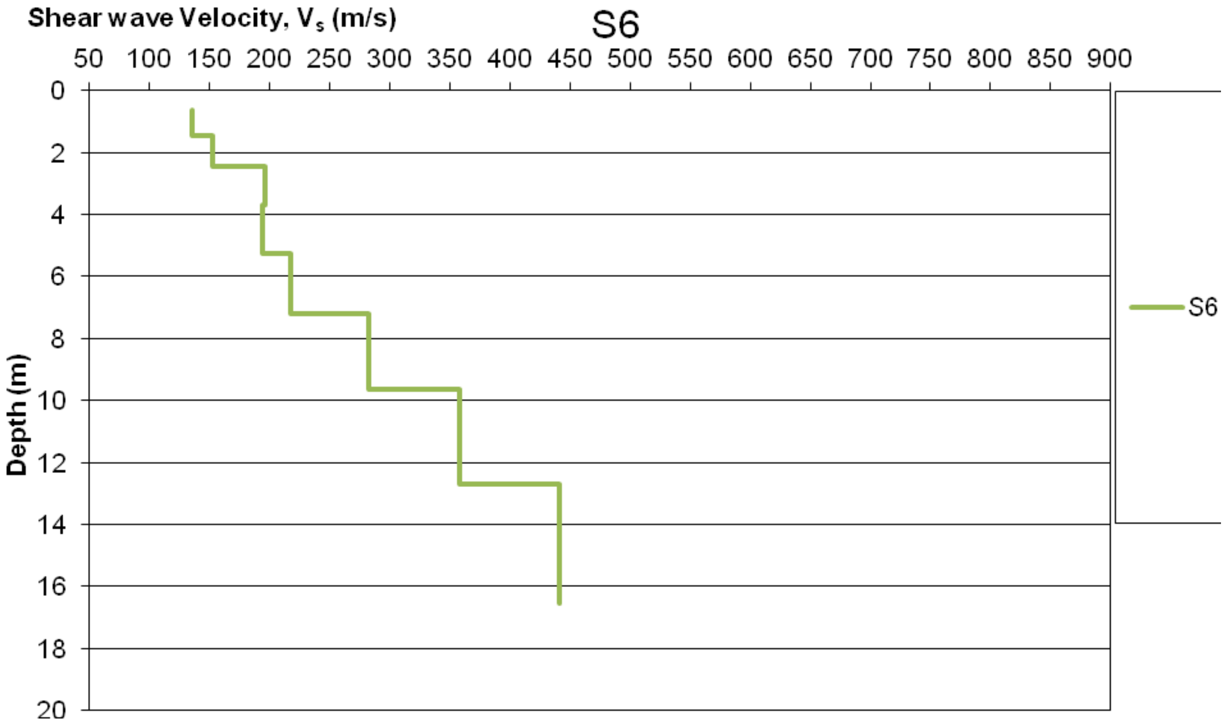


Figure 9.11. Shear wave velocity, Vs for spread S6 / M6.

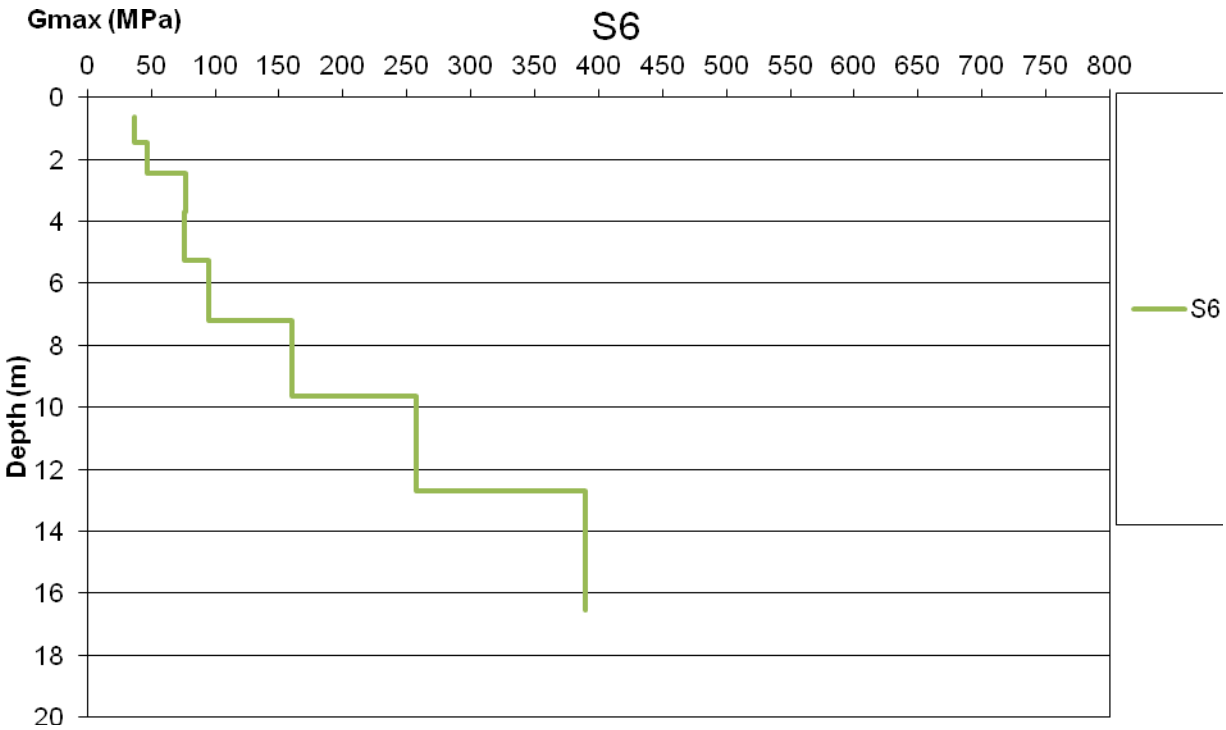


Figure 9.12. Gmax for spread S6 / M6.

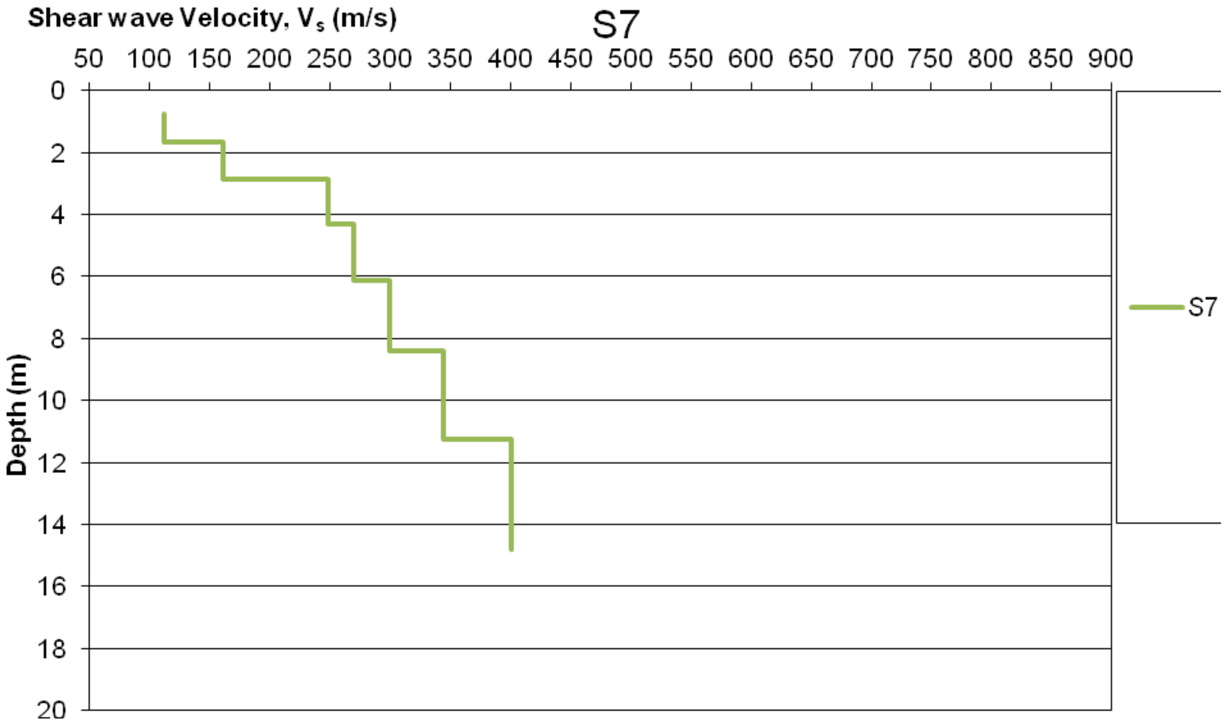


Figure 9.13. Shear wave velocity, Vs for spread S71 / M7.

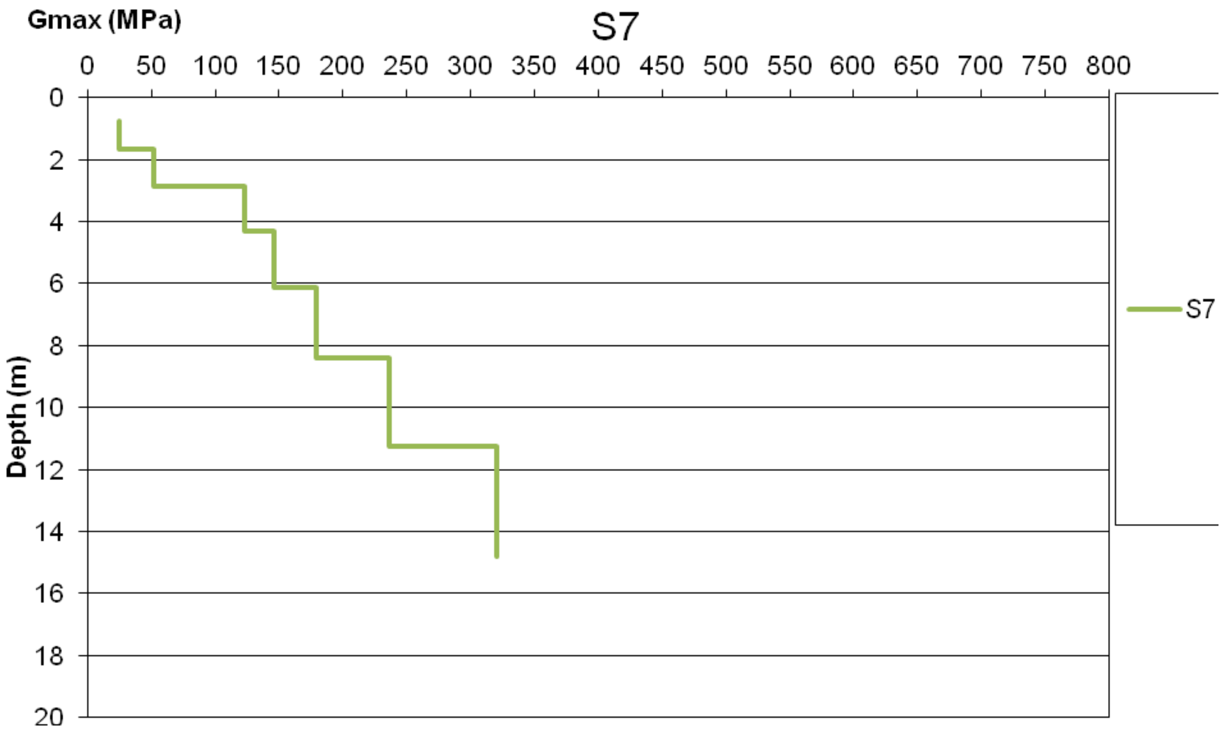


Figure 9.14. Gmax for spread S7 / M7.

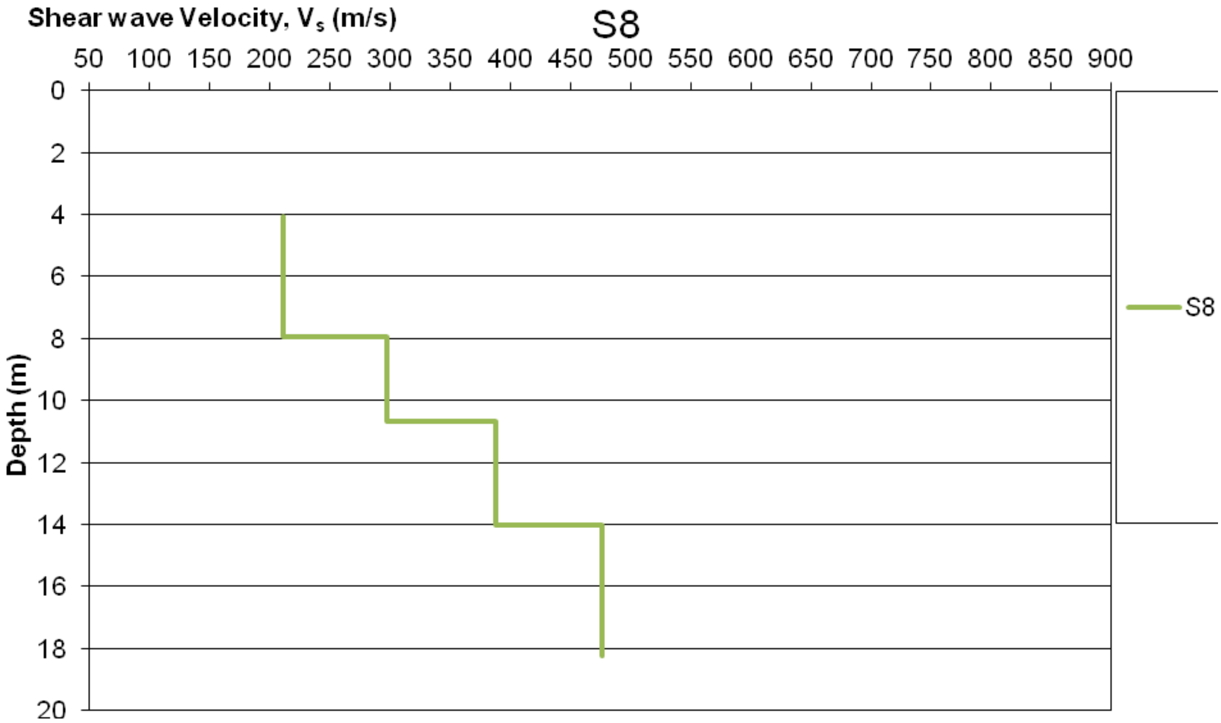


Figure 9.15. Shear wave velocity, Vs for spread S8 / M8.

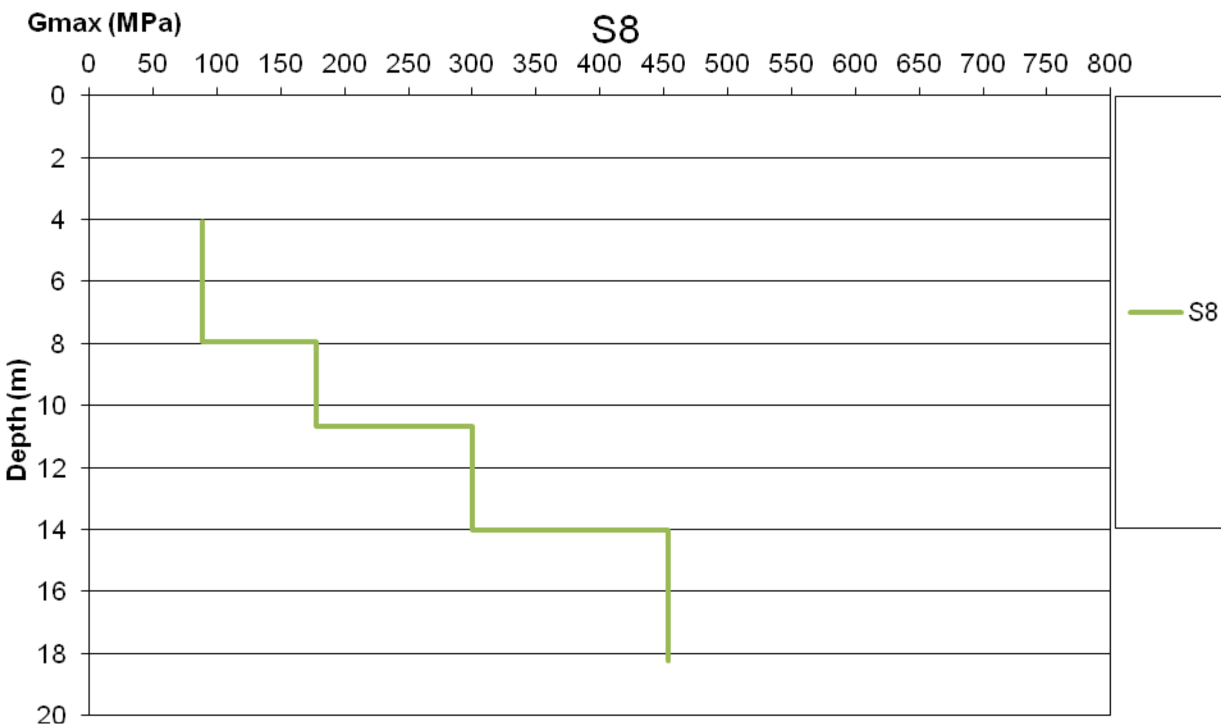


Figure 9.16. Gmax for spread S8 / M8.

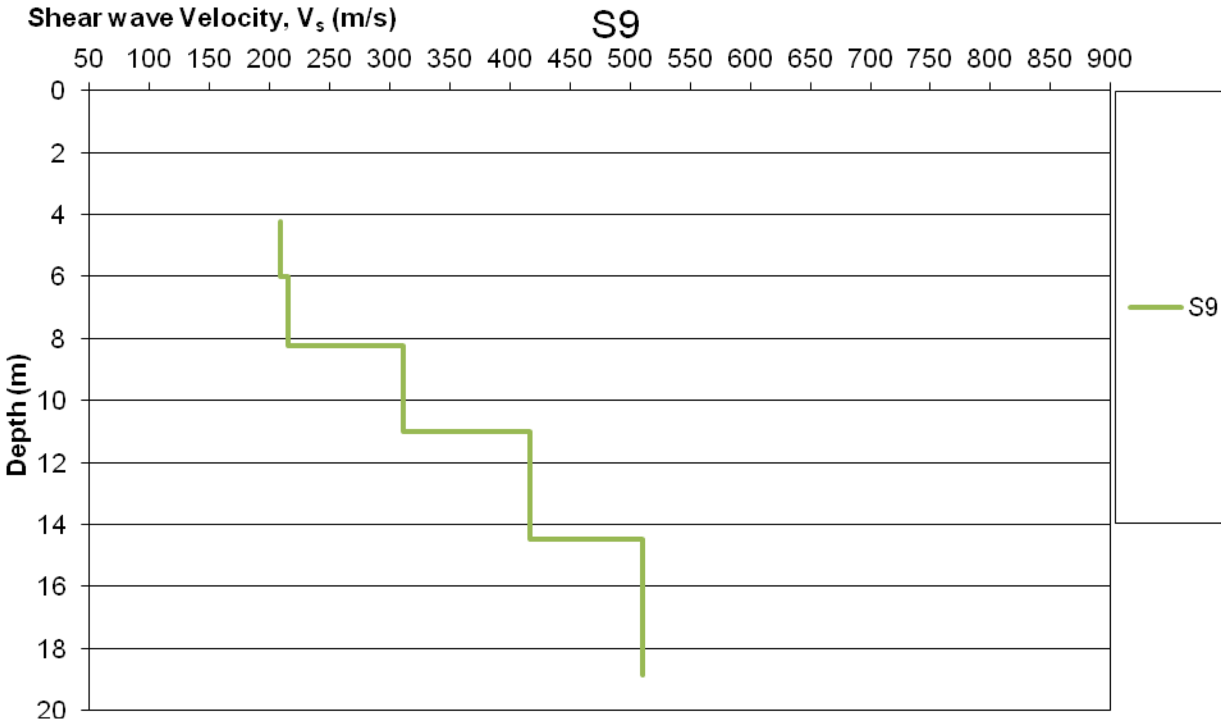


Figure 9.17. Shear wave velocity, Vs for spread S9 / M9.

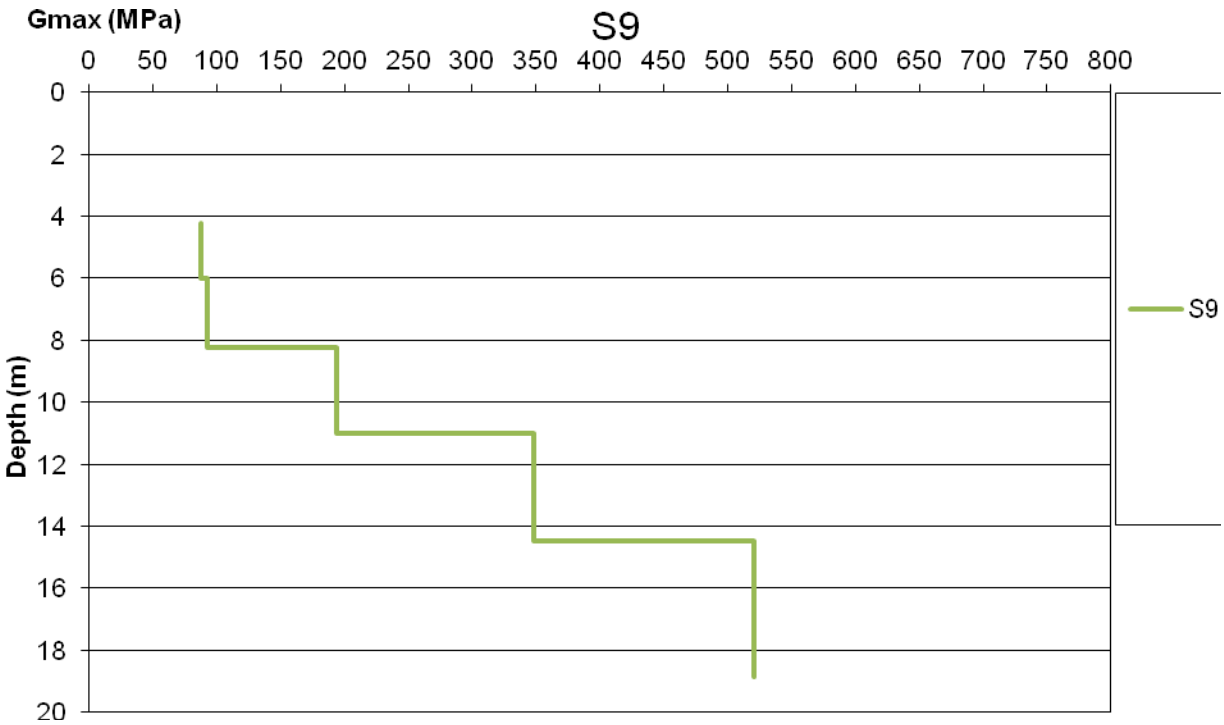


Figure 9.18. Gmax for spread S9 / M9.

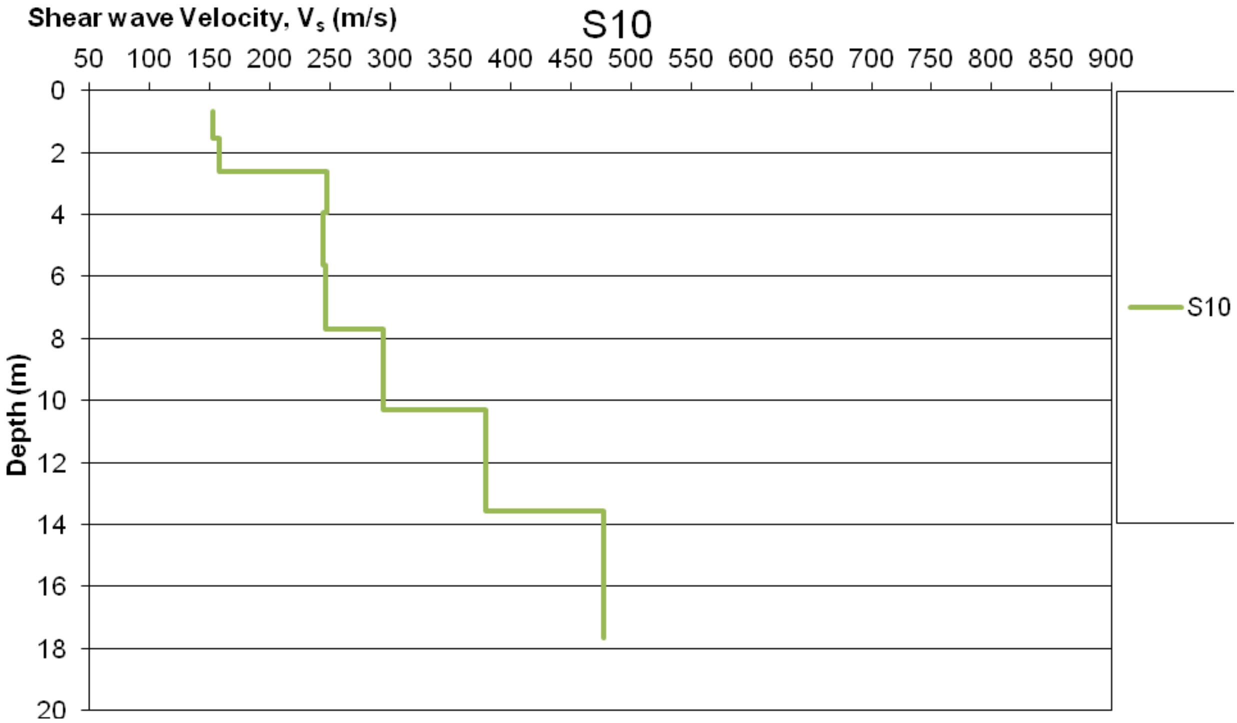


Figure 9.19. Shear wave velocity, Vs for spread S10 / M10.

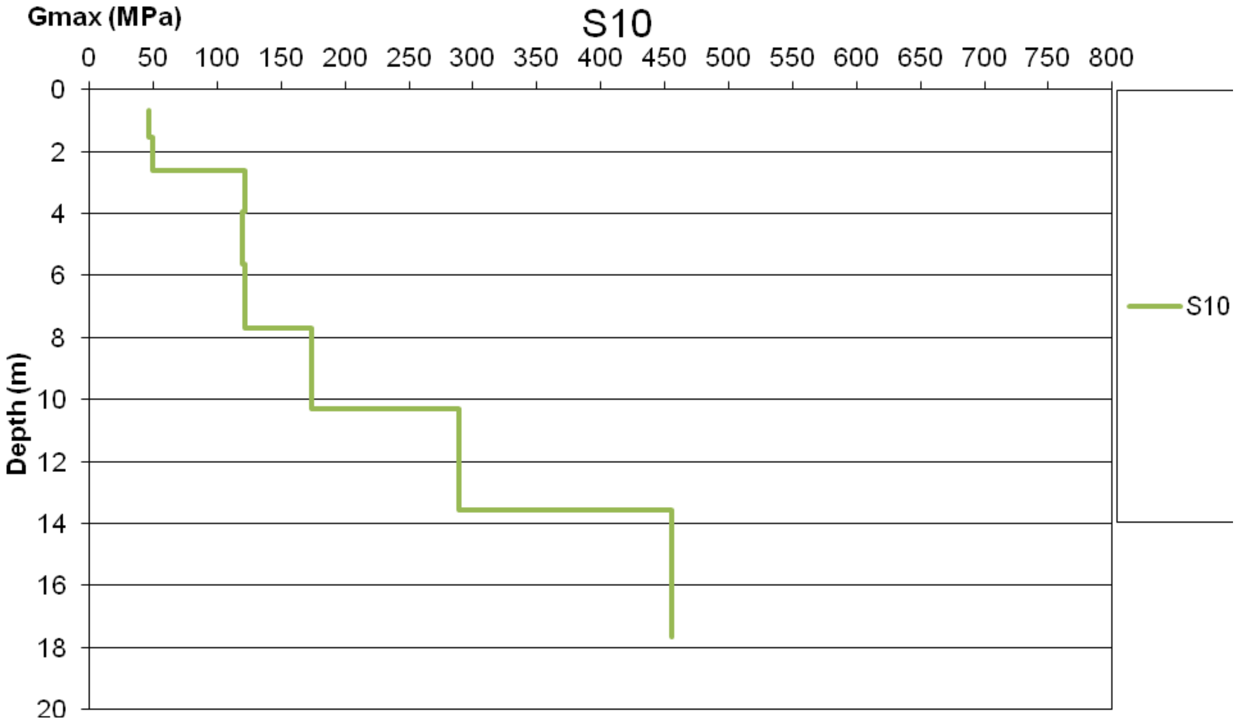


Figure 9.20. Gmax for spread S10 / M10.

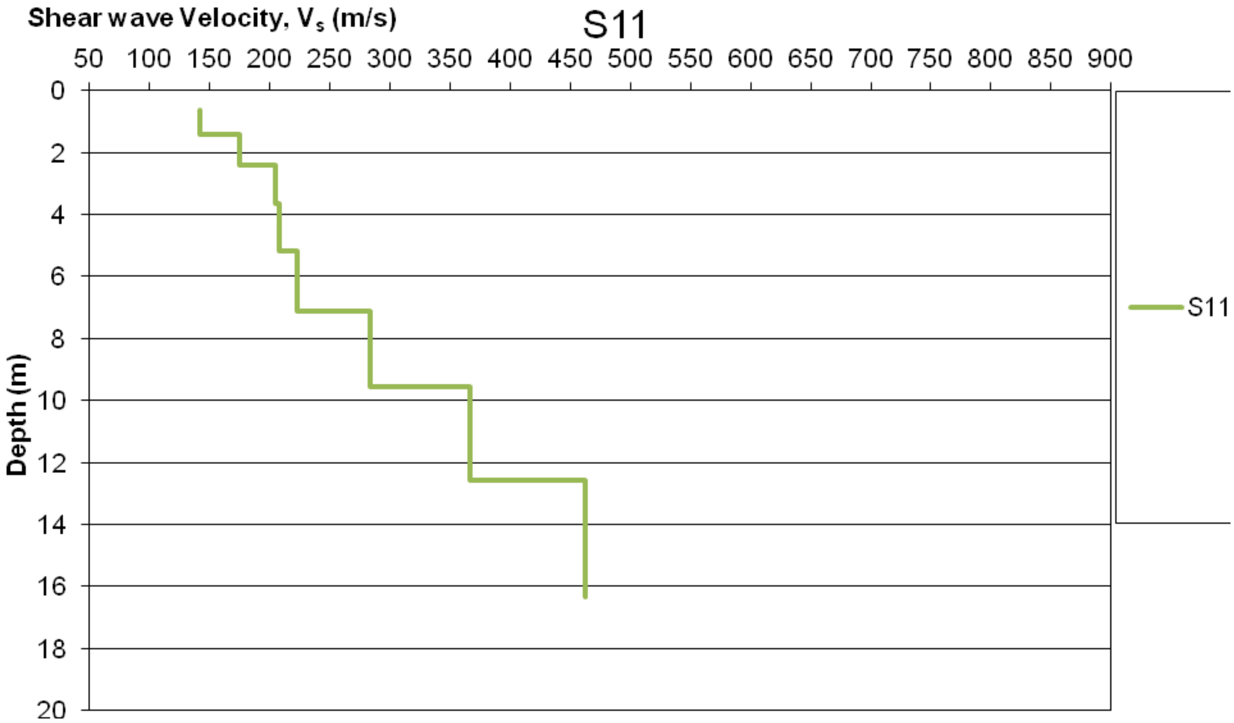


Figure 9.21. Shear wave velocity, Vs for spread S11 / M11.

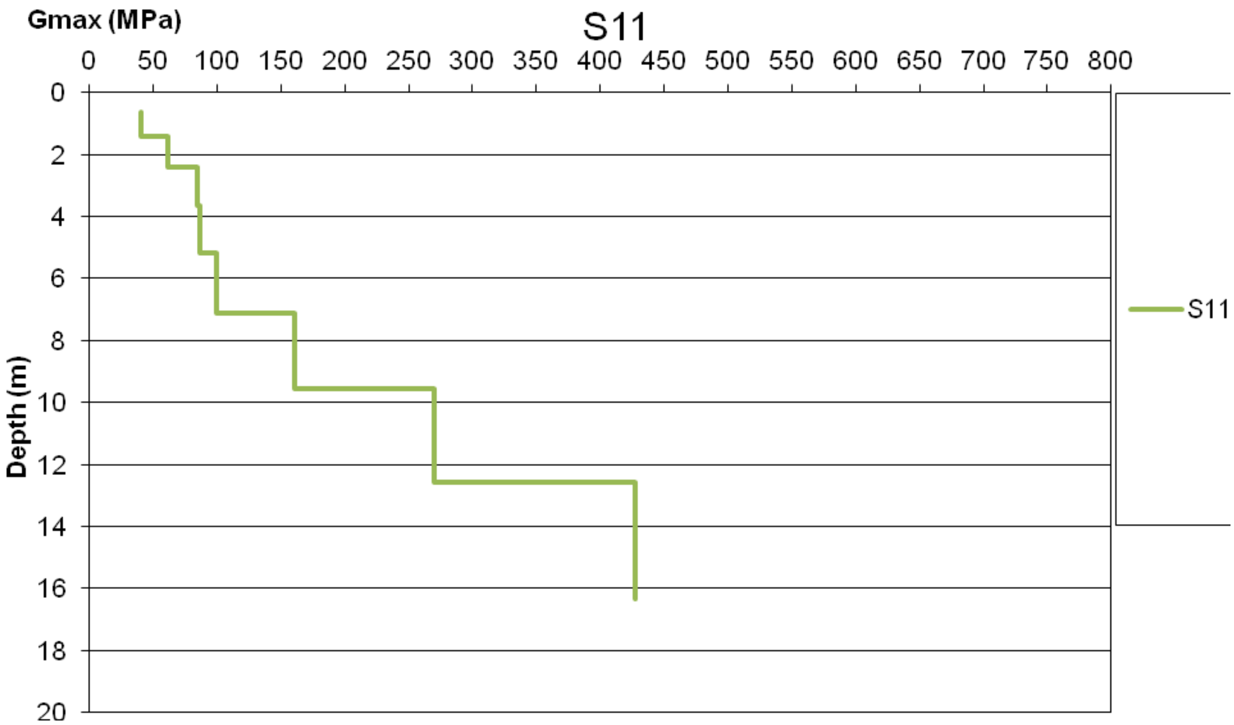


Figure 9.22. Gmax for spread S11 / M11

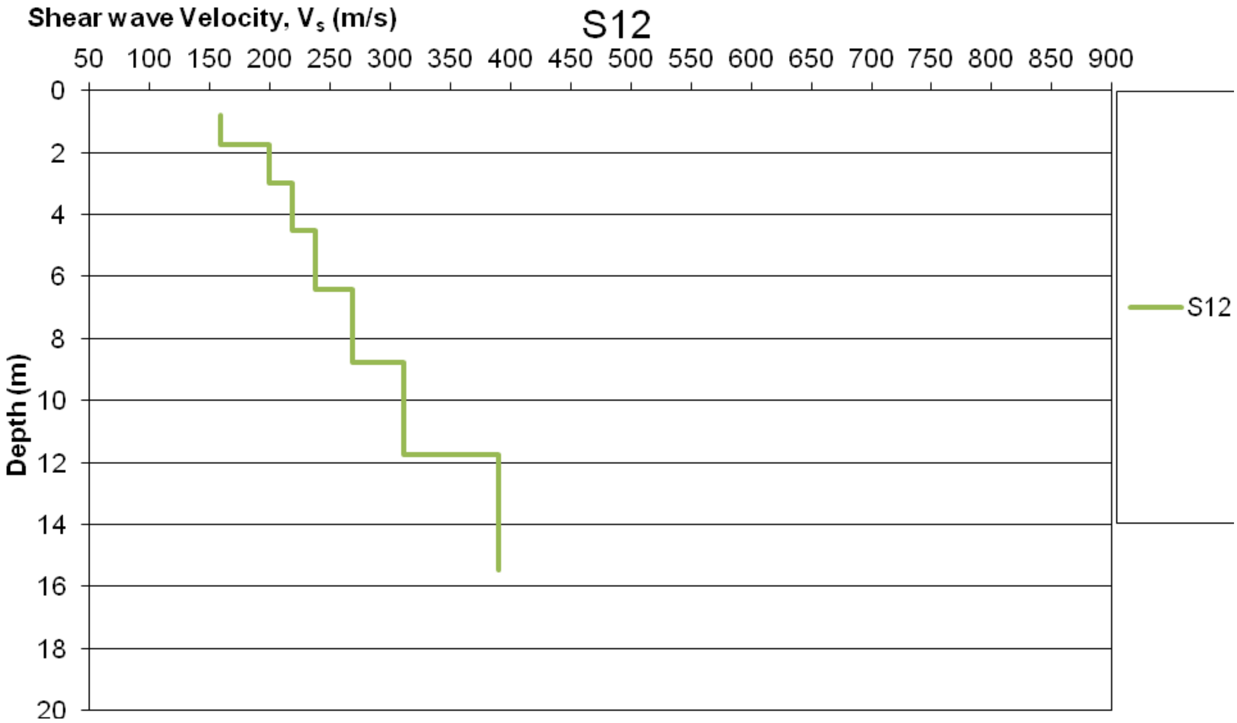


Figure 9.23. Shear wave velocity, Vs for spread S12 / M12.

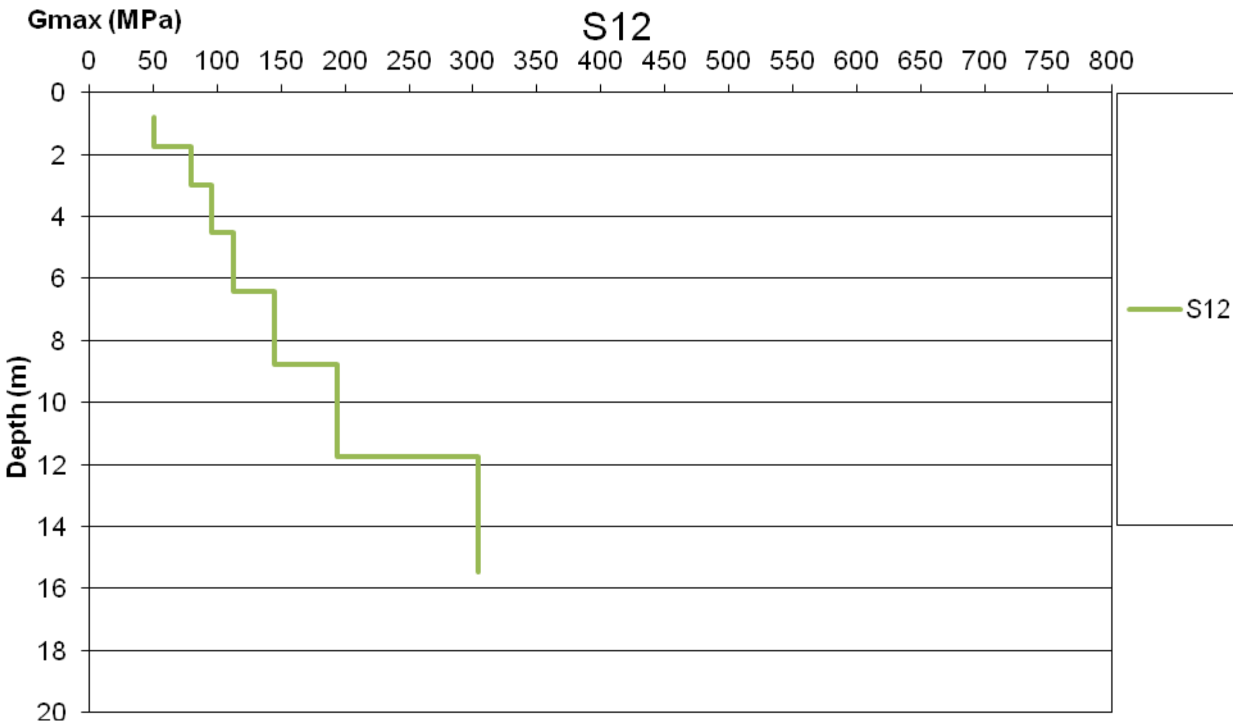


Figure 9.24. Gmax for spread S12 / M12.

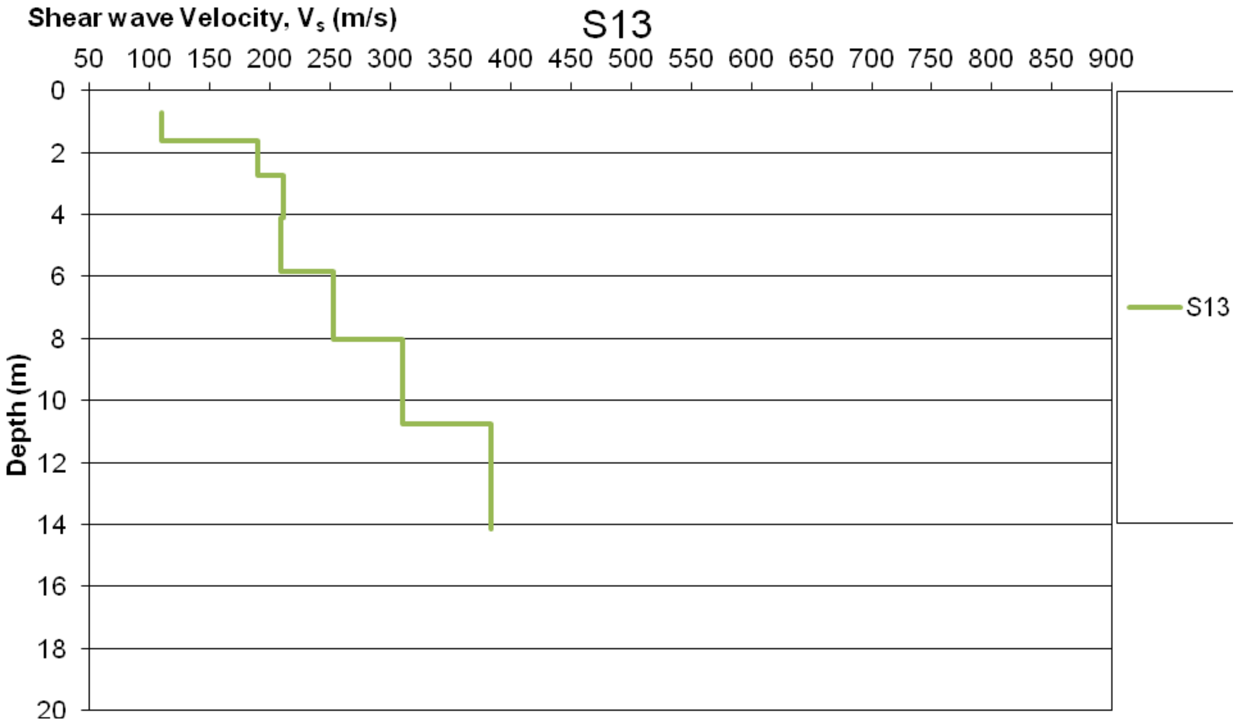


Figure 9.25. Shear wave velocity, Vs for spread S13 / M13.

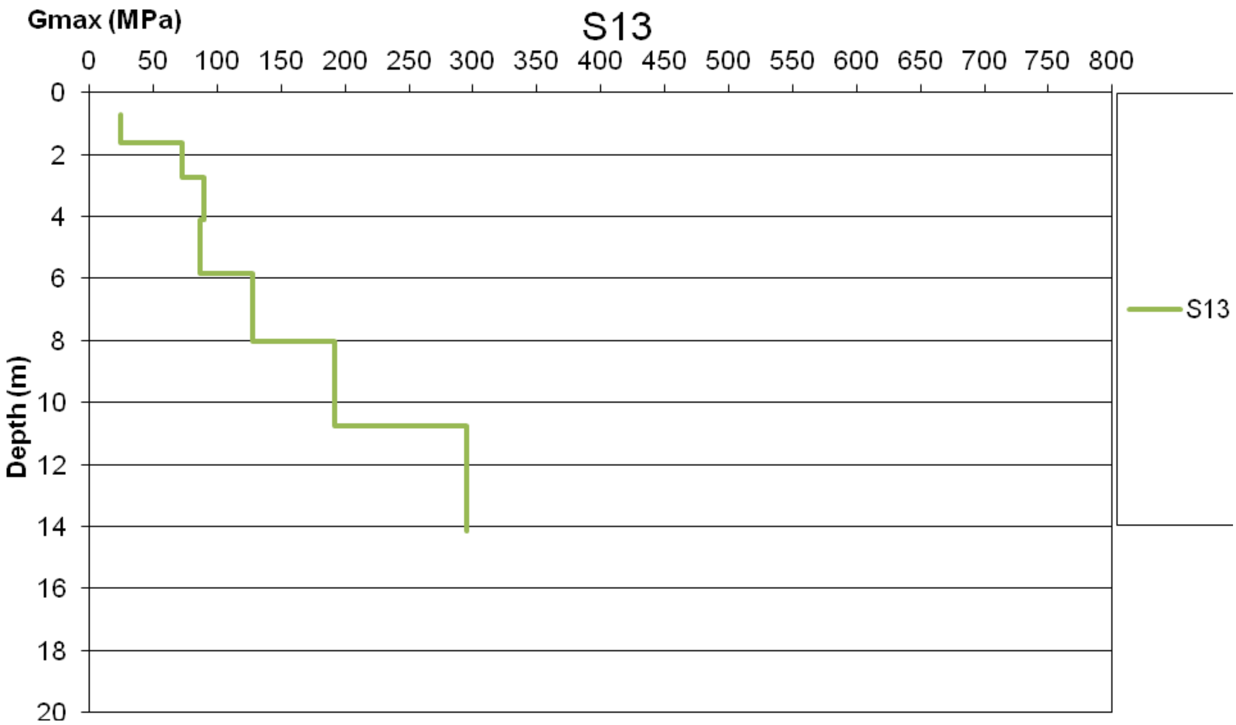


Figure 9.26. Gmax for spread S13 / M13.

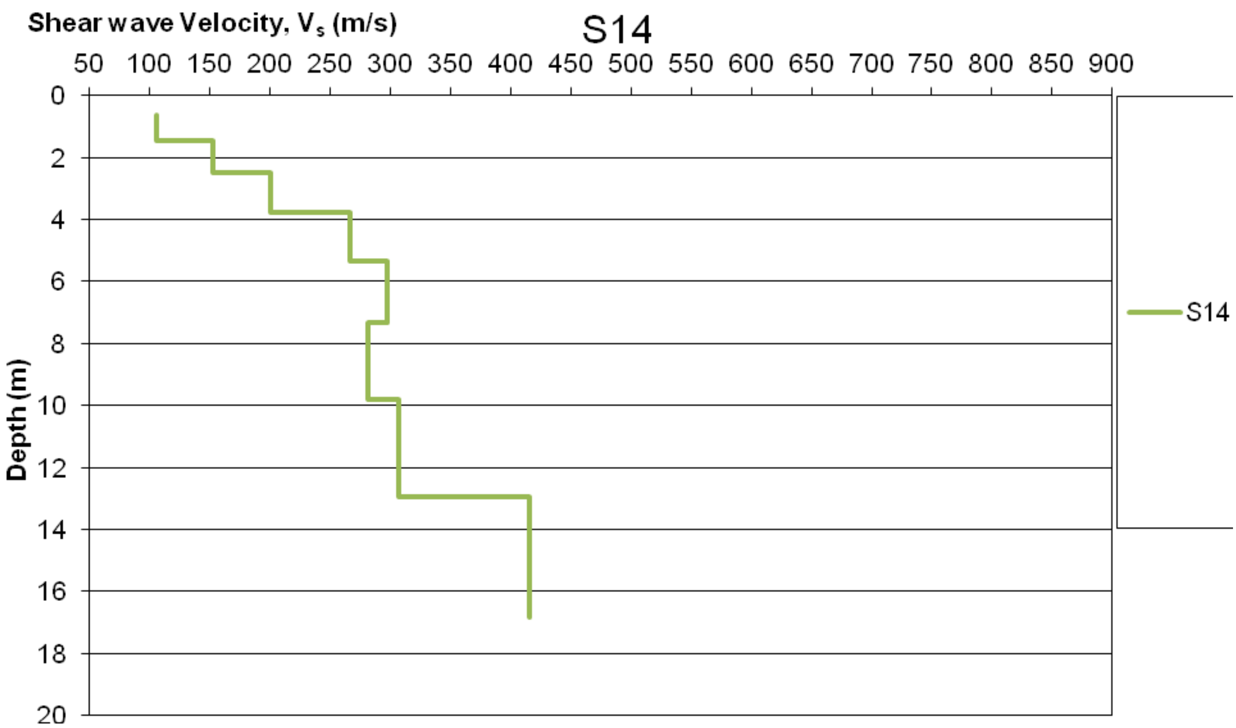


Figure 9.27. Shear wave velocity, Vs for spread S14 / M14.

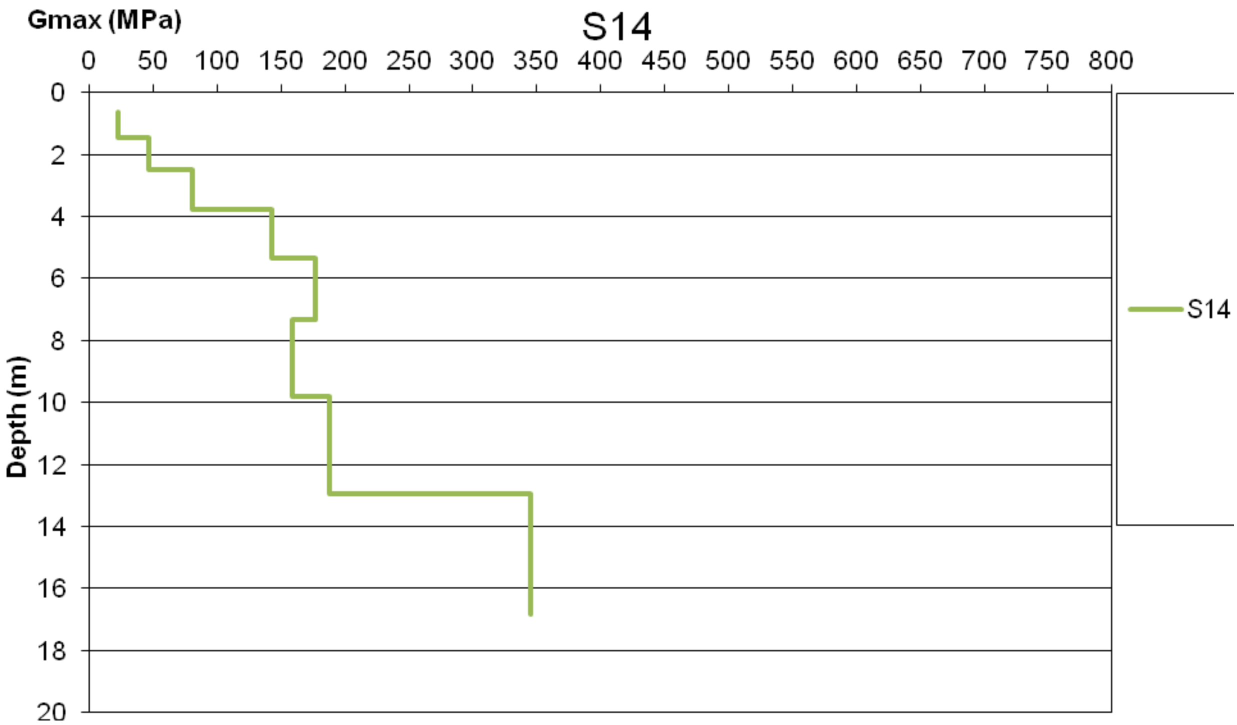


Figure 9.28. Gmax for spread S14 / M14.

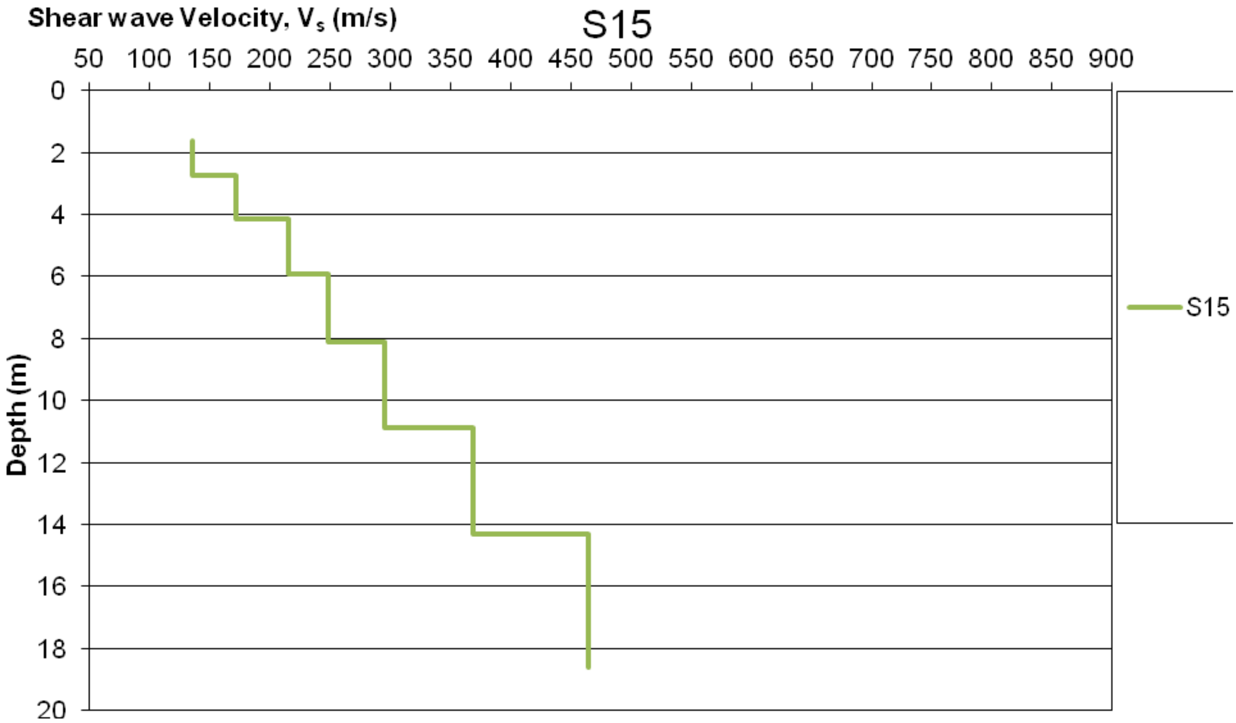


Figure 9.29. Shear wave velocity, Vs for spread S15 / M15.

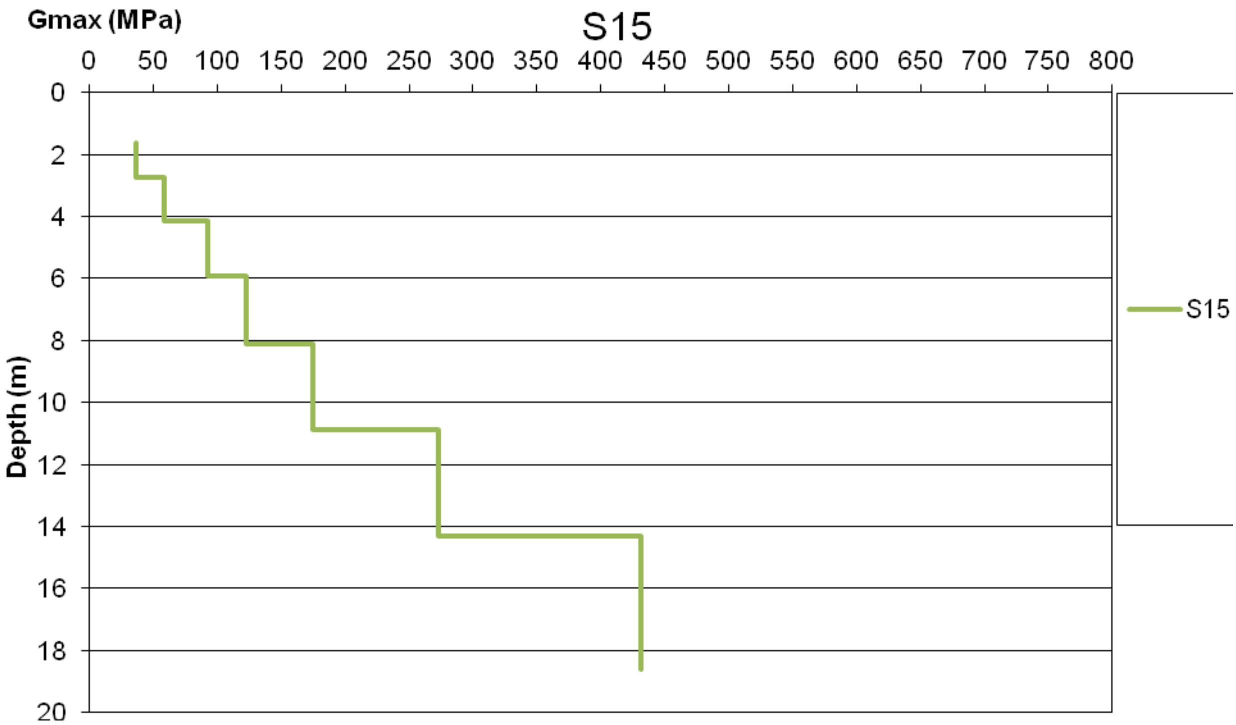


Figure 9.30. Gmax for spread S15 / M15.

9. APPENDIX D: SUMMARY INTERPRETATION TABLES

The information derived from the geophysical investigation at the locations of the 1D MASW soundings on each of the seismic refraction spreads is presented, from west to east across the site, in the attached summary tables.

The depth of overburden and bedrock layer boundaries is based on interpretation of mechanical properties from the seismic refraction and MASW datasets. Due to the nature of the saline environment across the area under investigation the model resistivity lithological boundaries from the ERT data are lower than normally expected, as a result the model resistivity contours are used for guidance only in areas of no seismic refraction and MASW acquisition. However, there is a generally good correlation between the shape of the model resistivity contours and the discrete seismic refraction boundaries.

All available geophysical data and borehole information was used to produce the integrated geological model presented here. The stiff to very stiff overburden material correlates to the sandy gravelly clay layer which is present on the two client supplied boreholes and is assumed to exist across the site.

The information presented in the tables is based on the following calculations and assumed parameters;

- For the overburden layers dynamic moduli, Gmax, was calculated based on a density of 2.0Kg/m^3. Gmax (Mpa) was calculated using the formula;

$$\text{Gmax (Mpa)} = (Vs^2 * \rho) / 100$$

Where Vs = Shear Wave Velocity (m/s)
ρ = Density (kg/m^3)

- The SPT value calculations for sediments are based on Imai et al * (1976) for both granular and cohesive sediments. The SPT values were calculated using the formula;

$$SPT = 0.0011 * Vs2 – 0.1665 * Vs + 7.1017 \text{ (Granular)}$$
$$SPT = 0.2061 * Vs – 23.076 \text{ (cohesive)}$$

- Bedrock R.Q.D calculations are based on Deere et al. ** (1967).

- Estimated stiffness and bedrock quality are based on Imai et al 1976.

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M1

Site	Portmarnock Golf Course
Data Location	**M1**

Location (ING)	
Easting	324961.9
Northing	242368.2
Elevation (mOD)	3.53

Methodology		
Seismic Refraction	24 ch. @ 3m geophones	
MASW	24 ch. @ 3m geophones	
ERT	96 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

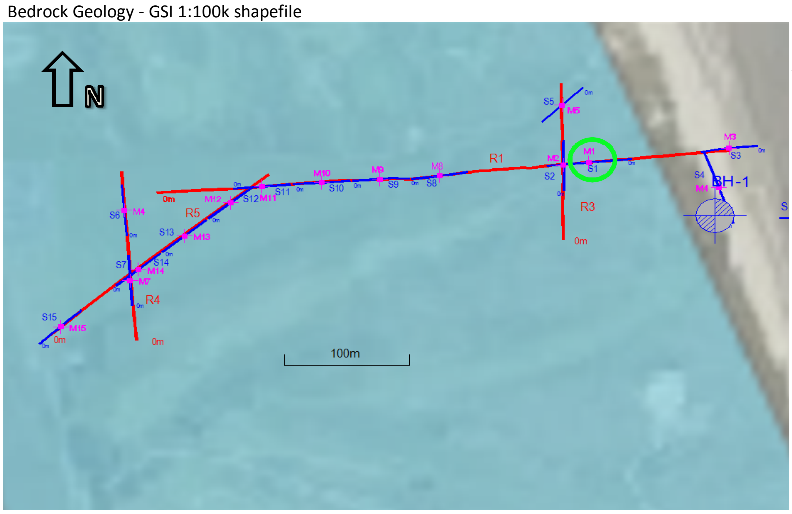
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	0.9	-	363	-	-	-	-	-	Overburden Silty SAND	-	Diggable	-
0.9	2.2	131	421	2000	0.45	34.34	0.10	0.89	Overburden Silty SAND	VERY LOOSE to LOOSE	Diggable	**4 N (SPT)**
2.2	3.6	201	732	2000	0.46	80.81	0.24	3.69	Overburden Silty SAND	MEDIUM DENSE	Diggable	**18 N (SPT)**
3.6	5.5	208	1008	2000	0.48	86.55	0.26	4.22	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
5.5	7.8	212	1372	2000	0.49	89.92	0.27	4.54	Overburden Silty SAND	MEDIUM DENSE	Diggable	**21 N (SPT)**
7.8	10.0	305	1875	2000	0.49	186.18	0.55	15.07	Overburden Silty SAND	VERY DENSE	Diggable	**>50 N (SPT)**
10.0	12.4	407	1875	2000	0.48	331.48	0.98	38.56	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
12.4	14.4	407	2175	2500	0.48	414.35	1.23	56.14	Moderately Weathered LIMESTONE	VERY POOR	Break / Blast	**23 RQD**
14.4	18.0	665	2835	2700	0.47	1193.75	3.51	317.82	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**39 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M1

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M2

Site	Portmarnock Golf Course
Data Location	**M2**

Location (ING)	
Easting	324941.6
Northing	242365.9
Elevation (mOD)	3.0

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	32 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

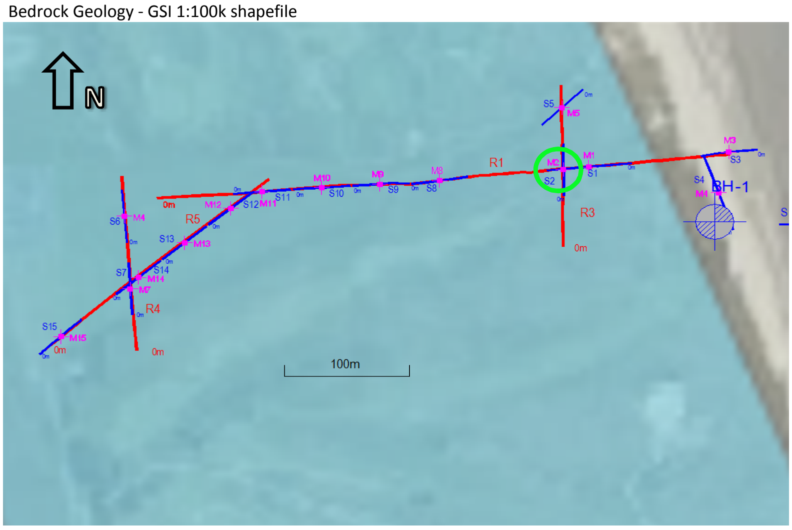
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.1	-	397	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.1	2.4	147	501	2000	0.45	42.96	0.12	1.29	Overburden Silty SAND	LOOSE	Diggable	**6 N (SPT)**
2.4	4.0	215	772	2000	0.46	92.45	0.27	4.60	Overburden Silty SAND	MEDIUM DENSE	Diggable	**22 N (SPT)**
4.0	6.1	223	1146	2000	0.48	99.69	0.30	5.34	Overburden Silty SAND	MEDIUM DENSE	Diggable	**24 N (SPT)**
6.1	9.2	225	1656	2000	0.49	100.95	0.30	5.52	Overburden Silty SAND	MEDIUM DENSE	Diggable	**25 N (SPT)**
9.2	11.2	328	1926	2000	0.49	214.87	0.64	19.06	Overburden Sandy Gravelly CLAY	STIFF to VERY STIFF	Diggable	**44 N (SPT)**
11.2	15.6	432	1928	2000	0.47	374.03	1.10	46.97	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
15.6	17.6	-	2311	2500	-	-	-	-	Moderately Weathered LIMESTONE	POOR	Break / Blast	**26 RQD**
17.6	19.9	-	2730	2700	-	-	-	-	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**36 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M2

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M3

Site	Portmarnock Golf Course
Data Location	**M3**

Location (ING)	
Easting	325074.5
Northing	242381.3
Elevation (mOD)	1.17

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	96 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

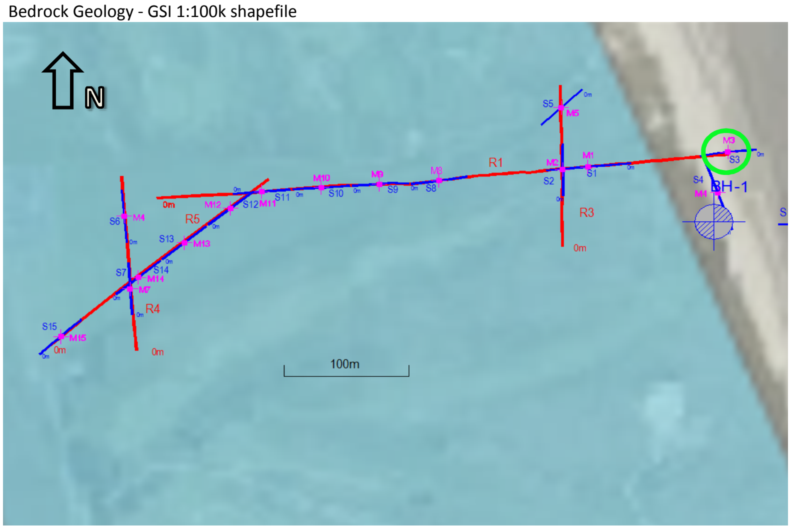
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.0	-	837	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.0	2.6	-	1035	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
2.6	4.4	198	1660	2000	0.49	78.63	0.23	3.66	Overburden Silty SAND	MEDIUM DENSE	Diggable	**17 N (SPT)**
4.4	6.9	237	1718	2000	0.49	112.56	0.34	6.60	Overburden Silty SAND	MEDIUM DENSE	Diggable	**29 N (SPT)**
6.9	10.7	302	1843	2000	0.49	181.90	0.54	14.50	Overburden Sandy Gravelly CLAY	STIFF	Diggable	**39 N (SPT)**
10.7	13.1	378	2344	2000	0.49	286.18	0.85	30.64	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
13.1	17.5	465	2829	2500	0.49	539.54	1.60	87.20	Moderately Weathered LIMESTONE	POOR	Break / Blast	**39 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M3

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M4

Site	Portmarnock Golf Course
Data Location	**M4**

Location (ING)	
Easting	325066.3
Northing	242345.6
Elevation (mOD)	2.49

Methodology		
Seismic Refraction	24 ch. @ 3m geophones	
MASW	24 ch. @ 3m geophones	
ERT	96 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

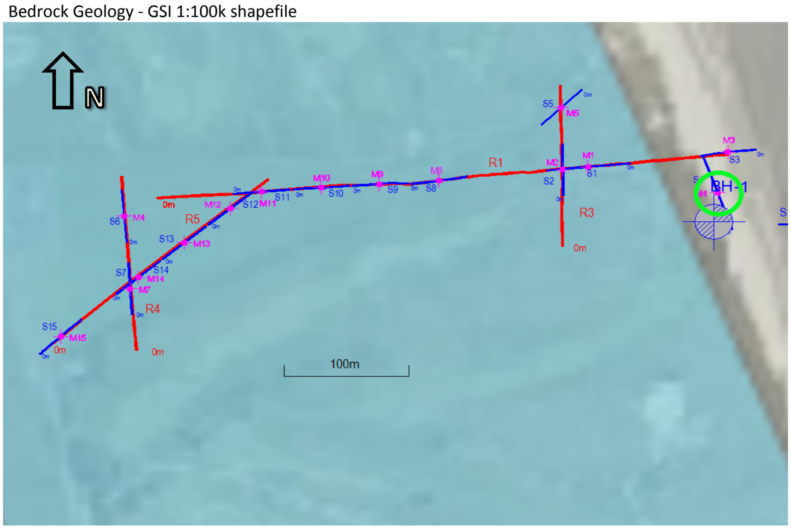
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	0.7	-		2000	-	-	-	-	Overburden Silty SAND		Diggable	-
0.7	1.6	151	1064	2000	0.49	45.47	0.14	1.48	Overburden Silty SAND	LOOSE	Diggable	**7 N (SPT)**
1.6	2.8	189	1493	2000	0.49	71.69	0.21	3.14	Overburden Silty SAND	MEDIUM DENSE	Diggable	**15 N (SPT)**
2.8	4.2	212	1614	2000	0.49	89.57	0.27	4.53	Overburden Silty SAND	MEDIUM DENSE	Diggable	**21 N (SPT)**
4.2	6.0	242	1635	2000	0.49	117.60	0.35	7.08	Overburden Silty SAND	MEDIUM DENSE to DENSE	Diggable	**31 N (SPT)**
6.0	8.2	289	1772	2000	0.49	166.71	0.50	12.56	Overburden Silty SAND	DENSE	Diggable	**50 N (SPT)**
8.2	11.0	344	1977	2000	0.48	236.09	0.70	22.25	Overburden Sandy Gravelly CLAY	STIFF to VERY STIFF	Diggable	**47 N (SPT)**
11.0	14.8	411	2298	2000	0.48	337.57	1.00	40.10	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
14.8	19.5	-	2996	2500	-	-	-	-	Moderately Weathered LIMESTONE	POOR	Break / Blast	**44 RQD**
19.5	20.3	-	3887	2700	-	-	-	-	Slightly Weathered -Fresh LIMESTONE	FAIR	Heavy Break / Blast	**74 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M4

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M5

Site	Portmarnock Golf Course
Data Location	**M5**

Location (ING)	
Easting	324940.6
Northing	242420.2
Elevation (mOD)	3.84

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	32 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

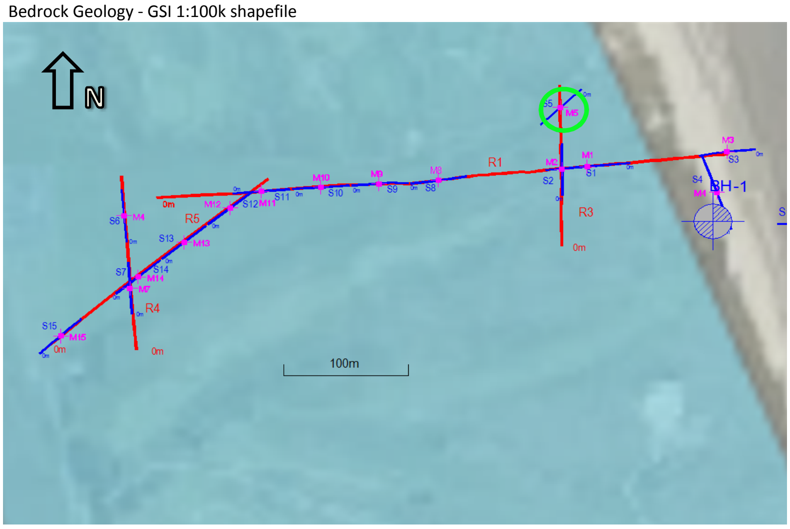
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.1	-		2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.1	2.6	-	773	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
2.6	3.8	-	1297	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
3.8	5.5	206	1636	2000	0.49	84.63	0.25	4.13	Overburden Silty SAND	MEDIUM DENSE	Diggable	**19 N (SPT)**
5.5	7.6	208	1744	2000	0.49	86.68	0.26	4.30	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
7.6	10.1	307	1774	2000	0.48	189.10	0.56	15.43	Overburden Sandy Gravelly CLAY	STIFF	Diggable	**40 N (SPT)**
10.1	13.3	413	2218	2000	0.48	341.32	1.01	40.77	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
13.3	17.4	503	2585	2500	0.48	633.00	1.87	112.76	Moderately Weathered LIMESTONE	POOR	Break / Blast	**33 RQD**
17.4	20.4	-	3666	2700	-	-	-	-	Slightly Weathered -Fresh LIMESTONE	FAIR	Heavy Break / Blast	**66 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M5

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M6

Site	Portmarnock Golf Course
Data Location	**M6**

Location (ING)	
Easting	324589.5
Northing	242325.0
Elevation (mOD)	2.67

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	32 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

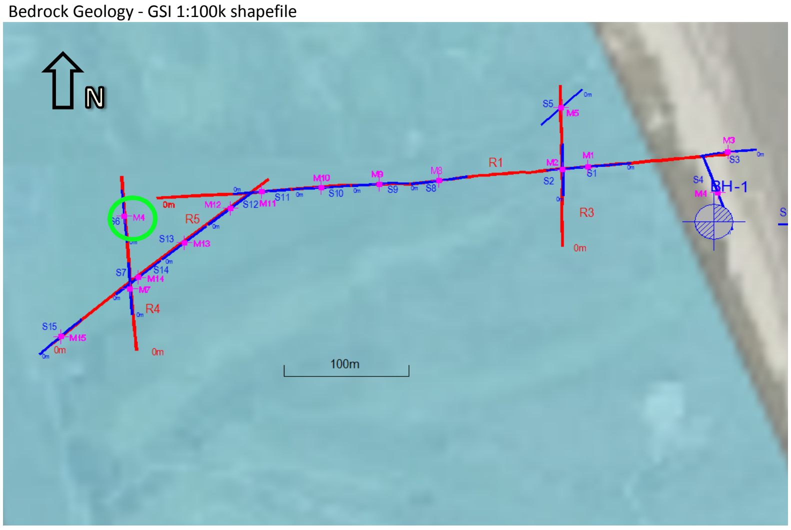
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.4	-	490	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.4	2.4	152	785	2000	0.48	46.39	0.14	1.51	Overburden Silty SAND	LOOSE	Diggable	**7 N (SPT)**
2.4	3.7	196	1042	2000	0.48	77.11	0.23	3.50	Overburden Silty SAND	MEDIUM DENSE	Diggable	**16 N (SPT)**
3.7	5.3	194	1406	2000	0.49	75.41	0.22	3.41	Overburden Silty SAND	MEDIUM DENSE	Diggable	**16 N (SPT)**
5.3	7.2	218	1706	2000	0.49	95.15	0.28	5.01	Overburden Silty SAND	MEDIUM DENSE	Diggable	**23 N (SPT)**
7.2	9.6	283	1740	2000	0.49	160.18	0.48	11.76	Overburden Silty SAND	DENSE	Diggable	**48 N (SPT)**
9.6	11.9	358	2078	2000	0.48	256.92	0.76	25.59	Overburden Sandy Gravelly CLAY	STIFF to VERY STIFF	Diggable	**50 N (SPT)**
11.9	15.6	441	2395	2500	0.48	486.45	1.44	73.20	Moderately Weathered LIMESTONE	POOR	Break / Blast	**28 RQD**
15.6	16.5	-	3016	2700	-	-	-	-	Slightly Weathered -Fresh LIMESTONE	POOR	Heavy Break / Blast	**44 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M6

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M7

apex geoservices

Site	Portmarnock Golf Course
Data Location	**M7**

Location (ING)	
Easting	324594.3
Northing	242261.4
Elevation (mOD)	2.56

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	32 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

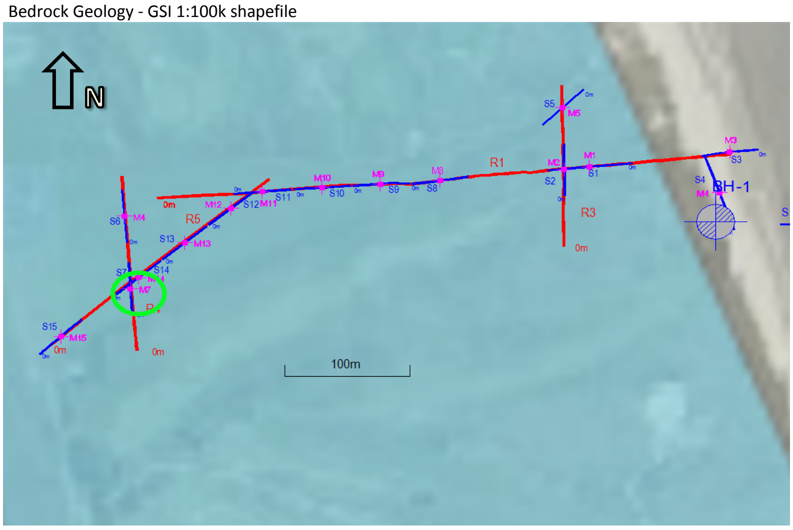
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.0	-	681	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.0	1.7	-	954	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.7	2.8	161	1258	2000	0.49	52.11	0.16	1.85	Overburden Silty SAND	LOOSE	Diggable	**8 N (SPT)**
2.8	4.3	248	1470	2000	0.49	123.40	0.37	7.64	Overburden Silty SAND	MEDIUM DENSE to DENSE	Diggable	**33 N (SPT)**
4.3	6.1	270	1587	2000	0.49	145.68	0.43	10.04	Overburden Silty SAND	DENSE	Diggable	**42 N (SPT)**
6.1	8.4	300	1672	2000	0.48	179.49	0.53	14.14	Overburden Silty SAND	DENSE to VERY DENSE	Diggable	**>50 N (SPT)**
8.4	12.5	372	1700	2000	0.47	277.06	0.82	28.67	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
12.5	14.8	401	2194	2500	0.48	401.08	1.19	53.25	Moderately Weathered LIMESTONE	VERY POOR	Break / Blast	**23 RQD**
14.8	16.9	498	2526	2500	0.48	620.26	1.84	108.97	Moderately Weathered LIMESTONE	POOR	Break / Blast	**31 RQD**
16.9	19.2	498	2927	2700	0.49	669.88	1.99	124.46	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**42 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M7

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M8

Site	Portmarnock Golf Course
Data Location	**M8**

Location (ING)	
Easting	324842.3
Northing	242356.2
Elevation (mOD)	3.18

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	96 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

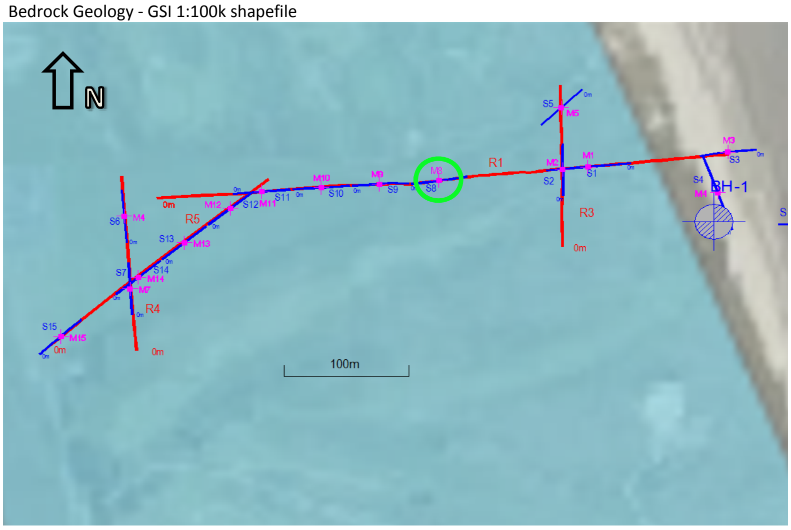
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.5	-	380	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.5	2.5	-	738	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
2.5	4.0	-	1029	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
4.0	5.8	211	1317	2000	0.49	88.78	0.26	4.44	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
5.8	8.0	211	1450	2000	0.49	88.76	0.26	4.45	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
8.0	10.7	298	1704	2000	0.48	177.38	0.53	13.88	Overburden Silty SAND	DENSE to VERY DENSE	Diggable	**>50 N (SPT)**
10.7	14.0	388	1863	2000	0.48	300.41	0.89	32.86	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
14.0	15.8	476	2162	2000	0.47	453.74	1.34	64.68	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
15.8	17.6	476	2366	2500	0.48	567.18	1.68	93.93	Moderately Weathered LIMESTONE	POOR	Break / Blast	**27 RQD**
17.6	20.8	-	2611	2700	-	-	-	-	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**33 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M8

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M9

Site	Portmarnock Golf Course
Data Location	**M9**

Location (ING)	
Easting	324794.4
Northing	242353.1
Elevation (mOD)	4.26

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	96 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

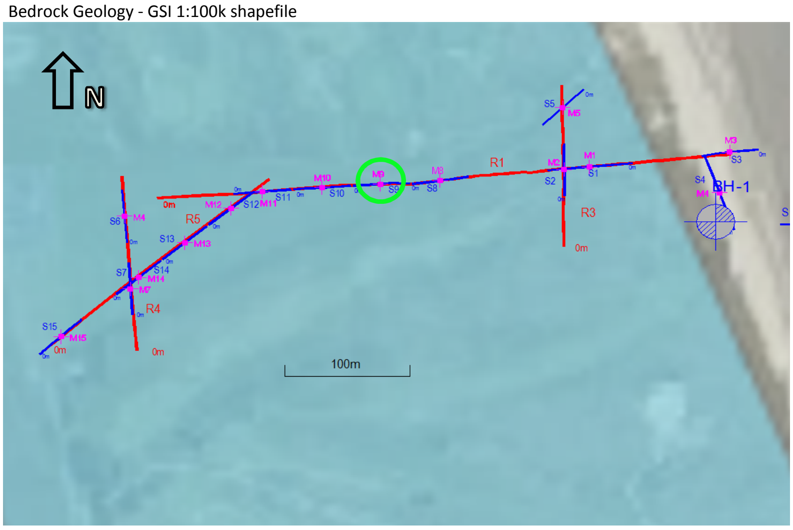
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.4	-	378	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.4	2.4	-	427	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
2.4	4.2	-	707	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
4.2	6.0	209	836	2000	0.47	87.76	0.26	4.26	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
6.0	8.2	215	977	2000	0.47	92.70	0.27	4.71	Overburden Silty SAND	MEDIUM DENSE	Diggable	**22 N (SPT)**
8.2	12.7	364	1494	2000	0.47	265.27	0.78	26.49	Overburden Silty SAND	VERY DENSE	Diggable	**>50 N (SPT)**
12.7	14.5	417	2239	2000	0.48	347.77	1.03	42.05	Overburden Sandy Gravelly CLAY	VERY STIFF	Diggable	**>50 N (SPT)**
14.5	16.2	510	2344	2500	0.48	650.23	1.92	117.19	Moderately Weathered LIMESTONE	POOR	Break / Blast	**27 RQD**
16.2	18.9	510	2398	2700	0.48	702.25	2.07	133.23	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**28 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M9

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M10

Site	Portmarnock Golf Course
Data Location	**M10**

Location (ING)	
Easting	324747.5
Northing	242350.1
Elevation (mOD)	2.76

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	96 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

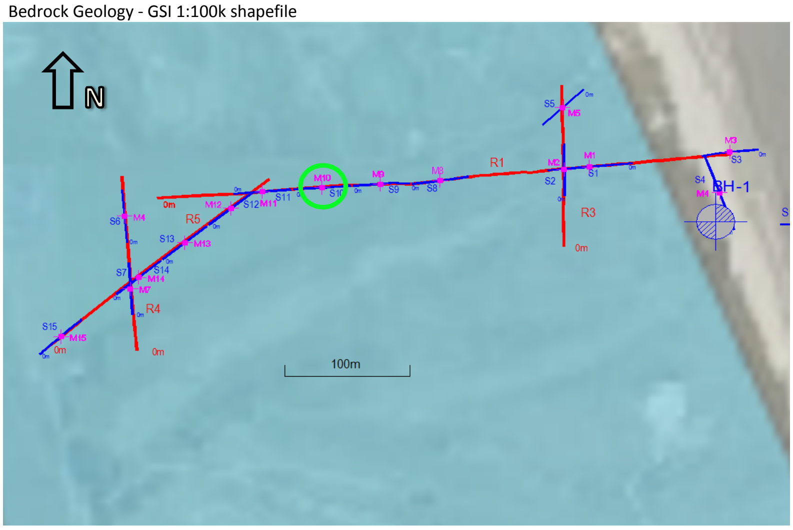
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.5	-	351	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.5	2.6	158	780	2000	0.48	49.80	0.15	1.70	Overburden Silty SAND	LOOSE	Diggable	**8 N (SPT)**
2.6	3.9	247	1035	2000	0.47	122.13	0.36	7.38	Overburden Silty SAND	MEDIUM DENSE to DENSE	Diggable	**33 N (SPT)**
3.9	5.6	244	1269	2000	0.48	119.26	0.35	7.18	Overburden Silty SAND	MEDIUM DENSE to DENSE	Diggable	**32 N (SPT)**
5.6	7.7	247	1607	2000	0.49	121.74	0.36	7.49	Overburden Silty SAND	MEDIUM DENSE to DENSE	Diggable	**32 N (SPT)**
7.7	9.9	295	1858	2000	0.49	173.59	0.52	13.44	Overburden Sandy Gravelly CLAY	STIFF	Diggable	**37 N (SPT)**
9.9	11.8	337	2245	2000	0.49	227.53	0.68	21.03	Overburden Sandy Gravelly CLAY	STIFF to VERY STIFF	Diggable	**46 N (SPT)**
11.8	15.5	428	2559	2500	0.49	459.02	1.36	66.74	Moderately Weathered LIMESTONE	POOR	Break / Blast	**32 RQD**
15.5	17.6	477	3016	2700	0.49	614.37	1.83	108.16	Slightly Weathered -Fresh LIMESTONE	POOR	Heavy Break / Blast	**44 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M10

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M11

Site	Portmarnock Golf Course
Data Location	**M11**

Location (ING)	
Easting	324699.8
Northing	242346.5
Elevation (mOD)	2.55

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	96 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

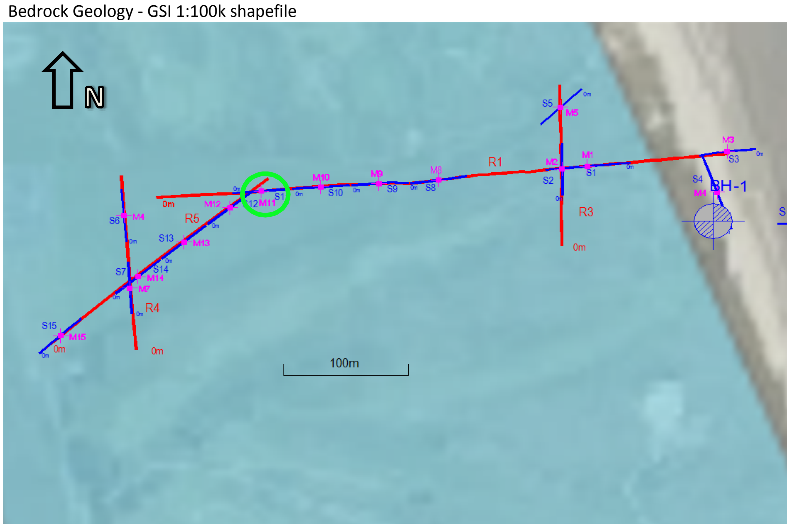
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.4	-	341	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.4	2.4	175	903	2000	0.48	61.35	0.18	2.40	Overburden Silty SAND	LOOSE to MEDIUM DENSE	Diggable	**11 N (SPT)**
2.4	3.6	205	1221	2000	0.49	84.11	0.25	4.06	Overburden Silty SAND	MEDIUM DENSE	Diggable	**19 N (SPT)**
3.6	5.2	208	1467	2000	0.49	86.49	0.26	4.27	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
5.2	7.1	223	1607	2000	0.49	99.18	0.30	5.35	Overburden Silty SAND	MEDIUM DENSE	Diggable	**24 N (SPT)**
7.1	9.0	283	1833	2000	0.49	160.50	0.48	11.82	Overburden Silty SAND	DENSE	Diggable	**48 N (SPT)**
9.0	12.6	367	1833	2000	0.48	269.57	0.80	27.53	Overburden Sandy Gravelly CLAY	STIFF to VERY STIFF	Diggable	**>50 N (SPT)**
12.6	16.3	462	2484	2500	0.48	533.61	1.58	85.23	Moderately Weathered LIMESTONE	POOR	Break / Blast	**30 RQD**
16.3	17.7	-	2976	2700	-	-	-	-	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**43 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M11

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M12

Site	Portmarnock Golf Course
Data Location	**M12**

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	48 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

Location (ING)	
Easting	324674.9
Northing	242331.8
Elevation (mOD)	2.80

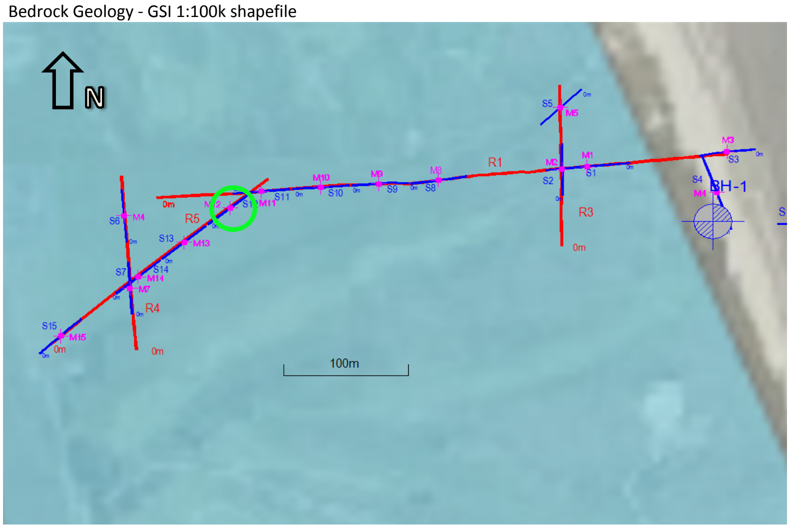
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.7	-	564	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.7	3.0	199	976	2000	0.48	79.53	0.24	3.67	Overburden Silty SAND	MEDIUM DENSE	Diggable	**17 N (SPT)**
3.0	4.5	219	1203	2000	0.48	95.52	0.28	4.99	Overburden Silty SAND	MEDIUM DENSE	Diggable	**23 N (SPT)**
4.5	6.4	238	1501	2000	0.49	113.08	0.34	6.63	Overburden Silty SAND	MEDIUM DENSE	Diggable	**29 N (SPT)**
6.4	9.0	269	1682	2000	0.49	144.87	0.43	9.97	Overburden Silty SAND	DENSE	Diggable	**41 N (SPT)**
9.0	11.8	312	1777	2000	0.48	194.09	0.58	16.10	Overburden Sandy Gravelly CLAY	STIFF	Diggable	**41 N (SPT)**
11.8	13.5	390	2141	2500	0.48	379.62	1.13	48.64	Moderately Weathered LIMESTONE	VERY POOR	Break / Blast	**22 RQD**
13.5	15.5	390	2571	2500	0.49	379.62	1.13	48.93	Moderately Weathered LIMESTONE	POOR	Break / Blast	**32 RQD**
15.5	16.5	496	2989	2700	0.49	665.08	1.98	123.10	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**44 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M12

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M13

Site	Portmarnock Golf Course
Data Location	**M13**

Location (ING)	
Easting	324637.7
Northing	242301.7
Elevation (mOD)	2.69

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	48 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

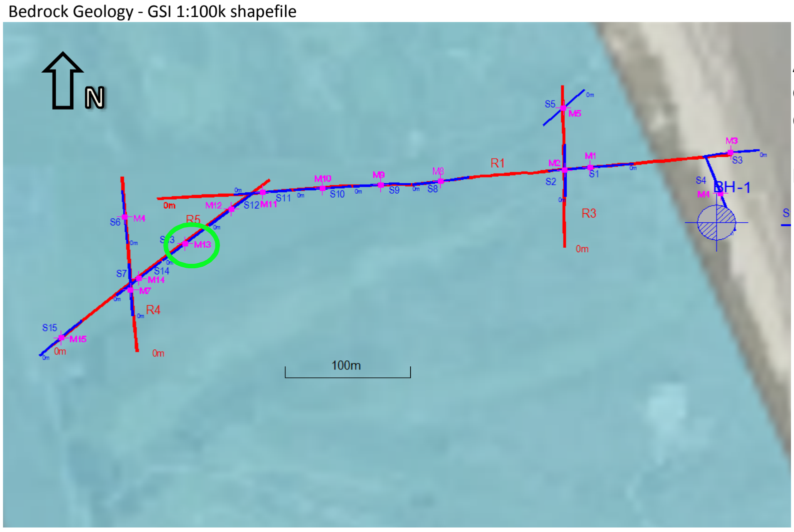
Depth (m) from	Depth (m) to	Avg. Velocity (m/s) S Wave	P Wave	Assumed Density kg/m^3	Poissons Ratio	Shear Mod MPa Dynamic	Youngs Mod GPa Dynamic	Youngs Mod MPa Static*	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
0.0	1.6	-	576	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.6	2.7	190	1010	2000	0.48	72.19	0.21	3.14	Overburden Silty SAND	MEDIUM DENSE	Diggable	**15 N (SPT)**
2.7	4.1	211	1282	2000	0.49	89.13	0.26	4.47	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
4.1	5.9	209	1621	2000	0.49	87.03	0.26	4.32	Overburden Silty SAND	MEDIUM DENSE	Diggable	**20 N (SPT)**
5.9	8.0	253	1739	2000	0.49	127.58	0.38	8.10	Overburden Silty SAND	MEDIUM DENSE to DENSE	Diggable	**35 N (SPT)**
8.0	12.0	310	1739	2000	0.48	191.98	0.57	15.80	Overburden Sandy Gravelly CLAY	STIFF	Diggable	**40 N (SPT)**
12.0	14.1	384	2351	2500	0.49	369.00	1.10	46.59	Moderately Weathered LIMESTONE	POOR	Break / Blast	**27 RQD**
14.1	16.5	478	2490	2500	0.48	570.75	1.69	95.12	Moderately Weathered LIMESTONE	POOR	Break / Blast	**30 RQD**
16.5	18.4	478	3287	2700	0.49	616.41	1.84	109.00	Slightly Weathered -Fresh LIMESTONE	FAIR	Heavy Break / Blast	**53 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M13

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M14

Site	Portmarnock Golf Course
Data Location	**M14**

Location (ING)	
Easting	324600.7
Northing	242271.2
Elevation (mOD)	2.55

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	48 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

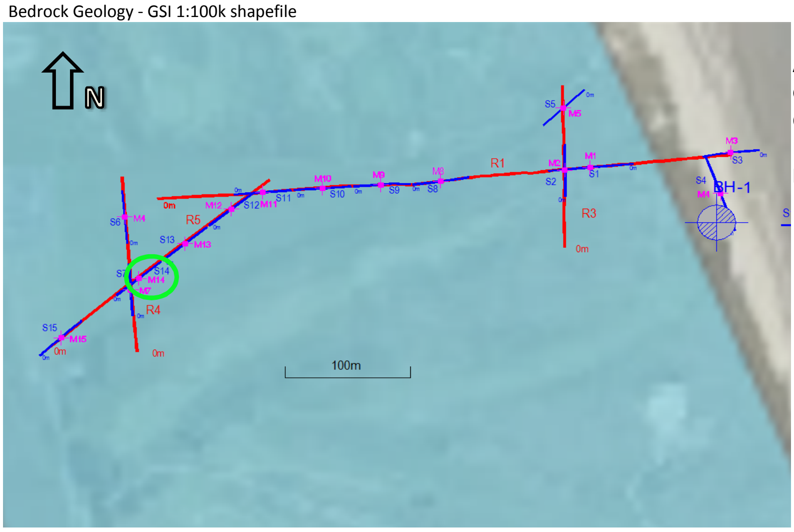
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.0	-	715	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.0	2.4	-	1164	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
2.4	3.8	201	1425	2000	0.49	80.67	0.24	3.81	Overburden Silty SAND	MEDIUM DENSE	Diggable	**18 N (SPT)**
3.8	5.4	267	1571	2000	0.49	142.36	0.42	9.67	Overburden Silty SAND	DENSE	Diggable	**40 N (SPT)**
5.4	7.4	297	1624	2000	0.48	176.35	0.52	13.72	Overburden Silty SAND	DENSE to VERY DENSE	Diggable	**>50 N (SPT)**
7.4	9.8	282	1893	2000	0.49	158.99	0.47	11.64	Overburden Silty SAND	DENSE	Diggable	**47 N (SPT)**
9.8	11.9	307	2119	2000	0.49	188.09	0.56	15.38	Overburden Sandy Gravelly CLAY	STIFF	Diggable	**40 N (SPT)**
11.9	14.0	361	2476	2500	0.49	325.67	0.97	38.03	Moderately Weathered LIMESTONE	POOR	Break / Blast	**30 RQD**
14.0	16.5	415	2875	2700	0.49	465.42	1.39	68.57	Slightly Weathered -Fresh LIMESTONE	POOR	Break / Blast	**40 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M14

Geophysical Investigation Summary
ERT/Seismic Refraction/MASW
Drawing No. AGL15247_M15

Site	Portmarnock Golf Course
Data Location	**M15**

Methodology		
Seismic Refraction	24 ch. @ 2m geophones	
MASW	24 ch. @ 2m geophones	
ERT	48 el. @ 5m electrodes	
GPS	GNSS GPS (10cm accuracy)	

Location (ING)	
Easting	324538.6
Northing	242219.3
Elevation (mOD)	2.91

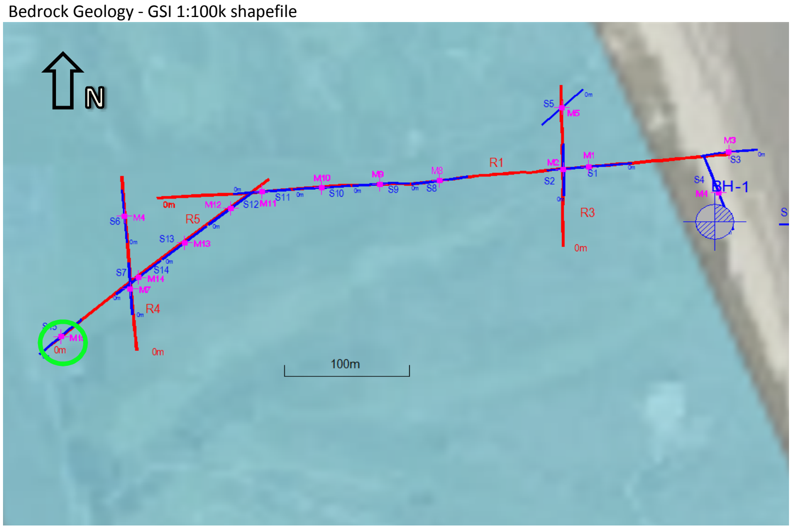
Depth (m)	Depth (m)	Avg. Velocity (m/s)		Assumed Density	Poissons Ratio	Shear Mod	Youngs Mod	Youngs Mod	Interpretation	Estimated Stiffness / Rock Quality **	Estimated Excavatability	Estimated SPT (N)** / RQD % ***
from	to	S Wave	P Wave	kg/m^3		MPa Dynamic	GPa Dynamic	MPa Static*				
0.0	1.1	-	502	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
1.1	2.7	-	812	2000	-	-	-	-	Overburden Silty SAND	-	Diggable	-
2.7	4.2	171	1037	2000	0.49	58.74	0.17	2.25	Overburden Silty SAND	LOOSE to MEDIUM DENSE	Diggable	**10 N (SPT)**
4.2	5.9	215	1272	2000	0.49	92.49	0.27	4.75	Overburden Silty SAND	MEDIUM DENSE	Diggable	**22 N (SPT)**
5.9	8.1	248	1511	2000	0.49	123.12	0.37	7.62	Overburden Silty SAND	MEDIUM DENSE to DENSE	Diggable	**33 N (SPT)**
8.1	10.9	295	1632	2000	0.48	174.55	0.52	13.50	Overburden Silty SAND	DENSE to VERY DENSE	Diggable	**>50 N (SPT)**
10.9	14.3	369	1705	2000	0.48	272.72	0.80	27.95	Overburden Sandy Gravelly CLAY	STIFF to VERY STIFF	Diggable	**>50 N (SPT)**
14.3	18.0	464	1949	2500	0.47	539.06	1.58	85.51	Moderately Weathered LIMESTONE	VERY POOR	Break / Blast	**18 RQD**
18.0	19.5	-	2391	2500	-	-	-	-	Moderately Weathered LIMESTONE	POOR	Break / Blast	**28 RQD**

* converted to static equivalent using empirical correlation from van Heerden, 1987.

** correlation from Imai et al, 1976

*** from Deere et al, 1967

Bedrock Geology - GSI 1:100k shapefile



According to the GSI 1:100k Bedrock Geology map the Portmarnock Golf Course is underlain by the Malahide Formation, described as argillaceous bioclastic limestone and shale.

M15

10. APPENDIX E: DETAILED METHODOLOGY

A combination of a number of geophysical techniques was used to provide the high quality interpretation and reduce any ambiguities, which may otherwise exist.

10.1 Electrical Resistivity Tomography (ERT)

Electrical Resistivity Tomography was carried out to provide information on lateral variations in the overburden material as well as on the underlying overburden and bedrock.

10.1.1 Principles

This surveying technique makes use of the Wenner resistivity array. The 2D-resistivity profiling method records a large number of resistivity readings in order to map lateral and vertical changes in material types. The 2D-resistivity profiling method involves the use of 64 electrodes connected to a resistivity meter, using computer software to control the process of data collection and storage.

10.1.2 Data Collection

Profiles were recorded using a Tigre resistivity meter, imaging software, two 32 takeout multicore cables and up to 64 stainless steel electrodes. Saline solution was used at the electrode/ground interface in order to gain a good electrical contact required for the technique to work effectively. The recorded data were processed and viewed immediately after survey.

10.1.3 Data Processing

The field readings were stored in computer files and inverted using the RES2DINV package (Campus Geophysical Instruments, 1997) with up to 5 iterations of the measured data carried out for each profile to obtain a 2D-Depth model of the resistivities.

The inverted 2D-Resistivity models and corresponding interpreted geology are displayed on the accompanying drawings alongside the processed seismic sections. Distance is indicated along the horizontal axis of the profiles. Profiles have been contoured using the same contour intervals and colour codes.

10.1.4 Relocation

All data were referenced using a GNSS Geo 7x GPS system with sub 10cm accuracy. All positions within this report are given in ING Grid coordinates.

10.2 Seismic Refraction Profiling

10.2.1 Principles

This method measures the velocity of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher seismic velocities while soft, loose or fractured materials have lower velocities.

Seismic profiling measures the p-wave velocity (Vp) of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher Vp velocities while soft, loose or fractured materials have lower Vp velocities. Readings are taken using geophones connected via multi-core cable to a seismograph.

10.2.2 Data Collection

A Geode high resolution 24 channel digital seismograph, 24 10HZ vertical geophones and a 10 kg hammer were used to provide first break information, with a 24 take-out cable (3m spacing). Equipment was carried was operated by a two-person crew.

Readings are taken using geophones connected via multi-core cable to a seismograph. The depth of resolution of soil/bedrock boundaries is determined by the length of the seismic spread, typically the depth of resolution is about one third the length of the profile.(eg. 69m profile ~23m depth, 33m profile ~ 11m depth)

Shots from seven different positions were taken (2 x off-end, 2 x end, 3 x middle) to ensure optimum coverage of all refractors. All profiles were surveyed to Irish National Grid using a ProXR dGPS system.

10.2.3 Data Processing

First break picking in digital format was carried out using the FIRSTPIX software program to construct p-wave (Vp) traveltime plots for each spread. Velocity phases were selected from these plots using the GREMIX software program and were used to calculate the thickness of individual velocity units. Topographic data were input. Material types were assigned and estimation made of material properties, cross-referenced to borehole and MASW data. The processed seismic data are displayed in Appendix A.

Approximate errors for Vp velocities are estimated to be +/- 10%. Errors for the calculated layer thicknesses are of the order of +/-20%. Possible errors due to the "hidden layer" and "velocity inversion" effects may also occur (Soske, 1959).

10.2.4 Relocation

All data were referenced using a GNSS Geo 7x GPS system with sub 10cm accuracy. All positions within this report are given in ING Grid coordinates.

10.3 Multichannel Analysis of Surface Waves (MASW)

MASW profiling was carried out to provide information on overburden material stiffness or density and on the bedrock quality.

10.3.1 Principles

The Multi-channel Analysis of Surface Waves (MASW) (Park et al., 1998, 1999) utilizes Surface waves (Rayleigh waves) to determine the elastic properties of the shallow subsurface (<15m). Surface waves carry up to two/thirds of the seismic energy but are usually considered as noise in conventional body wave reflection and refraction seismic surveys.

The penetration depth of surface waves changes with wavelength, i.e. longer wavelengths penetrate deeper. When the elastic properties of near surface materials vary with depth, surface waves then become dispersive, i.e. propagation velocity changes with frequency. The propagation (or phase) velocity is determined by the average elastic property of the medium within the penetration depth. Therefore the dispersive nature of surface waves may be used to investigate changes in elastic properties of the shallow subsurface.

The MASW method employs the multi-channel recording and processing techniques (Sheriff and Geldart, 1982) that have similarities to those used in a seismic reflection survey and which allow better waveform analysis and noise elimination. To produce a shear wave velocity (Vs) profile and a stiffness profile of the subsurface using Surface waves the following basic procedure is followed:

(i)A point source (eg. a sledgehammer) is used to generate vertical ground motions,

(ii)The ground motions are measured using low frequency geophones, which are disposed along a straight line directed toward the source,

(iii)the ground motions are recorded using either a conventional seismograph, oscilloscope or spectrum analyzer,

(iv)a dispersion curve is produced from a spectral analysis of the data showing the variation of Surface wave velocity with wavelength,

(v)the dispersion curve in inverted using a modeling and least squares minimization process to produce a subsurface profile of the variation of Surface wave and shear wave velocity with depth.

10.3.2 Data Collection

The recording equipment consisted of a Geode 24 channel digital seismograph, 24 no. 10HZ vertical geophones, hammer energy source with mounted trigger and a 24 take-out cable.

10.3.3 Data Processing

MASW processing was carried out using the SURFSEIS processing package developed by Kansa Geological Survey (KGS, 2000). SURFSEIS is designed to generate a shear wave (Vs) veolocity profile.

SURFSEIS data processing involves three steps:

(i) Preparation of the acquired multichannel record. This involves converting data file into the processing format.

(ii) Production of a dispersion curve from a spectral analysis of the data showing the variation of Raleigh wave phase velocity with wavelength. Confidence in the dispersion curve can be estaimated through a measure of signal to noise ratio (S/N), which is obtained from a coherency analysis. Noise includes both body waves and higher mode surface waves. To obtain an accurate dispersion curve the spectral content and phase velocity characteristics are examined through an overtone analysis of the data.

(iii) Inversion of the dispersion curve is then carried out to produce a subsurface profile of the variation of shear wave velocity with depth.

10.3.4 Relocation

All data were referenced using a GNSS Geo 7x GPS system with sub 10cm accuracy. All positions within this report are given in ING Grid coordinates.