Appendix A

A.4.3 Rahoon Ground Investigation

A1

IRISH DRILLING LIMITED

LOUGHREA, CO. GALWAY, IRELAND

CONTRACT DRILLING
SITE INVESTIGATION

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GCOB PHASE 1
GROUND INVESTIGATION

GALWAY

SITE INVESTIGATION

FACTUAL REPORT

Arup,
50 Ringsend Rd.,
Dublin 4

Galway City Council,
City Hall,
College Rd.,
Galway.

Contents:

1.0 Introduction.

Irish Drilling Ltd. was instructed by Arup to carry out a site investigation for Galway City Outer Bypass (GCOB) Phase 1, on behalf of the client Galway County Council.

The site investigation has been carried out to assess the ground conditions and provide data to assist in the design of earthworks and foundations.

The fieldwork commenced on July 3rd 2014 and was completed on July 23rd 2014.

This Report presents the factual data.

2.0 Site & Geology

The site is located at Knocknacarra on the west side of Galway City. The boreholes are located about 300m apart as shown on the Site Plan.

The geology of the area is generally Glacial Till, overlying the Galway Granite.

3.0 Fieldwork.

The fieldwork consisted of the following:

Two rotary core boreholes were drilled using PQ (84mm dia. core) wire-line drilling equipment, with plastic liner used to assist core recovery and this was reduced to PQ (65mm diameter) below 18.6m in Bh RC-1-001 and 17.0m in Bh RC-1-002.

Standard Penetration Tests were carried out in the overburden in both boreholes.

A standpipe (19mm dia.) was installed in both boreholes, with the response zones extending between 20m and 25m depth.

The boreholes were logged by an engineering geologist from this company. The borehole records are included in Appendix 1.

Laboratory testing was carried out on representative rock samples. Tests included Point Load Index (PLT) and UCS tests. The laboratory test results are presented in Appendix 2.

Photographs of the rock cores are included in Appendix 3.

A Geophysical survey was carried out by Minerex Geophysics Limited and the report is included in Appendix 4.

The borehole locations were surveyed, to National co-ordinates, using a Trimble CU Bluetooth Total Station.

4.0 Ground conditions.

Generally the boreholes encountered Glacial till of varying consistency, over granite rock.

Rock was encountered at 5.1m in RC-1-001 and 6.2m in RC-1-002 and generally consists of very strong to extremely strong grey fine to coarse grained granite, micro-granite, dolerite and felsic porphyry with predominantly medium spaced and frequently closely spaced fractures.

Reference should be made to the logs in Appendix 1 for detailed descriptions of the soils and rock.

4.1 Groundwater.

Groundwater was recorded in standpipes at the following depths:

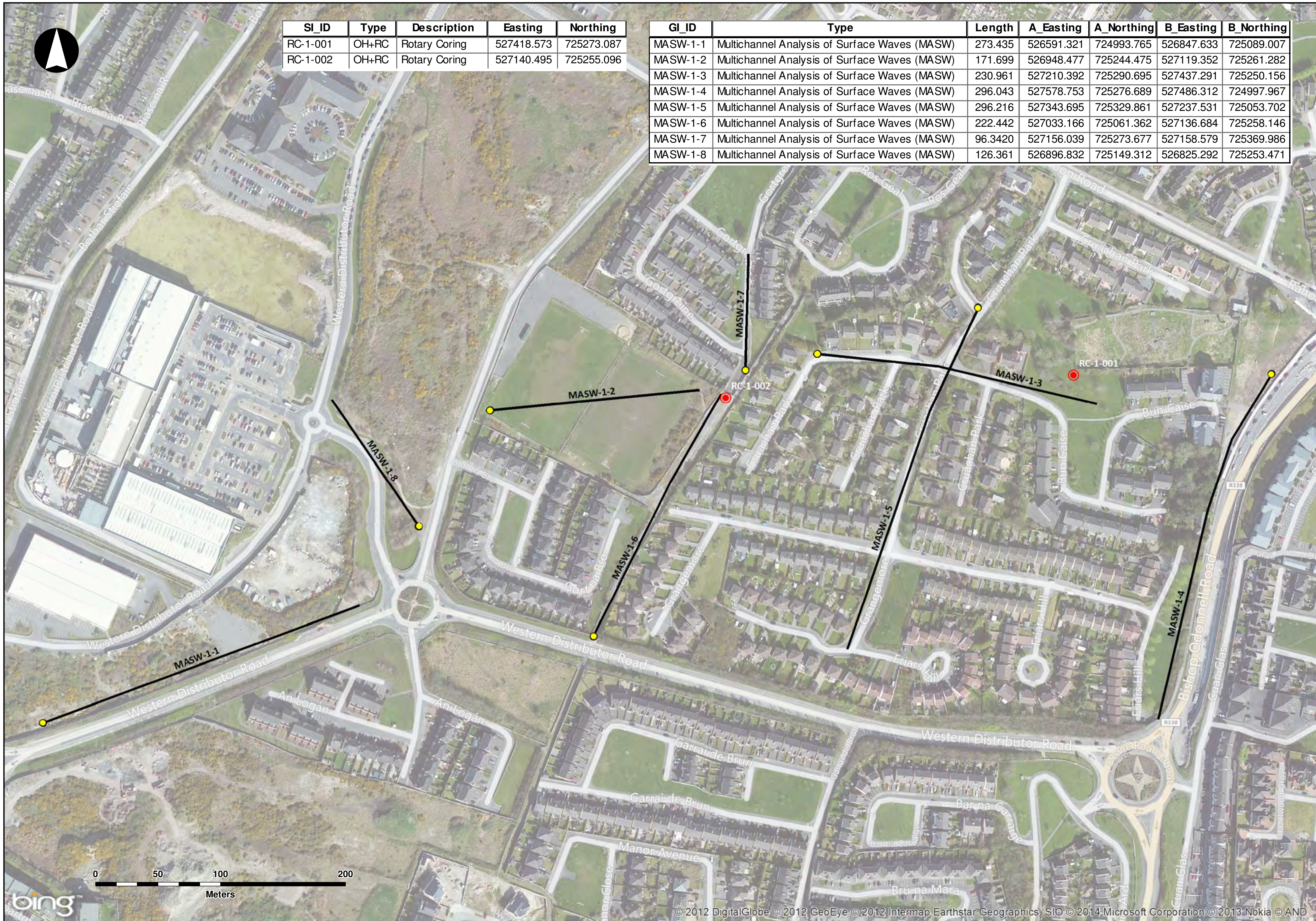
Location	RC-1-001	RC-1-002
13 Aug. '14 11:25	3.51m *(21.24m O.D.)*	6.15m *(31.16m O.D.)*

Declan Joyce, B.E., M.Eng.Sc., C.Eng., M.I.E.I.
Chartered Geotechnical Engineer

A3

SI_ID	Type	Description	Easting	Northing
RC-1-001	OH+RC	Rotary Coring	527418.573	725273.087
RC-1-002	OH+RC	Rotary Coring	527140.495	725255.096

GI_ID	Type	Length	A_Easting	A_Northing	B_Easting	B_Northing
MASW-1-1	Multichannel Analysis of Surface Waves (MASW)	273.435	526591.321	724993.765	526847.633	725089.007
MASW-1-2	Multichannel Analysis of Surface Waves (MASW)	171.699	526948.477	725244.475	527119.352	725261.282
MASW-1-3	Multichannel Analysis of Surface Waves (MASW)	230.961	527210.392	725290.695	527437.291	725250.156
MASW-1-4	Multichannel Analysis of Surface Waves (MASW)	296.043	527578.753	725276.689	527486.312	724997.967
MASW-1-5	Multichannel Analysis of Surface Waves (MASW)	296.216	527343.695	725329.861	527237.531	725053.702
MASW-1-6	Multichannel Analysis of Surface Waves (MASW)	222.442	527033.166	725061.362	527136.684	725258.146
MASW-1-7	Multichannel Analysis of Surface Waves (MASW)	96.3420	527156.039	725273.677	527158.579	725369.986
MASW-1-8	Multichannel Analysis of Surface Waves (MASW)	126.361	526896.832	725149.312	526825.292	725253.471



ROUTE OPTIONS

Legend

- Phase One Site Investigation - Boreholes
- Phase One Site Investigation - Geophysical Surveys

Note: Geophysical survey starting point (A) is displayed using a yellow dot

Coordinate System: IRENET95 Irish Transverse Mercator
Projection: Transverse Mercator
Datum: IRENET95

Clients

Consultant

ARUP

50 Ringsend Road
Dublin 4
Tel +353 (0)1 233 4455 Fax +353 (0)1 668 3169
www.arup.com

Job Title

N6 Galway City Outer Bypass

Scale: 1:3,000

Date: June 2014

Issue	Date	By	Chkd	Appd
P1	10/06/2014	CMtS	PQ	EMcC

Drawing Title

Geotechnical Information Proposed Ground Investigation

Drawing Status

Information

Job No	Drawing No	Issue
233985-00	GCOB-SK-R-600-001	P1

APPENDIX 1

BOREHOLE RECORDS

Irish Drilling Limited
Old Galway Rd
Loughrea, Co. Galway
Telephone: 091 841274
Fax: 091 880861

DRILLHOLE LOG

Project: GCOB - Phase 1			Location: Knocknacarra, Galway	DRILLHOLE No **RC-1-001**
Job No: 2014G117	Date: 09-07-14 16-07-14	Ground Level (m): 24.75	Co-Ordinates (): E 527,416.2 N 725,273.6	
Engineer: ARUP				Sheet 1 of 4 Rev. 1

RUN DETAILS / STRATA

Date	Depth	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Depth (Thickness)	Discontinuities	Main
09.07	0.00					0.00 - 5.10 5.10m: overburden.	Subrounded to sub-angular fine to coarse GRAVEL with a little brown slightly sandy clay. Sand is fine and medium. Gravel is of assorted lithologies including assorted grey limestone and grey and pink granitic clasts.
	1.00	80 (-) -	1.00(30/40mm)				
	2.60	50 (-) -	2.00 (16)		(5.10)		
09.07	4.10	75 (-) -	3.00(54/95mm)				
10.07	4.90	25 (-) -	4.00(30/45mm)				
			5.00(30/25mm)	19.65	5.10		
11.07	6.00	100 (71) 0	20			5.10 - 7.20 Non-intact as fractured rock.	Strong to extremely strong thinly flow banded greenish grey groundmass with dark green rounded and cubic fine and medium grained phenocrysts as DOLERITE.
11.07	7.20	100 (28) 10	NI	17.55	(2.10) 7.20		
14.07		100 (70) 27	9			7.20 - 12.00 Discontinuities, very closely spaced, dipping 70 to 72o, irregular, smooth, with ~0.5mm thick milky white calcitic smear and ~0.5mm thick grey clay smear.	

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing
09-07-14	08.00	0.00	0.00	150	84		-
09-07-14	17.00	4.10	4.10	150	84		2.90
10-07-14	08.00	4.10	4.10	150	84		2.70
11-07-14	08.00	6.00	6.00	150	84		2.60
11-07-14	17.00	7.20	6.00	150	84		3.00
14-07-14	08.00	7.20	6.00	150	84		2.80
14-08-14	11.30		standpipe				3.51

Rotary Flush

From (m)	To (m)	Type	Return (%)
0	3.00	water	100%
3	6.30	water	0%
6.3	30.1	water	100%

GENERAL REMARKS

Driller described rock as extremely strong and difficult to drill between 5.1m and 18.9m.19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/ Plant Used: Hydreq	Bit Design	Driller: DC	Logged By: EAT

IDL AGS UK DH (SPTS) GCOB RC1.GPJ IDL TP TEMPLATE.GDT 15/8/14

Irish Drilling Limited
Old Galway Rd
Loughrea, Co. Galway
Telephone: 091 841274
Fax: 091 880861

DRILLHOLE LOG

Project: GCOB - Phase 1		Location: Knocknacarra, Galway	DRILLHOLE No: **RC-1-001**
Job No: 2014G117	Date: 09-07-14 16-07-14	Ground Level (m): 24.75	Co-Ordinates (): E 527,416.2 N 725,273.6
Engineer: ARUP			Sheet 2 of 4, Rev. 1

Depth / Date	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Depth (Thickness)	Discontinuities Detail	Main
8.10		9				Strong to extremely strong and occasionally medium strong, thinly flow banded pink groundmass with milky white dark grey and white fine and medium grained phenocrysts as fine and medium grained MICROGRANITE. *(continued)*
9.80	100 (96) 46	10				
10.07 10.70	100 (68) 0	NI				
10.07 / 14.07 11.60	100 (54) 0	7		(8.40)		
15.07 / 12.60	100 (81) 60	5				12.00m: phenocrysts becoming coarse grained.
13.60	100 (96) 81	6				
14.50	100 (98) 51	6				
15.60	100 (97) 78	3	9.15	15.60		15.00m to 18.60m: with 'anastomosing' milky white calcitic veins and veinlets. 15.05m to 15.60m: pink groundmass with dark green and grey phenocrysts coarse.
		7			15.60 - 18.90 Discontinuities, closely spaced to 16.00m, then medium	

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing
10-07-14	17.00	10.70	4.10	150	84		2.90
14-07-14	17.00	11.60	6.00	150	84		3.10
15-07-14	08.00	11.60	6.00	150	84		2.70

Rotary Flush

From (m)	To (m)	Type	Return (%)

GENERAL REMARKS

Driller described rock as extremely strong and difficult to drill between 5.1m and 18.9m.19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/Plant Used: Hydreq	Bit Design	Driller: DC	Logged By: EAT

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DRILLHOLE LOG

Project	Location	DRILLHOLE No
GCOB - Phase 1	Knocknacarra, Galway	RC-1-001

Job No	Date	Ground Level (m)	Co-Ordinates ()	Sheet
2014G117	09-07-14 16-07-14	24.75	E 527,416.2 N 725,273.6	3 of 4

Engineer	Rev.
ARUP	1

Depth / Date	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Depth (Thickness)	Discontinuities Detail	Main
17.10	100 (98) 81	2	5.85	(3.30) 18.90	spaced, dipping 30 to 32o, planar, locally irregular, smooth, with a ~0.5mm thick grey calcitic smear and minor orange brown iron stain.	Strong to extremely strong thinly flow banded green groundmass with elongated dark green rounded and cubic fine and medium grained phenocrysts FELSIC PORPHYRY. *(continued)* 16.50m to 17.70m: with visible finely disseminated pyrite.
17.80	100 (94) 88	3				
15.07 18.60 16.07	100 (95) 79	7				
19.90	100 (96) 76	2	4.85	(1.00) 19.90	18.90 - 19.90 Discontinuities, medium spaced, dipping 22 to 24o, irregular, smooth, with ~5mm thick yellowish cream clay smear.	Extremely strong thinly flow banded pink groundmass with grey milky white black and dark green coarse grained GRANITE.
21.50	100 (95) 72	1 8		(5.90)	19.90 - 25.80 Discontinuities, medium spaced, locally closely spaced, dipping 20 to 22o to 22.50m, then 30 to 32o, undulating, smooth, with ~<0.5mm thick grey clay smear.	Very strong to extremely strong, weakly thinly flow banded, greyish green groundmass with white and dark green elongated rounded and cubic fine and medium grained phenocrysts, FELSIC PORPHYRY.
23.00	100 (97) 69	8 7				
	100 (96) 88	5				

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing
15-07-14	17.00	18.60	6.00	150	84		3.00
16-07-14	08.00	18.60	6.00	150	65		2.50

Rotary Flush

From (m)	To (m)	Type	Return (%)

GENERAL REMARKS

Driller described rock as extremely strong and difficult to drill between 5.1m and 18.9m.19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/ Plant Used	Bit Design	Driller	Logged By
		Hydreq		DC	EAT

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DRILLHOLE LOG

Project	GCOB - Phase 1	Location	Knocknacarra, Galway	DRILLHOLE No	RC-1-001
Job No: 2014G117	Date: 09-07-14 16-07-14	Ground Level (m): 24.75	Co-Ordinates (): E 527,416.2 N 725,273.6		
Engineer: ARUP				Sheet	4 of 4
				Rev.	1

Depth / Date	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Legend	Depth (Thickness)	Discontinuities Detail	Main Description	Geology	Instrument/ Backfill
		6					Very strong to extremely strong, weakly thinly flow banded, greyish green groundmass with white and dark green elongated rounded and cubic fine and medium grained phenocrysts, FELSIC PORPHYRY. *(continued)*		
24.60	100 (97) 77	6	-1.05		25.80				
25.90	100 (90) 80	8	-2.25		(1.20) 27.00	25.80 - 27.00 Discontinuities, medium spaced, dipping 20 to 22o, undulating, smooth, with ~1mm thick grey clay smear.	Extremely strong thinly flow banded pink groundmass with black and grey and white fine and medium grained phenocrysts as medium grained GRANITE.		
27.00	100 (94) 84	4				27.00 - 29.50 Discontinuities, medium spaced, locally closely spaced, dipping 38 to 40o, undulating, smooth, with ~1mm thick grey clay smear.	Very strong to extremely strong, thinly flow banded, dark greenish grey groundmass, with elongated rounded and cubic pink and white and rare dark green fine and medium grained, FELSIC PORPHYRY.		
28.60	100 (96) 74	5 / 3	-4.75		(2.50) 29.50				
16.07 30.10		3	-5.35		(0.60) 30.10	29.50 - 30.10 Discontinuities, closely spaced, dipping 38 to 40o, irregular, rough, with ~1mm thick brown clay smear.	Very strong to extremely strong, thinly flow banded groundmass, with black and grey and white fine and medium grained phenocrysts as medium grained GRANITE.		
							BH terminated at 30.10m bgl on REs instruction.		

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing
16-07-14	17.00	30.10	6.00	150	65		2.90

Rotary Flush

From (m)	To (m)	Type	Return (%)

GENERAL REMARKS

Driller described rock as extremely strong and difficult to drill between 5.1m and 18.9m.19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/ Plant Used: Hydreq	Bit Design	Driller: DC	Logged By: EAT

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DRILLHOLE LOG

Project	GCOB - Phase 1	Location	Knocknacarra, Galway	DRILLHOLE No	RC-1-002
Job No: 2014G117	Date: 18-07-14 23-07-14	Ground Level (m): 37.31	Co-Ordinates (): E 527,125.0 N 725,237.3		
Engineer: ARUP				Sheet 1 of 4	Rev. 1

RUN DETAILS / STRATA

Date	Depth	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Depth (Thickness)	Discontinuities / Detail	Main
18.07	0.00					0.00 - 6.20 : overburden.	
				36.81	(0.50) 0.50		Angular to sub-angular medium to coarse GRAVEL. Gravel is of assorted lithologies including assorted grey limestone and pink granitic clasts.
				36.51	0.80		Orange brown sandy gravelly CLAY. Sand is fine to medium. Gravel is sub-angular fine of limestone.
	1.90	63 (-) -	1.00 (16)				Brownish grey slightly sandy gravelly CLAY with cobbles. Sand is fine. Gravel is sub-angular to rounded fine to coarse of limestone with rare sandstone clasts. Cobbles are of limestone.
	3.10	42 (-) -	2.00 (19)				
	4.30	75 (-) -	3.00 (25)				
	5.40	82 (-) -	4.00 (18) 5.00(30/25mm)		(5.40)		
	6.10	100 (14) 0		31.11	6.20		
18.07 21.07	7.20	100 (85) 46	8			6.20 - 30.00 Discontinuities, closely spaced to 8.00m, medium spaced to 27.30m, then closely spaced, dipping 54 to 56o, planar, locally undulating, smooth, with <0.5mm thick grey clay smear and ~0.5mm thick light green calcareous smear.	Extremely strong and occasionally very strong, weakly thickly flow banded, pink groundmass, with pink, black, grey and milky white, coarse grained GRANITE.
	7.60	100 (100) 100	3				

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing
18-07-14	08.00	0.00	0.00	150	84		
18-07-14	17.00	7.20	6.00	150	84		
21-07-14	08.00	7.20	6.00	150	84		6.40
14-08-14	11.20		standpipe				6.15

Rotary Flush

From (m)	To (m)	Type	Return (%)
0	30.00	water	100%

GENERAL REMARKS

Driller described rock as extremely strong and slow to drill .
19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/Plant Used: Hydreq	Bit Design	Driller: TH/BD	Logged By: EAT

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DRILLHOLE LOG

Project	GCOB - Phase 1	Location	Knocknacarra, Galway	DRILLHOLE No
Job No: 2014G117	Date: 18-07-14 23-07-14	Ground Level (m): 37.31	Co-Ordinates (): E 527,125.0 N 725,237.3	RC-1-002
Engineer: ARUP				Sheet 2 of 4; Rev. 1

Depth / Date	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Legend	Depth (Thickness)	Discontinuities	Detail	Main	Geology	Instrument/ Backfill
8.90	100 (90) 73	3						Extremely strong and occasionally very strong, weakly thickly flow banded, pink groundmass, with pink, black, grey and milky white, coarse grained GRANITE. *(continued)*		
		3								
10.50	100 (98) 95	4								
		3								
12.10	100 (98) 92									
12.80	100 (96) 94	2								
14.10	100 (98) 96	2								
		2								
15.60	100 (98) 96	3						15.40m to 17.80m: groundmass becoming brownish pink.		
	100 (100)									

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing

Rotary Flush

From (m)	To (m)	Type	Return (%)

GENERAL REMARKS

Driller described rock as extremely strong and slow to drill .
19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/ Plant Used: Hydreq	Bit Design	Driller: TH/BD	Logged By: EAT

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DRILLHOLE LOG

Project	GCOB - Phase 1	Location	Knocknacarra, Galway	DRILLHOLE No	RC-1-002
Job No	2014G117	Date	18-07-14 23-07-14	Ground Level (m)	37.31
Co-Ordinates ()	E 527,125.0 N 725,237.3				
Engineer	ARUP	Sheet	3 of 4	Rev.	1

RUN DETAILS / STRATA

Depth / Date	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Legend	Depth (Thickness)	Discontinuities	Detail	Main
16.10	100							Extremely strong and occasionally very strong, weakly thickly flow banded, pink groundmass, with pink, black, grey and milky white, coarse grained GRANITE. *(continued)*
	100 (97) 96	0						
17.70		1						
					(23.80)			17.80m to 30.00m: groundmass becoming pinkish grey.
21.07 21.07	100 (98) 96	1						
21.07 19.20 22.07								
	100 (98) 97	3						
20.60		2						
	100 (98) 97	2						
22.10								
	100 (96) 94	2						
22.90								
	100 (99) 99	0						
23.90								

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing
21-07-14	15.00	18.60	18.60	125	84		8.00
21-07-14	17.00	19.20	18.60	125	65		8.00
22-07-14	08.00	19.20	18.60	125	65		8.00

Rotary Flush

From (m)	To (m)	Type	Return (%)

GENERAL REMARKS

Driller described rock as extremely strong and slow to drill .
19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/ Plant Used: Hydreq	Bit Design	Driller: TH/BD	Logged By: EAT

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DRILLHOLE LOG

Project: GCOB - Phase 1		Location: Knocknacarra, Galway	DRILLHOLE No: **RC-1-002**
Job No: 2014G117	Date: 18-07-14 23-07-14	Ground Level (m): 37.31	Co-Ordinates (): E 527,125.0 N 725,237.3
Engineer: ARUP			Sheet 4 of 4, Rev. 1

Depth / Date	TCR (SCR) RQD	(SPT) Fracture Spacing	Red'cd Level	Legend	Depth (Thickness)	Discontinuities	Detail	Main	Geology	Instrument/Backfill
24.60	100 (100) 100	0						Extremely strong and occasionally very strong, weakly thickly flow banded, pink groundmass, with pink, black, grey and milky white, coarse grained GRANITE. *(continued)*		
25.90	100 (98) 97	1								
27.00	100 (98) 96	1								
28.00	100 (97) 95	2								
28.90	100 (96) 90	4								
22.07 30.00 23.07	100 (96) 80	9	7.31		30.00					
								BH terminated at 30.00m bgl on REs instruction.		

Drilling Progress and Water Observations

Date	Time	Depth	Casing Depth	Casing Dia	Core Dia mm	Water Strike	Water Standing
22-07-14	17.00	30.00	18.60	125	65		8.70
23-07-14	08.00	30.00	18.60	125	65		8.40

Rotary Flush

From (m)	To (m)	Type	Return (%)

GENERAL REMARKS

Driller described rock as extremely strong and slow to drill .
19mm piezometer installed.

All dimensions in metres Scale 1:50	Client	Method/Plant Used: Hydreq	Bit Design	Driller: TH/BD	Logged By: EAT

APPENDIX 2

LABORATORY TEST RESULTS

IRISH DRILLING LTD.
Loughrea Co. Galway

Tel: (091) 841274 Fax: (091) 880861

Contract:	GCOB - Phase 1
Client:	Galway City Council
Engineer:	ARUP
Date:	12-Aug-14
Tested by: DMJ	Checked: JDJ

Point Load Tests (ISRM Methods)

Borehole	Depth	D	W	De^2	P	Is MPa	F	$Is_{(50)}$ MPa	UCS MPa	Remarks
RC-1-001	4.96-5.04	84.7	84.7	7174	21.0	2.93	1.268	3.71	90.91	Strong
	6.60-6.76	84.7	84.7	7174	18.4	2.56	1.268	3.25	79.66	Strong
	7.20-7.45	84.7	84.7	7174	20.0	2.79	1.268	3.53	86.58	Strong
	9.40-9.55	84.8	84.8	7191	50.0	6.95	1.268	8.82	216.07	Extremely Strong
	10.12-10.23	85.0	85.0	7225	40.0	5.54	1.270	7.03	172.22	Very Strong
	10.75-10.90	85.0	85.0	7225	4.0	0.55	1.270	0.70	17.22	Medium Strong
	12.05-12.25	85.0	85.0	7225	19.8	2.74	1.270	3.48	85.25	Strong
	13.00-13.17	85.0	85.0	7225	15.0	2.08	1.270	2.64	64.58	Strong
	14.31-14.50	85.3	85.3	7276	32.3	4.44	1.272	5.65	138.31	Very Strong
	14.74-14.92	85.0	85.0	7225	23.0	3.18	1.270	4.04	99.03	Strong
	16.60-16.76	85.0	85.0	7225	26.0	3.60	1.270	4.57	111.94	Very Strong
	17.67-17.80	85.0	85.0	7225	15.5	2.15	1.270	2.72	66.74	Strong
	18.06-18.30	85.0	85.0	7225	15.0	2.08	1.270	2.64	64.58	Strong
	19.00-19.25	63.1	63.1	3982	37.0	9.29	1.110	10.32	252.81	Extremely Strong
	21.50-21.65	63.1	63.1	3982	18.9	4.75	1.110	5.27	129.14	Very Strong
	23.00-23.20	63.1	63.1	3982	32.8	8.24	1.110	9.15	224.11	Extremely Strong
	24.90-25.08	63.1	63.1	3982	24.0	6.03	1.110	6.69	163.98	Very Strong
	26.07-26.27	63.1	63.1	3982	23.5	5.90	1.110	6.55	160.57	Very Strong
	27.00-27.18	63.2	63.2	3994	17.5	4.38	1.111	4.87	119.28	Very Strong

IRISH DRILLING LTD.
Loughrea Co. Galway

Tel: (091) 841274   Fax: (091) 880861

Contract:	GCOB - Phase 1
Client:	Galway City Council
Engineer:	ARUP
Date:	12-Aug-14
Tested by: DMJ	Checked: JDJ

Point Load Tests **(ISRM Methods)**

Borehole	Depth	D	W	De^2	P	Is MPa	F	$Is_{(50)}$ MPa	UCS MPa	Remarks
RC-1-002	6.95-7.15	85.1	85.1	7242.01	35.0	4.83	1.270	6.14	150.42	Very Strong
	7.30-7.45	85.1	85.1	7242.01	60.0	8.28	1.270	10.53	257.86	Extremely Strong
	8.40-8.60	63.2	63.2	3994.24	31.0	7.76	1.111	8.62	211.29	Extremely Strong
	9.00-9.22	63.2	63.2	3994.24	32.0	8.01	1.111	8.90	218.11	Extremely Strong
	11.14-11.27	63.2	63.2	3994.24	44.0	11.02	1.111	12.24	299.90	Extremely Strong
	12.26-12.41	63.1	63.1	3981.61	45.0	11.30	1.110	12.55	307.47	Extremely Strong
	13.09-13.28	63.2	63.2	3994.24	46.0	11.52	1.111	12.80	313.53	Extremely Strong
	14.55-14.75	63.2	63.2	3994.24	42.5	10.64	1.111	11.82	289.67	Extremely Strong
	15.60-15.82	63.2	63.2	3994.24	38.5	9.64	1.111	10.71	262.41	Extremely Strong
	16.36-16.51	63.2	63.2	3994.24	29.0	7.26	1.111	8.07	197.66	Very Strong
	18.15-18.30	63.2	63.2	3994.24	30.5	7.64	1.111	8.49	207.88	Extremely Strong
	19.50-19.64	63.3	63.2	4000.56	45.0	11.25	1.112	12.50	306.34	Extremely Strong
	20.70-20.86	63.3	63.2	4000.56	49.0	12.25	1.112	13.61	333.57	Extremely Strong
	22.10-22.27	63.2	63.2	3994.24	40.0	10.01	1.111	11.13	272.63	Extremely Strong
	22.90-23.06	63.2	63.2	3994.24	26.0	6.51	1.111	7.23	177.21	Very Strong
	24.40-24.60	63.2	63.2	3994.24	44.0	11.02	1.111	12.24	299.90	Extremely Strong
	25.10-25.30	63.2	63.2	3994.24	28.0	7.01	1.111	7.79	190.84	Very Strong
	26.34-26.54	63.2	63.2	3994.24	38.5	9.64	1.111	10.71	262.41	Extremely Strong
	27.34-27.48	63.2	63.2	3994.24	31.5	7.89	1.111	8.76	214.70	Extremely Strong
	28.54-28.67	63.2	63.2	3994.24	21.0	5.26	1.111	5.84	143.13	Very Strong
	29.00-29.20	63.2	63.2	3994.24	6.0	1.50	1.111	1.67	40.89	Medium Strong

Irish Drilling Ltd

Uniaxial Compressive Strength of rock cores
ASTM D7012-07

Contract	GCOB Phase 1 Ground Investigation	**Job Code:**	14G117
Client	Galway City Council	**Date:**	12/08/2014
Engineer	**ARUP Consulting Engineers**	**Tested By:**	DMJ

Borehole No:	Depth (m)	Sample Diameter (mm)	Sample Length (mm)	Bulk density . . (Mg/m3)	Test Duration (secs)	Mode of Failure	Maximum Load (kN)	Uniaxial Compressive Strength (MPa)	Strength Designation:BSEN ISO14689-1:2003
RC-1-001	8.40-8.70	84.97	181.47	2.630	167.0	Vertical Shear	211.00	37.2	Medium Strong
	12.70-13.00	85.02	186.93	2.630	170.0	Vertical Shear	186.80	32.9	Medium Strong
	17.43-17.70	85.06	186.66	2.720	231.0	Vertical Shear	133.20	23.4	Weak
	23.50-23.86	63.05	*157.24*	2.660	105.0	Diagonal	66.80	21.4	Weak

Irish Drilling Ltd

Uniaxial Compressive Strength of rock cores

ASTM D7012-07

Contract	GCOB Phase 1 Ground Investigation	**Job Code:**	14G117
Client	Galway City Council	**Date:**	12/08/2014
Engineer	**ARUP Consulting Engineers**	**Tested By:**	DMJ

Borehole No:	Depth (m)	Sample Diameter (mm)	Sample Length (mm)	Bulk density . . (Mg/m3)	Test Duration (secs)	Mode of Failure	Maximum Load (kN)	Uniaxial Compressive Strength (MPa)	Strength Designation:BSEN ISO14689-1:2003
RC-1-002	6.22-6.42	84.99	172.93	2.630	200.0	Vertical Shear	294.80	52.0	Strong
	9.22-9.62	63.19	157.38	2.620	193.0	Vertical Shear	220.50	70.3	Strong
	12.85-13.09	63.09	151.24	2.640	359.0	Vertical Shear	537.40	171.9	Very Strong
	16.10-16.36	63.10	153.33	2.640	210.0	Vertical Shear	297.50	95.1	Strong
	22.42-22.59	63.50	*137.60*	2.600	287.0	Vertical Shear	349.70	110.4	Very Strong

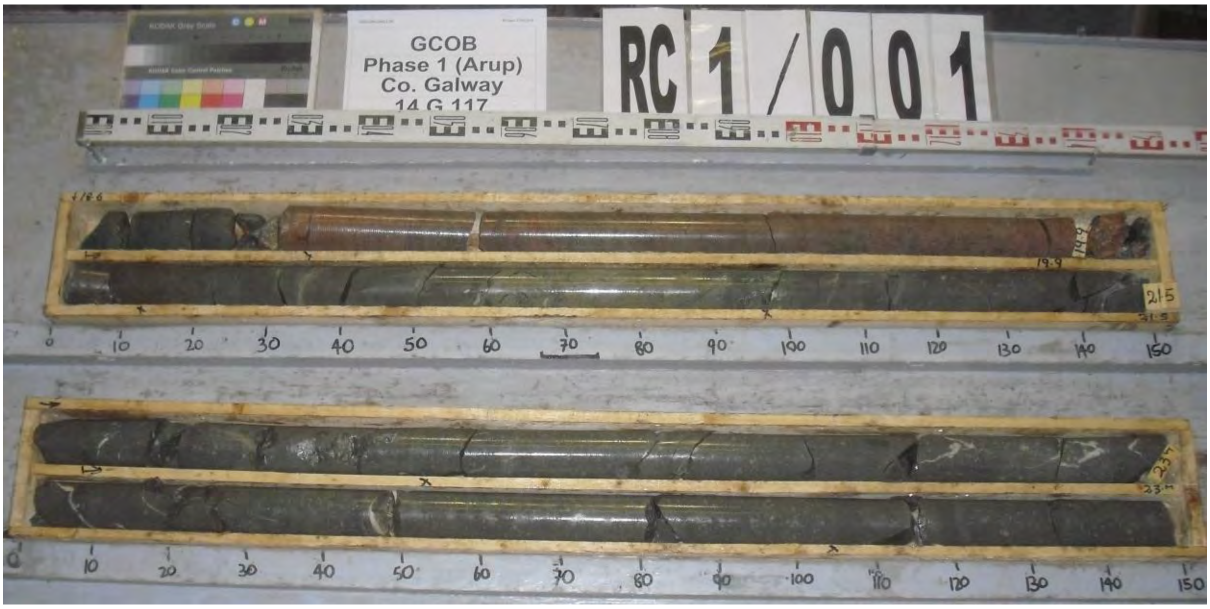
APPENDIX 3

PHOTOGRAPHS


GCOB
Phase 1 (Arup)
Co. Galway
14 G 117
RC 1 / 001


GCOB
Phase 1 (Arup)
Co. Galway
14 G 117
RC 1 / 001


GCOB
Phase 1 (Arup)
Co. Galway
14 G 117
RC 1 / 0 0 1
14.5
15.6m
17.8m
18.6m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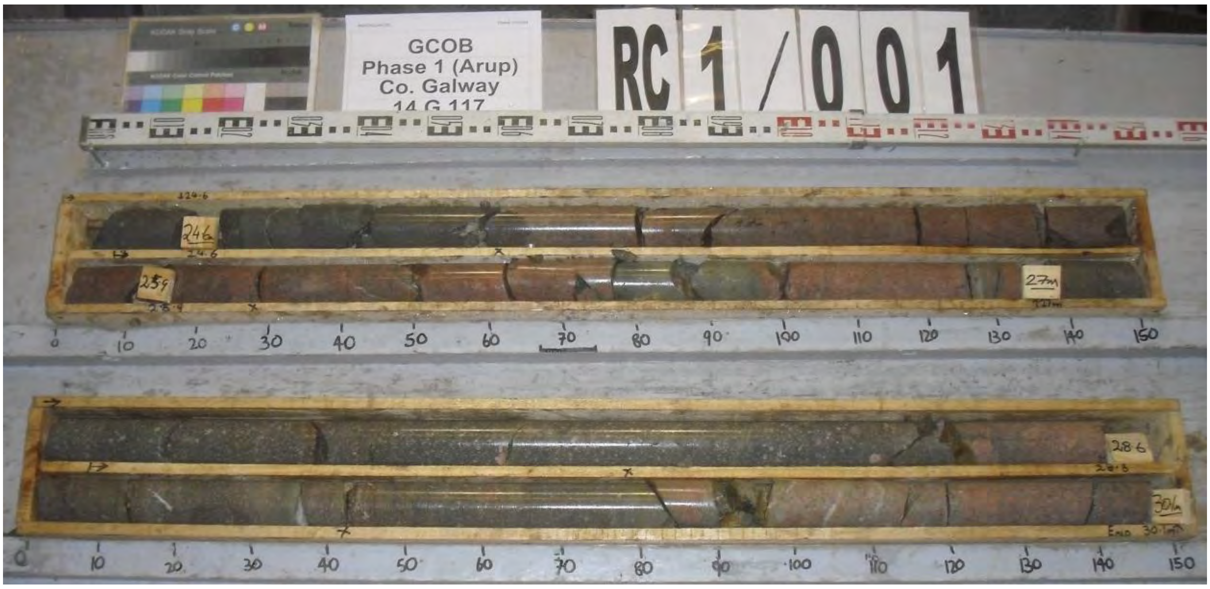
Phase 1 (Arup)
Co. Galway
14 G 117
RC 1 / 0 0 1
21.5


GCOB
Phase 1 (Arup)
Co. Galway
14 G 117
RC 1 / 0 0 1


GCOB
Phase 2 (Arup)
Co. Galway
14 G 117
RC 1002 BH2


GCOB
Phase 2 (Arup)
Co. Galway
14 G 117
RC 1002 BH2


GCOB
Phase 2 (Arup)
Co. Galway
14 G 117
RC 1 0 0 2 BH 2


GCOB
Phase 2 (Arup)
Co. Galway
14 G 117
RC 1 0 0 2 BH 2


GCOB
Phase 2 (Arup)
Co. Galway
14 G 117
RC 1002 BH2


GCOB
Phase 2 (Arup)
Co. Galway
14 G 117
RC 1002 BH2

APPENDIX 4

GEOPHYSICAL SURVEY

Galway City Outer Bypass Phase 1

Geophysical Survey

Report Status: Draft

MGX Project Number:5820

MGX File Ref: 5820d-005.doc

23rd July 2014

Confidential Report To:

Irish Drilling Limited
Old Galway Road
Loughrea
Co. Galway

Arup
50 Ringsend Road
Dublin 4

Report submitted by :
Minerex Geophysics Limited

Unit F4, Maynooth Business Campus
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Issued by:

Ruth Jackson (Senior Geophysicist)

Hartmut Krahn (Senior Geophysicist)

Minerex Geophysics Limited

Subsurface Geophysical Investigations

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey consisting seismic refraction (p-wave) and MASW (s-wave) for the ground investigation of the N6 Galway City Outer Bypass, at Rahoon, Galway city.
2. The main objectives of the survey were to determine ground conditions, estimate the depth to bedrock and the strength of the overburden.
3. Ground conditions were modelled with four layers that represent the transition from soft/loose overburden to strong granite rock.
4. The uppermost layer is generally thin (1m) and comprises topsoil, made ground, overburden and solid pavement surfaces. The geological material within this layer is soft or loose.
5. Layer 2 has a thickness of 1 to 5 m and mainly overburden with firm – stiff compaction but may contain some very weathered granite, especially large boulders.
6. A transitional layer between overburden and fresh granite bedrock contains poor to fair weathered granite or some highly consolidated hard or very dense overburden material.
7. The depth to top of strong granite rock varies between 3 and 12 m bgl. below the survey profiles.
8. The rock is generally shallower on the higher elevated parts of the survey area. The transitional layer 3 containing weathered rock and highly consolidated overburden is usually thicker where is appears deeper under the ground surface.
9. The MASW survey showed results with mixed quality due to shallow rock and changing ground conditions. Ranges for shear wave velocity and small strain shear modulus (G_{max}) have been defined for the overburden. Values of 150 – 500 m/s for velocity and 45 – 500 MPa for G_{max} have been modelled.

CONTENTS

List of Tables, Maps and Figures:

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey for the Galway City Outer Bypass (GCOB) Phase 1. The survey consisted of seismic refraction (p-wave) and MASW (s-wave) measurements for the ground investigation. The survey was commissioned by Irish Drilling Ltd. acting on behalf of Arup.

The role of geophysics as a non-destructive fast method is to allow later targeted direct investigations. Those results can be used to improve the initial results and interpretation.

The proposed development is along the existing roads and open park areas, with approx. 1720 m of geophysics to be carried out.

The survey was aimed both at investigating the depth to intact rock using seismic refraction, while using MASW along the same lines to measure the shear wave velocity and small strain shear modulus of the overburden.

1.2 Objectives

The main objectives of the geophysical survey were:

- To determine the depth to bedrock
- To estimate the strength/stiffness/compaction of overburden materials and the quality of rock
- To determine the type of overburden and rock

1.3 Site Description

The site is located at Rahoon in Galway city. The site consists of a residential area bounded by the Western Distributor Road.

1.4 Geology

Ground conditions are summarised as made ground (asphalt, concrete pavements, granular fill) over natural sandy gravelly till. The bedrock geological map of Galway Bay (GSI, 2004) indicates that the survey area is underlain by Devonian granite.

1.5 Report

This report includes the results and interpretation of the geophysical survey. Maps, figures and tables are included to illustrate the results of the survey. More detailed descriptions of geophysical methods and measurements can be found in GSEG (2002), Milsom (1989) and Reynolds (1997).

The client provided maps of the site and the digital version were used as the background map in this report. Elevations were surveyed / taken from the supplied maps and vertical sections.

The interpretative nature and the non-invasive survey methods must be taken into account when considering the results of this survey and Minerex Geophysics Limited, while using appropriate practice to execute, interpret and present the data, give no guarantees in relation to the existing subsurface.

2. GEOPHYSICAL SURVEY

2.1 Methodology

The methodology consisted of MASW in conjunction with seismic refraction as outlined in the tender documents.

The survey locations are indicated on Map 1. The profiles, locations, chainage and parameters are tabulated in Tab. 1.

All geophysical surveys are acquired, processed and reported in accordance with British Standards BS 5930:1999 +A2:2010 ‘Code of Practice for Site Investigations’.

Table 1: Data Acquisition Parameters for Geophysical Profiles

Line Number	**Profile Name**	**Geophone Spacing/m**	**Profile Length/m**
Line 1	S33 - 38	2	286
Line 2	S6 - 9	2	176
Line 3	S12 - 14 S18 - 19	2	218
Line 4	S27 – 32	2	286
Line 5	S20 - 26	2	300
Line 6	S1 - 5	2	238
Line 7	S10 - 11	2	94
Line 8	S15 - 17	2	128

2.2 Seismic Refraction

The seismic survey consisted of p-wave seismic refraction profiling at the locations shown on Map 1. Each of the profiles consisted of 24 geophones with 2 m spacing, resulting in lengths of 46m per profile. The recording equipment consisted of a 24 Channel GEOMETRICS ES-3000 engineering seismograph with 4.5 Hz vertical geophones. The seismic energy source consisted of a hammer and plate. A zero delay trigger was used to start the recording. At least 7 shot points per p-wave profile were used.

In the seismic refraction survey method a p-wave is generated by a source at the surface resulting in energy travelling through surface layers directly and along boundaries between layers of differing seismic wave velocities. Processing of the seismic data allows geological layer thicknesses and boundaries to be established.

Seismic Refraction generally determines the depth to horizontal or near horizontal layers where the compaction/strength/rock quality changes with an accuracy of 10 – 20% of depth to that layer. Where low velocity layers or shadow zones are present or where layers dip with more than 20 degrees angle the accuracy becomes much less.

In areas with thick concrete or tarmac a low velocity layer exists for the seismic waves below the hard surface layer. This makes it less certain or impossible to pick first breaks from geophones near the source and therefore no velocity determination for the shallow subsurface is possible. This results in larger deviations in the modelling and borehole results are required for a final calibration of the results.

During the survey hard standing surfaces were avoided as much as possible but in some locations the survey had to follow the road or footpath. On Line 4 at S29 and S30 the survey went over a heavily reinforced concrete footpath and a negative effect was caused for the data. On Line 3 at S18 and S19 there was also some detrimental effect on the data from the solid surface layer.

2.3 MASW (Multichannel Analysis of Surface Waves)

The seismic shear wave velocity was determined by active MASW surveying. MASW (Multi-Channel Analysis of Surface Waves) determines the bulk seismic shear wave velocity versus depth. The velocities are used to determine the small strain shear modulus versus depth.

The MASW method was acquired along with the seismic refraction survey though the shots were done with a larger time window. The MASW used 24 geophones with 2 m spacing and a length of 46m per profile. The recording equipment consisted of a 24 Channel GEOMETRICS ES-3000 engineering seismograph with 4.5 Hz vertical geophones. The seismic energy source consisted of a hammer and plate. A zero delay trigger was used to start the recording.

Many constraints exist for the MASW method and the main factors on this site that affect the methods are strong vertical velocity gradients, lateral changing velocity structure and shallow rock along some of the profiles.

2.4 Site Work

The data acquisition was carried out between the 3rd and 8th of May 2014. The weather conditions were variable throughout the acquisition period. Health and safety standards were adhered to at all times. While working on roadways the area was clearly highlighted by the use of warning signs and cones and a traffic management system was in place. Road work was carried out at night when traffic was at a minimum.

The locations and elevations were surveyed with a TRIMBLE RTK-GPS to accuracy < 0.02m.

3. RESULTS AND INTERPRETATION

The interpretation of geophysical data was carried out utilising the known response of geophysical measurements, typical physical parameters for subsurface features that may underlay the site, and the experience of the authors.

3.1 Seismic Refraction Data

The seismic refraction data was positioned and processed with the SEISIMAGER software package to give a layered model of the subsurface. The numbers of layers has been determined by analysing the seismic traces and up to 4 layers were used in the models. All seismic profiles were subject to a standardised processing sequence which consisted of a topographic correction which was based on integrated elevation data, first break picking, tomographic inversion, travel-time computation via ray-tracing and velocity modelling. Residual deviations of typically 0.5 to 1.5 msec RMS have been obtained for each profile. Following each processing stage QC procedures were adhered to. The resulting layer boundaries are shown as thick lines on the cross sections (Figures 1a – 1d). The average seismic velocities obtained within the layers are annotated on the sections as bold black numbers.

Layer 1 is generally thin (1m) and comprises topsoil, made ground, overburden and solid pavement surfaces. The seismic velocity of 300 – 500 m/s indicates that the geological material in this layer would be mainly soft or loose in term of stiffness and compaction.

Layer 2 was modelled with a velocity range of 800 – 1100 m/s and has a general thickness between 1 to 5 m. This layer is mainly overburden with firm – stiff compaction but may contain some very weathered granite, especially large boulders. The layer can be excavated by digging with some ripping. Large boulders may have to be broken up.

Layer 3 velocities of 2200 - 2400 m/s indicate a poor to fair weathered granite or some highly consolidated hard or very dense overburden material. The average depth to the top of this layer is 4 m but is variable along the profiles. The elevation/depth can be seen on the sections for the profiles in Figures 1a – 1d. The excavatability for this layer is rippable to marginal rippable though may require some breaking where large residual granite boulders are present.

The depth to top of strong rock (Layer 4 with a seismic velocity of 4400 – 4600 m/s) varies between 3 and 12 m bgl. under the survey profiles. This layer requires breaking/blasting for removal.

Table 2 summarises the interpretation. The strength/stiffness/compaction and the rock quality have been estimated from the seismic velocity. The estimation of the excavatability for the bedrock has been made according to the caterpillar chart published in Reynolds (1997). The geotechnical assessment for rippability will have to take factors like rock type and jointing into account and the estimation in this report is solely based on the seismic velocities. Excavation of rock may not be required for the future development but it gives a good indication about the rock quality.

Interpreted cross sections are shown in Figures 2a – 2d. The interpretation has been made by delineating four different layers according to their seismic velocity.

Table 2: Summary of Results and Interpretation

Layer	General Seismic Velocity Range (km/sec)	Compaction/ Strength/ Rock Quality	Interpretation	Estimated Excavation Method
1	300 - 500	Soft/Loose	Topsoil/Overburden/Pavement Layers	Diggable
2	800 - 1100	Firm-Stiff/Dense	Overburden or very weathered granite	Diggable/Rippable
3	2200 – 2400	Poor – fair Rock Hard/Very dense	Weathered Granite or highly consolidated overburden	Rippable/Marginal rippable/Some breaking
4	4400 - 4600	Strong competent Rock	Strong Granite	Breaking & Blasting

Draft results for rotary core holes indicate a similar depth to rock in drilling and geophysical survey.

3.2 MASW

The MASW profiles were positioned, processed, analysed and modelled with the SEISIMAGER/SW and the SURFSEIS3 software packages. The objective is to obtain a profile of shear wave velocity versus depth and to calculate the small strain shear modulus (stiffness) Gmax from the velocities.

For the interpretation the end shots and some other shots of each profile were analysed in order to extract the best possible dispersion curves for the modelling stage. The selected shot points were then allocated to distances along profiles and one shot (most representative of the profile) is used in the display of the results for the MASW data (Appendix A).

Following processing steps are done to achieve this:

1. Edit the shot point geometry and display the shot points for each profile
2. A dispersion curve (phase velocity versus frequency plot) is computed
3. The maximum amplitudes of the dispersion curve are selected and then the picks for the dispersion curve are truncated (frequency gate) and smoothed
4. An initial model of shear-wave velocity versus depth V_s is computed

5. An inversion is carried out to create the final V_s curve (Shear wave versus depth)
6. For stable repeatable results the shear wave velocity versus depth is displayed
7. The small strain shear modulus (also named Gmax) for each shot point and depth has been computed by using a density of 2000kg/m^3 typical for highly consolidated overburden (Eq. 1)

   (Eq. 1) $G = V_s^2 * \rho * 10^{-6}$

   Where G = Shear Modulus (MPa)

   V_s = Seismic Shear Wave Velocity (m/s)

   ρ = Density (kg/m^3)

Intensive efforts have been made to extract the best dispersion curves by time gating, trace selecting and test processing various sources versus receiver trace distances and trace ranges and by directional selection of traces. The MASW method works best on profiles where the velocity increases continuously with depth rather than where sudden velocity jumps occur (e.g. shallow rock).

Appendix A shows the results for a shot point from each line. The images for each shot are the shot record, the dispersion image (phase velocity – frequency transformation, dispersion image) and the shear wave velocity versus depth model.

These examples show the large variation of quality and quality of the shear waves and dispersion images. The first example (Line 1, Profile S36) shows a good fan of surface waves (left image) and a clear dispersion curve (indicated by the blue-green central zone within the red that rises at lower frequencies). The resulting model of s-wave velocity versus depth is well defined, the dark grey zone indicates the depth range covered by the model (The light grey part of the model at shallow and deep depths is only required for the numerical model but does not represent the ground).

The second example (Line 2, Profile 9) shows no good fan of surface waves and the dispersion image is poor, with the velocity picks only roughly indicating a possible ground model.

Table 3 give the ranges for s-wave velocities and small strain shear modulus along each profile line. The values are representative for the overburden material as the depth range generally falls within the overburden. Some comments are made about the quality of the dispersion curves and which distances along the profile the data is best.

Table 3: MASW Shear Wave Velocity

Line	Range of S-Wave Velocities (m/s) along profile	Range of Small Strain Shear Modulus (MPa) along profile	Comments
1	300 - 600	180 – 720	Good dispersion curves, the ranges are valid for the entire length of Line 1
2	300 - 400	180 – 320	Poor curves, the ranges are only apparent on some of the shots from this profile and rock velocities start to show on the dispersion curves as the rock is quite shallow and the layer surfaces quite ragged
3	150 - 500	45 – 500	Good curves, the lowest values of 150 are appearing at the end of the profile (S14) where the rock is also quite deep
4	150 - 350	45 – 245	Good curves for the relatively shallow overburden range
5	200 - 650	80 – 845	Good curves for the first half of the line, for the second part the rock is relatively shallow and high rock velocities rather than lower overburden velocities are dominating the second half of Line 5
6	300 - 600	180 – 720	Poor curves as rock is relatively shallow, only the start of the profile shows good results for the overburden
7	400 - 850	320 – 1445	Poor curves on the first half of the profile with better values for overburden on the second half where the rock is deeper
8	350 - 500	245 – 500	Good curves for the overburden range

The lowest recorded s-wave velocities are 150 m/s so it can be said that there is no very soft ground like peat, organic sediments or soft silt present under the survey profiles.

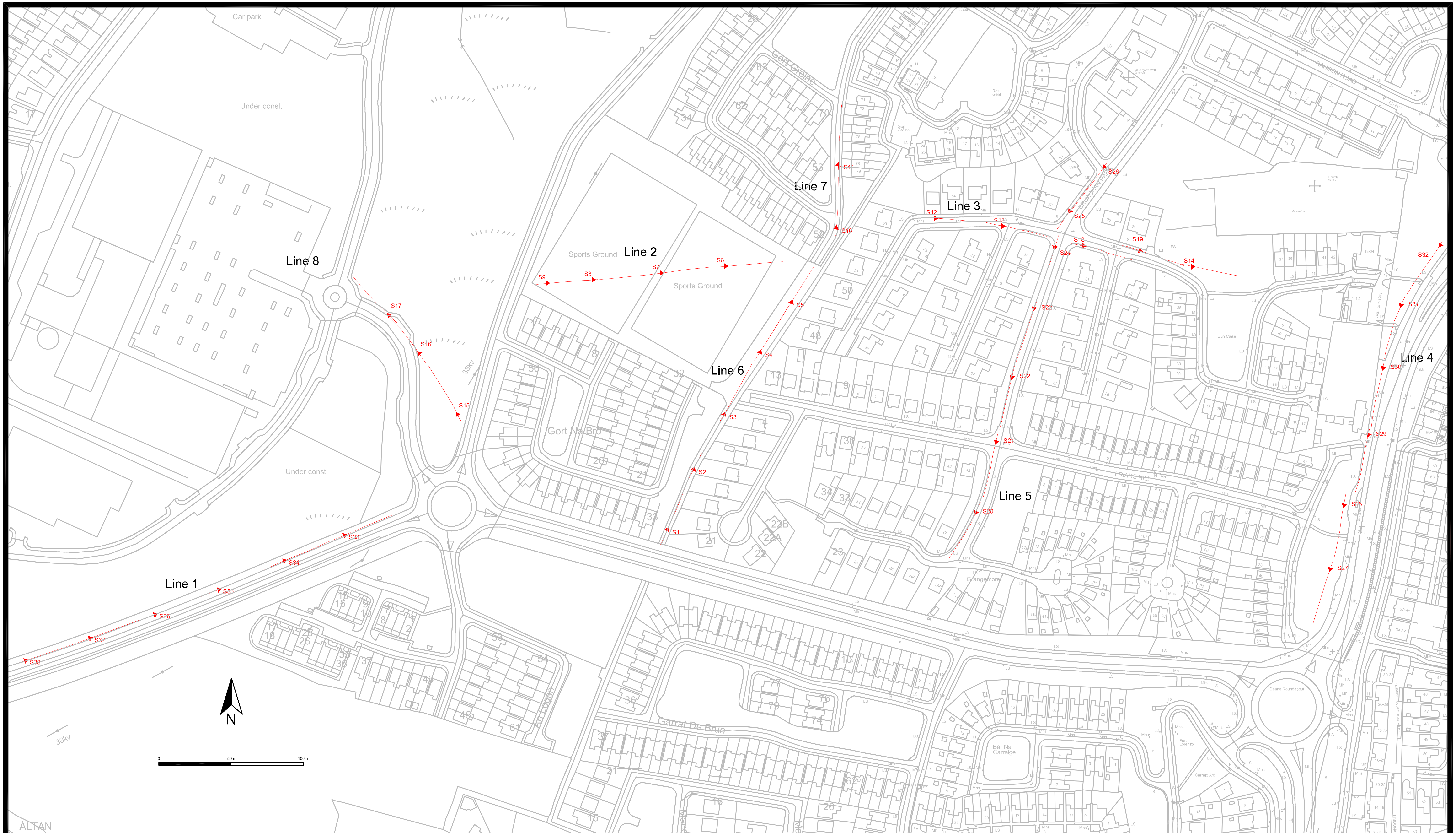
4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made:

- The geophysical data from the GCOB Phase 1 survey shows that the subsurface geology can be represented by a four layer model with a transition from soft and loose overburden to strong granite rock.
- Layer 1 is generally thin (1m) and comprises topsoil, made ground, overburden and solid pavement surfaces.
- Layer 2 is mainly overburden with firm – stiff compaction but may contain some very weathered granite, especially large boulders. This layer has a thickness of 1 to 5 m.
- Layer 3 is a transitional layer between overburden and bedrock. It is a poor to fair weathered granite or some highly consolidated hard or very dense overburden material. The average depth to the top of this layer is 4 m but is variable along the profiles.
- The depth to top of strong granite rock varies between 3 and 12 m bgl. below the survey profiles.
- The rock is generally shallower on the higher elevated parts of the survey area. The transitional layer 3 containing weathered rock and highly consolidated overburden is usually thicker where is appears deeper under the ground surface.
- The MASW survey showed results with mixed quality due to shallow rock and changing ground conditions. Ranges for shear wave velocity and small strain shear modulus (G_{max}) have been defined for the overburden. Values of 150 – 500 m/s for velocity and 45 – 500 MPa for G_{max} have been modelled.

5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.
2. **GSI, 1995.** Geology of South Cork. Geological Survey of Ireland 1995.
3. **Milsom, 1989.** Field Geophysics. John Wiley and Sons.
4. **Reynolds, 1997.** An Introduction to Applied and Environmental Geophysics. John Wiley and Son.



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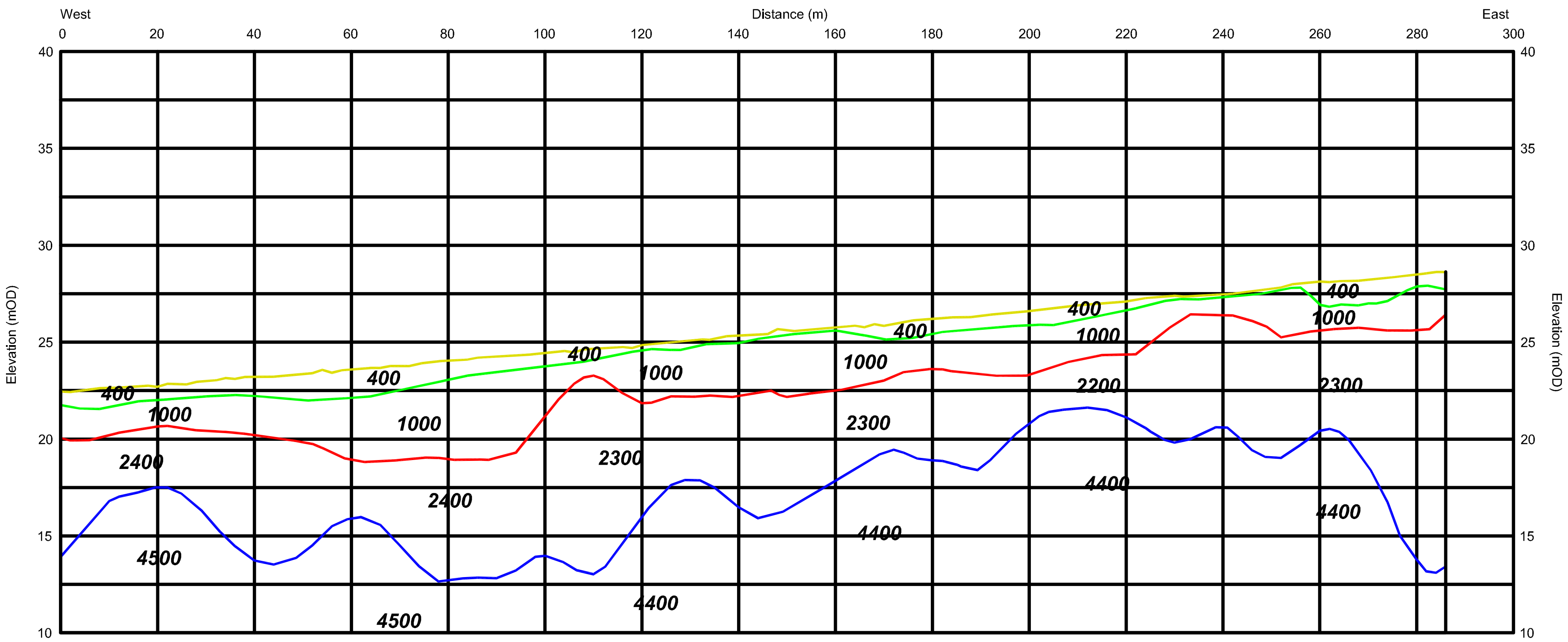
CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Map 1: Geophysical Survey Location Map

SCALE:	1:2500 @ A3
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFigs.dwg
STATUS:	Draft

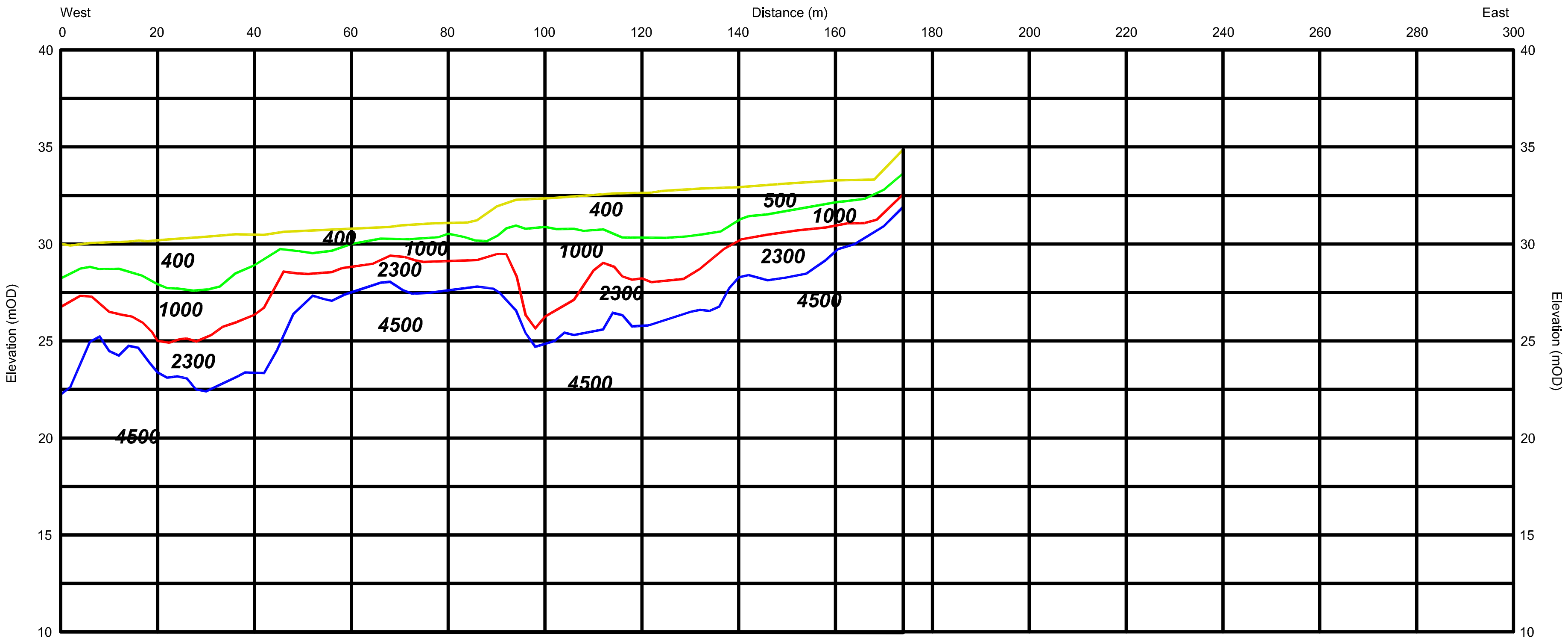
LEGEND:

Seismic Refraction and MASW Profile

Seismic Refraction Line 1 (S38 - S33) Model



Seismic Refraction Line 2 (S9 - S6) Model



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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 1a: Models of Geophysical Survey

SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

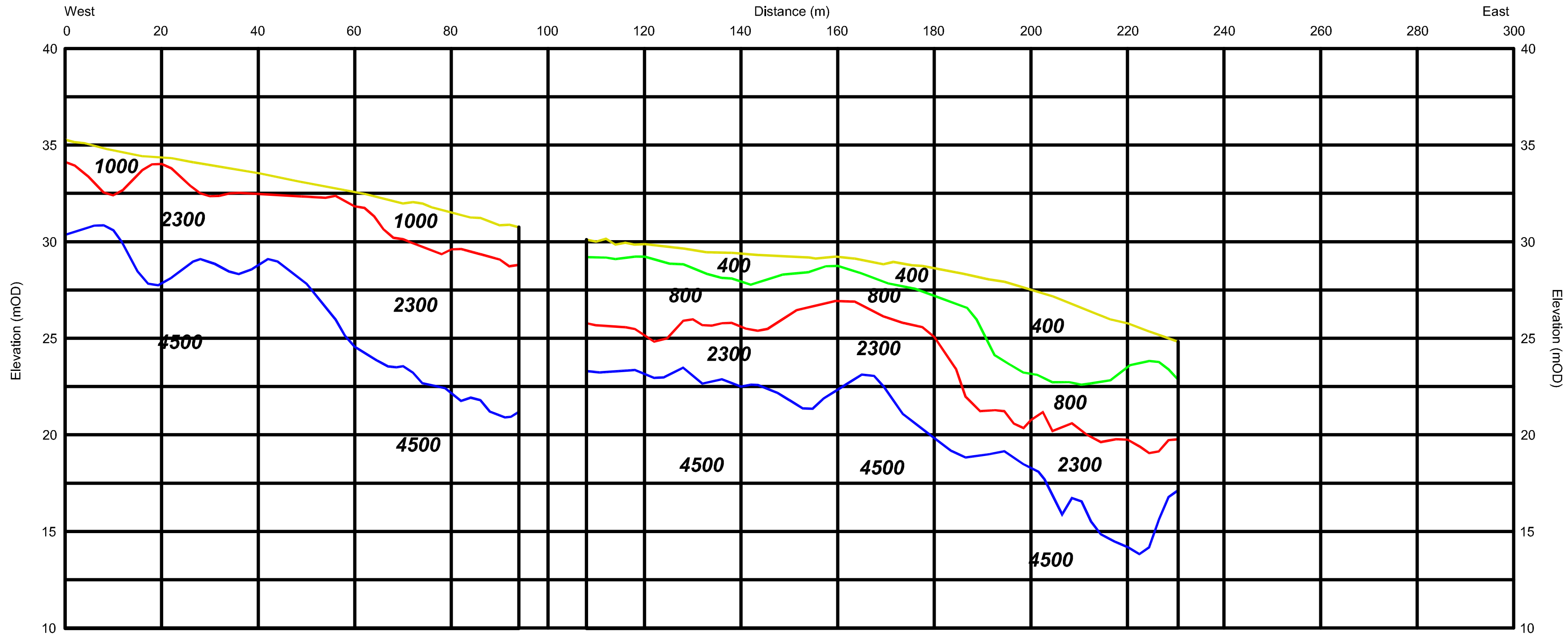
LEGEND:

2200 Average Seismic Velocity in m/s

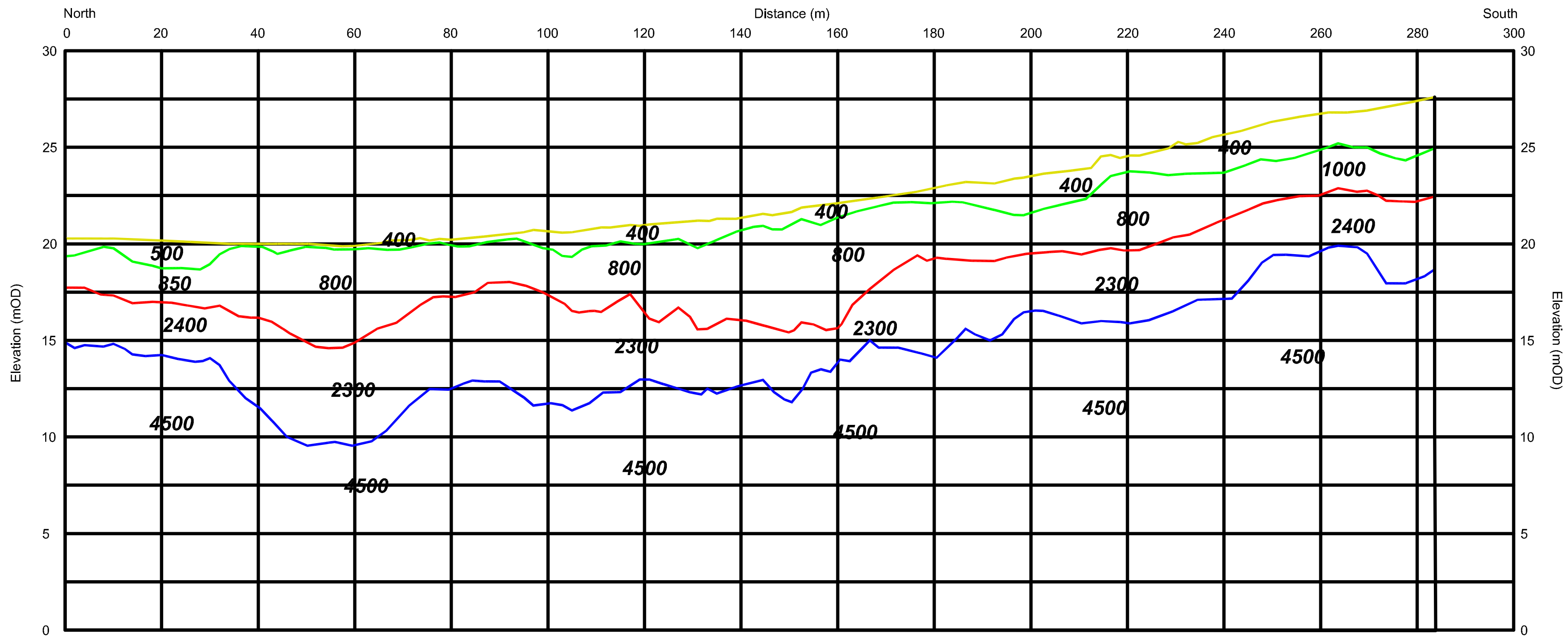
Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (300 - 500 m/s)
- Top of Layer 2 (800 - 1100 m/s)
- Top of Layer 3 (2200 - 2400 m/s)
- Top of Layer 4 (4400 - 4600 m/s)

Seismic Refraction Line 3 (S12 - S14, S18 - 19) Model



Seismic Refraction Line 4 (S32 - S27) Model



Seismic Refraction Line 5 (S26 - S20) Model

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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 1b: Models of Geophysical Survey

SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

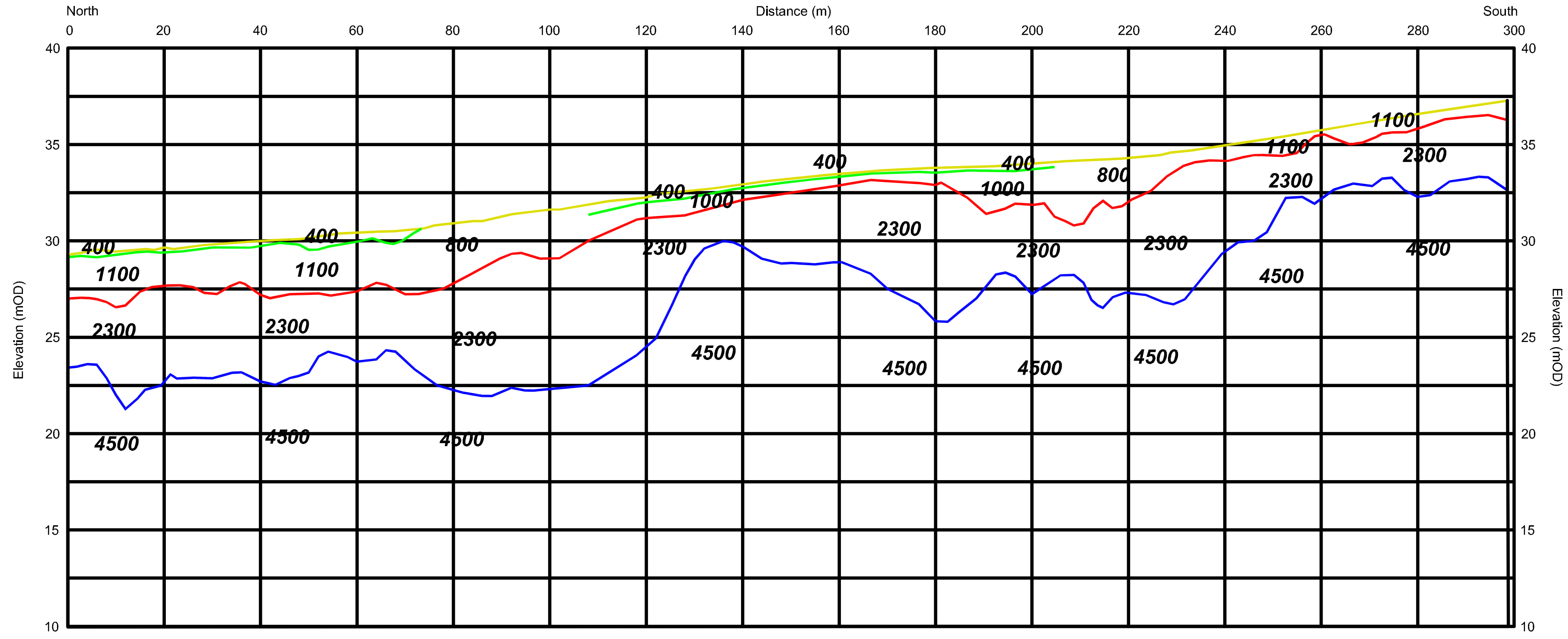
LEGEND:

2200 Average Seismic Velocity in m/s

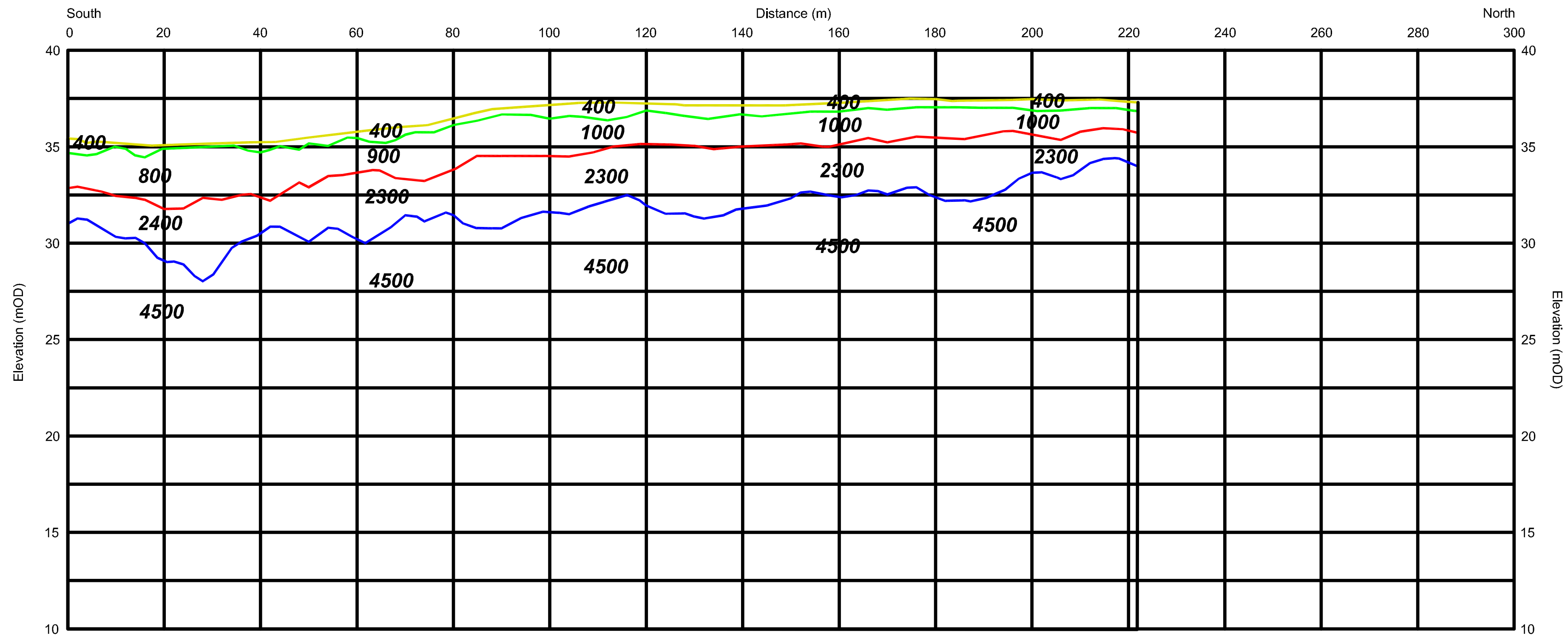
Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (300 - 500 m/s)
- Top of Layer 2 (800 - 1100 m/s)
- Top of Layer 3 (2200 - 2400 m/s)
- Top of Layer 4 (4400 - 4600 m/s)

Seismic Refraction Line 5 (S26 - S20) Model



Seismic Refraction Line 6 (S1 - S5) Model



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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 1c: Models of Geophysical Survey

SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

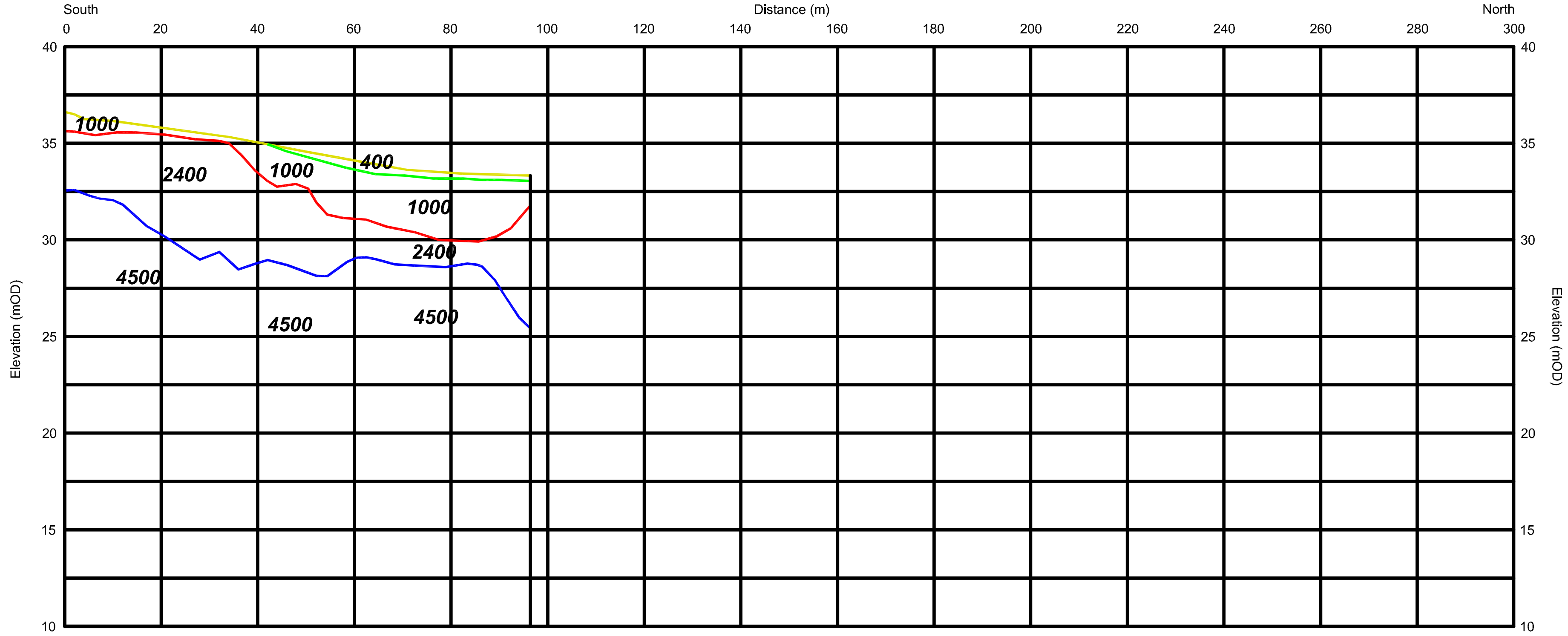
LEGEND:

2200 Average Seismic Velocity in m/s

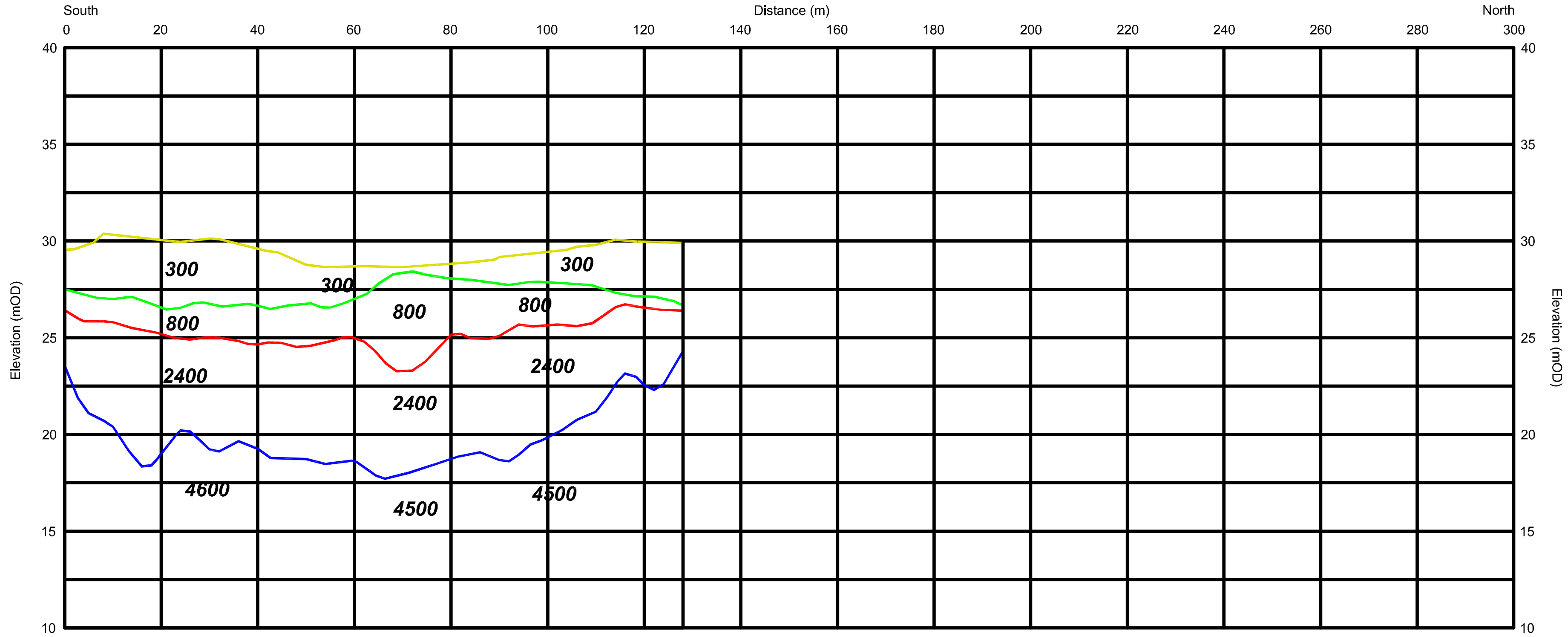
Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (300 - 500 m/s)
- Top of Layer 2 (800 - 1100 m/s)
- Top of Layer 3 (2200 - 2400 m/s)
- Top of Layer 4 (4400 - 4600 m/s)

Seismic Refraction Line 7 (S10 - S11) Model



Seismic Refraction Line 8 (S15 - S17) Model



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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 1d: Models of Geophysical Survey

SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

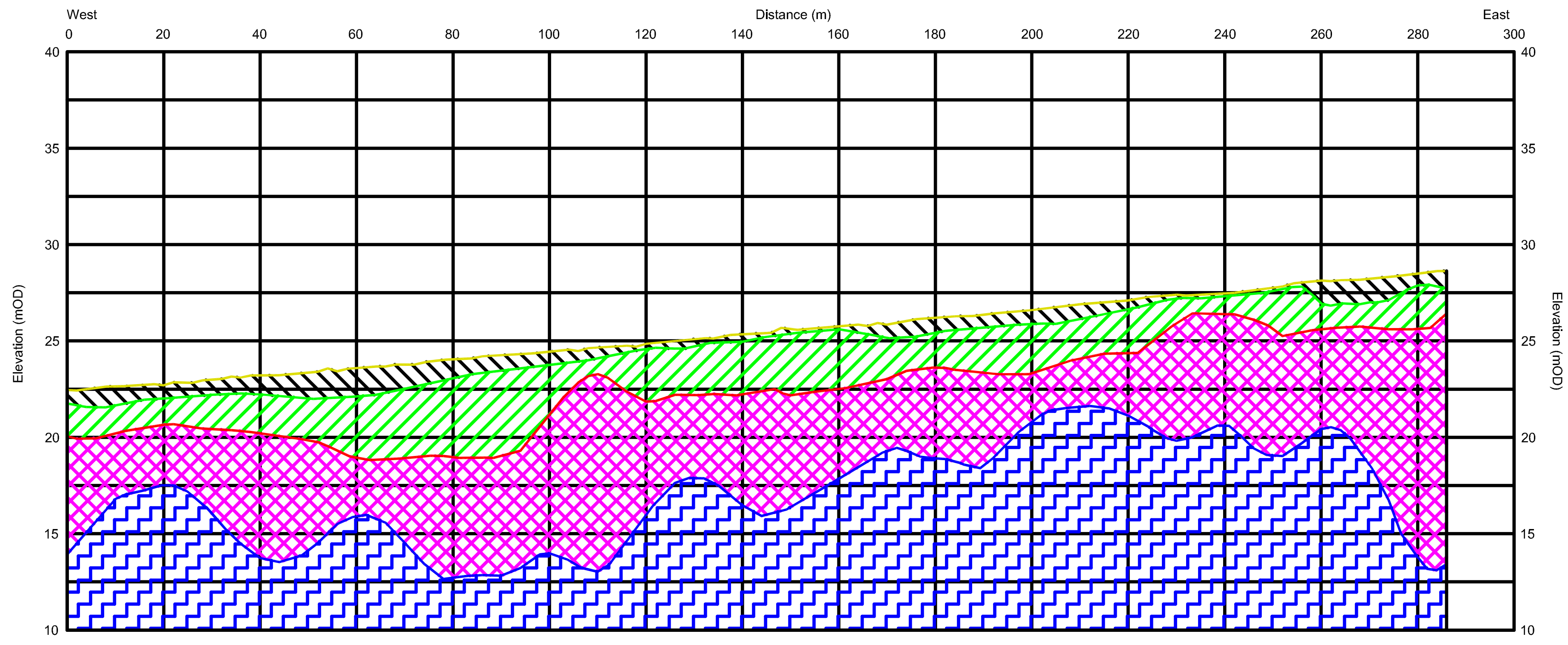
LEGEND:

2200 Average Seismic Velocity in m/s

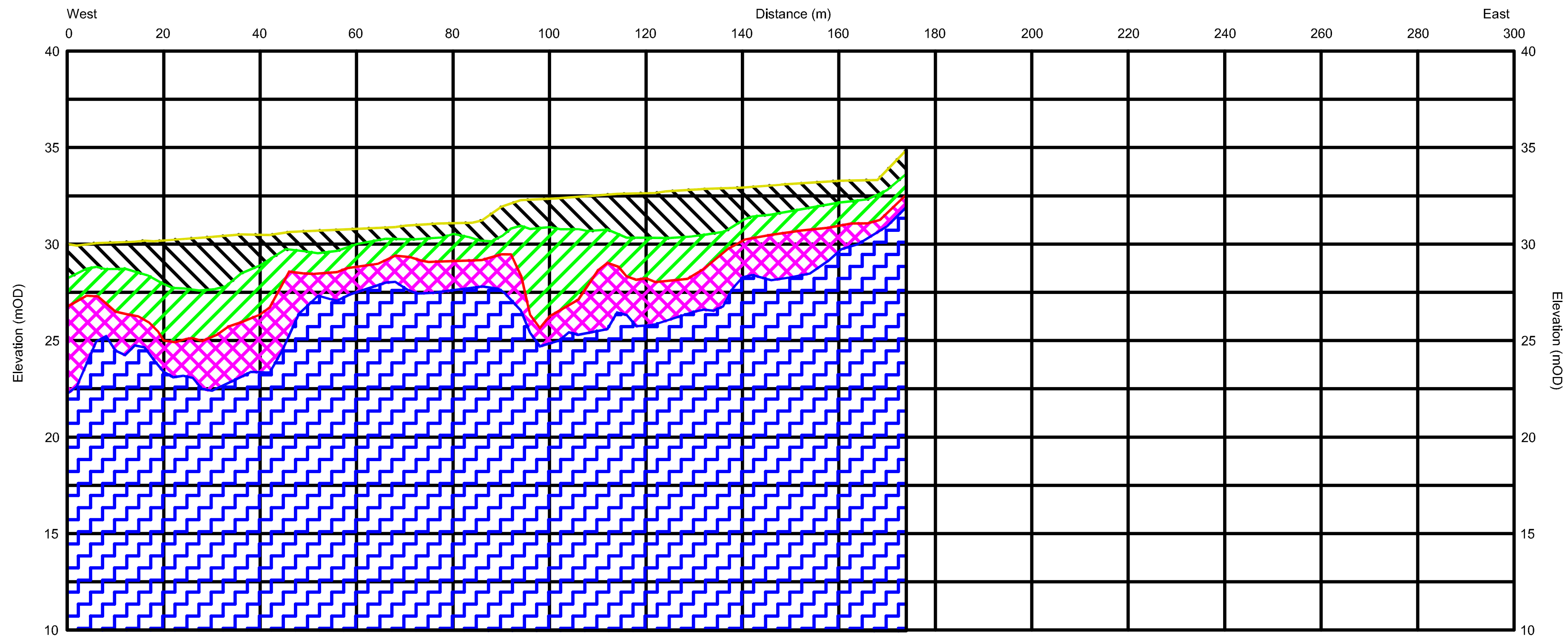
Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (300 - 500 m/s)
- Top of Layer 2 (800 - 1100 m/s)
- Top of Layer 3 (2200 - 2400 m/s)
- Top of Layer 4 (4400 - 4600 m/s)

Seismic Refraction Line 1 (S38 - S33) Interpretation



Seismic Refraction Line 2 (S9 - S6) Interpretation



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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 2a: Interpretation of Geophysical Survey

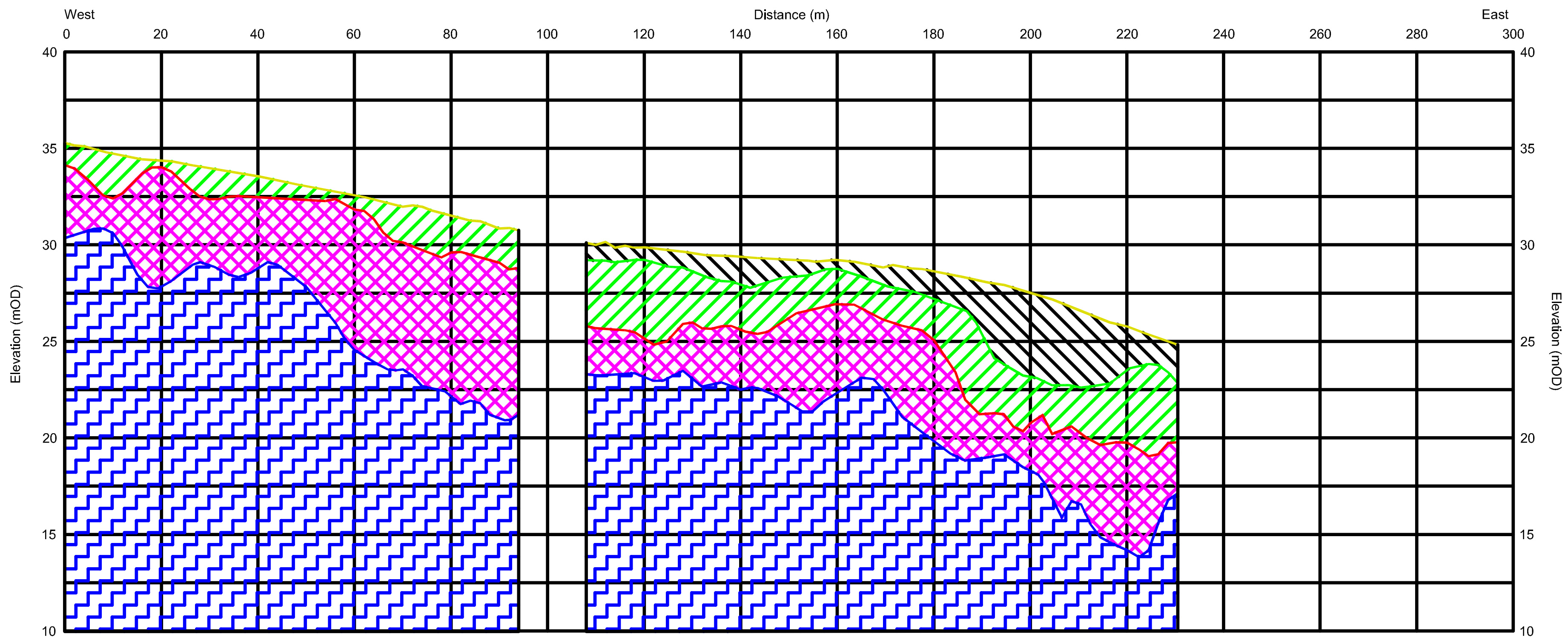
SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

LEGEND:

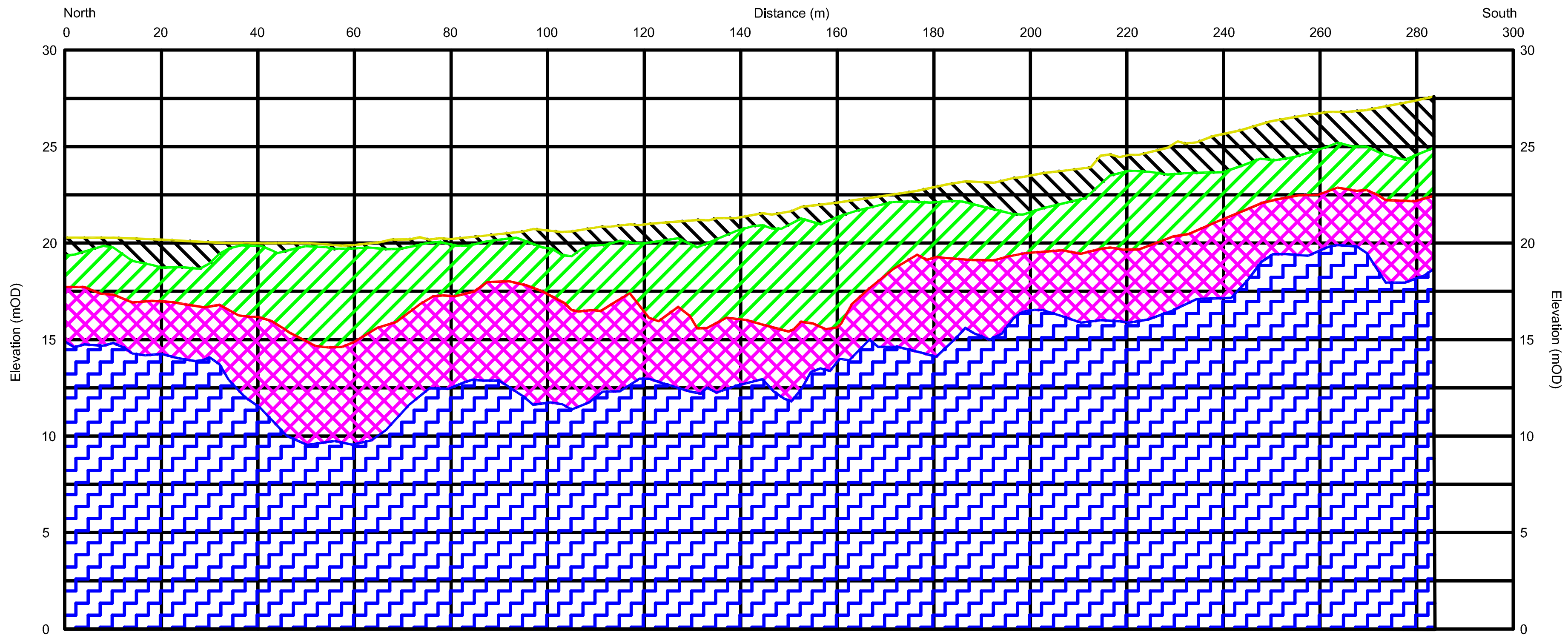
Integrated Combined Interpretation:

1 Soft/loose Topsoil/Overburden/Pavement Layers
2 Firm to Stiff/Dense Overburden or very weathered Granite
3 Poor to Fair Weathered Granite or hard/very dense Overbruden
4 Strong Granite

Seismic Refraction Line 3 (S12 - S14, S18 - 19) Interpretation



Seismic Refraction Line 4 (S32 - S27) Interpretation



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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 2b: Interpretation of Geophysical Survey

SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

LEGEND:

Integrated Combined Interpretation:

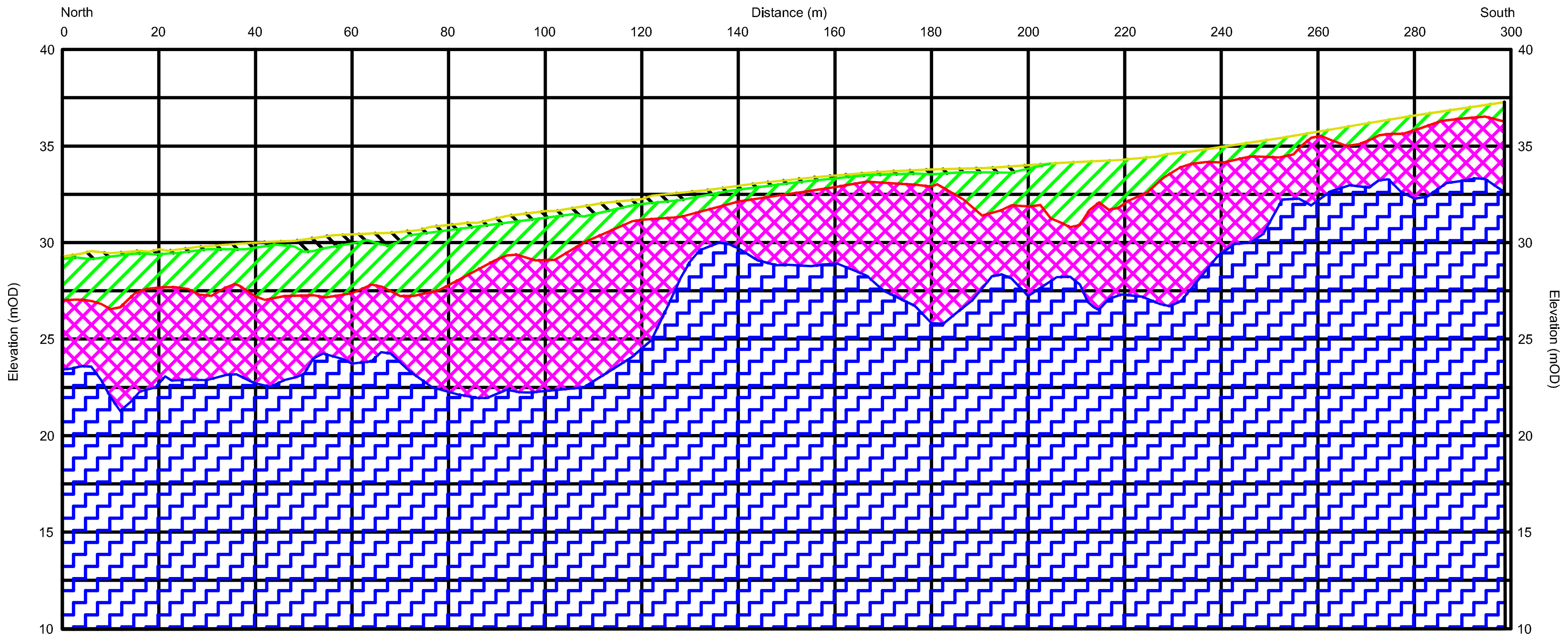
1 Soft/loose Topsoil/Overburden/Pavement Layers

2 Firm to Stiff/Dense Overburden or very weathered Granite

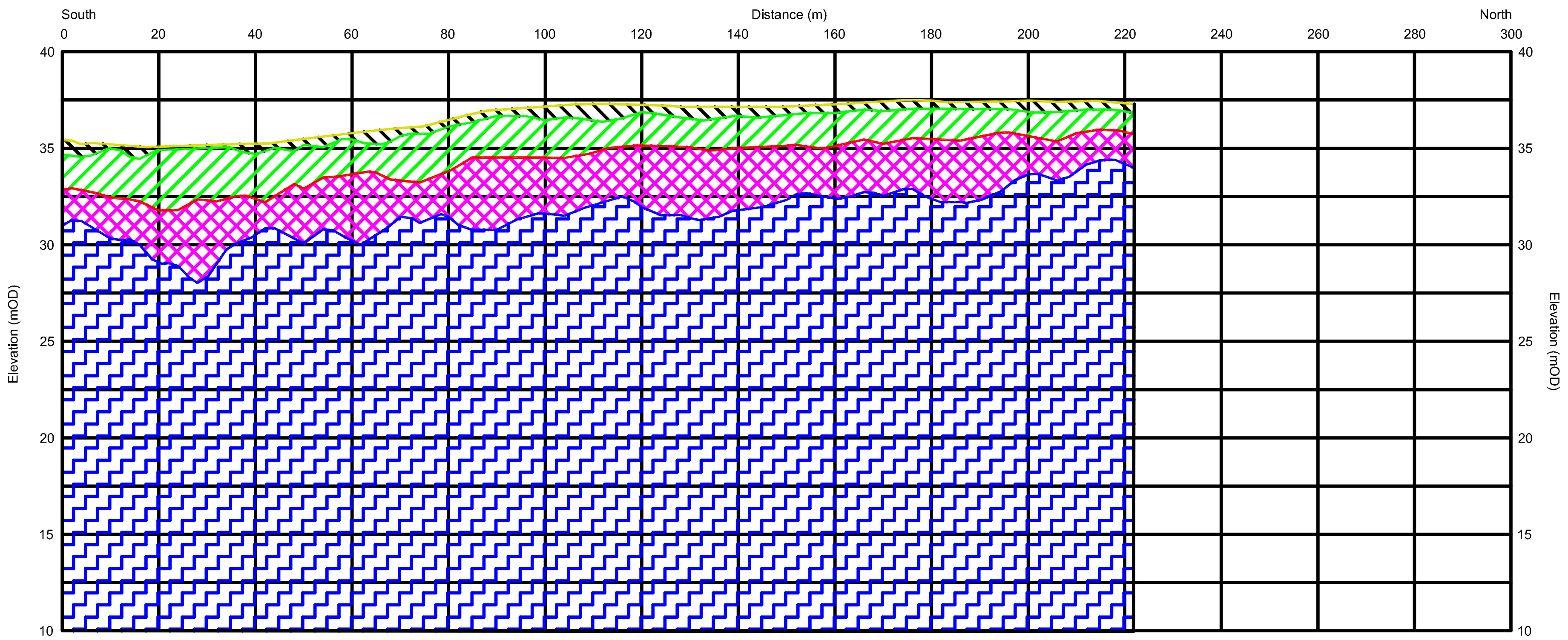
3 Poor to Fair Weathered Granite or hard/very dense Overbruden

4 Strong Granite

Seismic Refraction Line 5 (S26 - S20) Interpretation



Seismic Refraction Line 6 (S1 - S5) Interpretation



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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 2c: Interpretation of Geophysical Survey

SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

LEGEND:

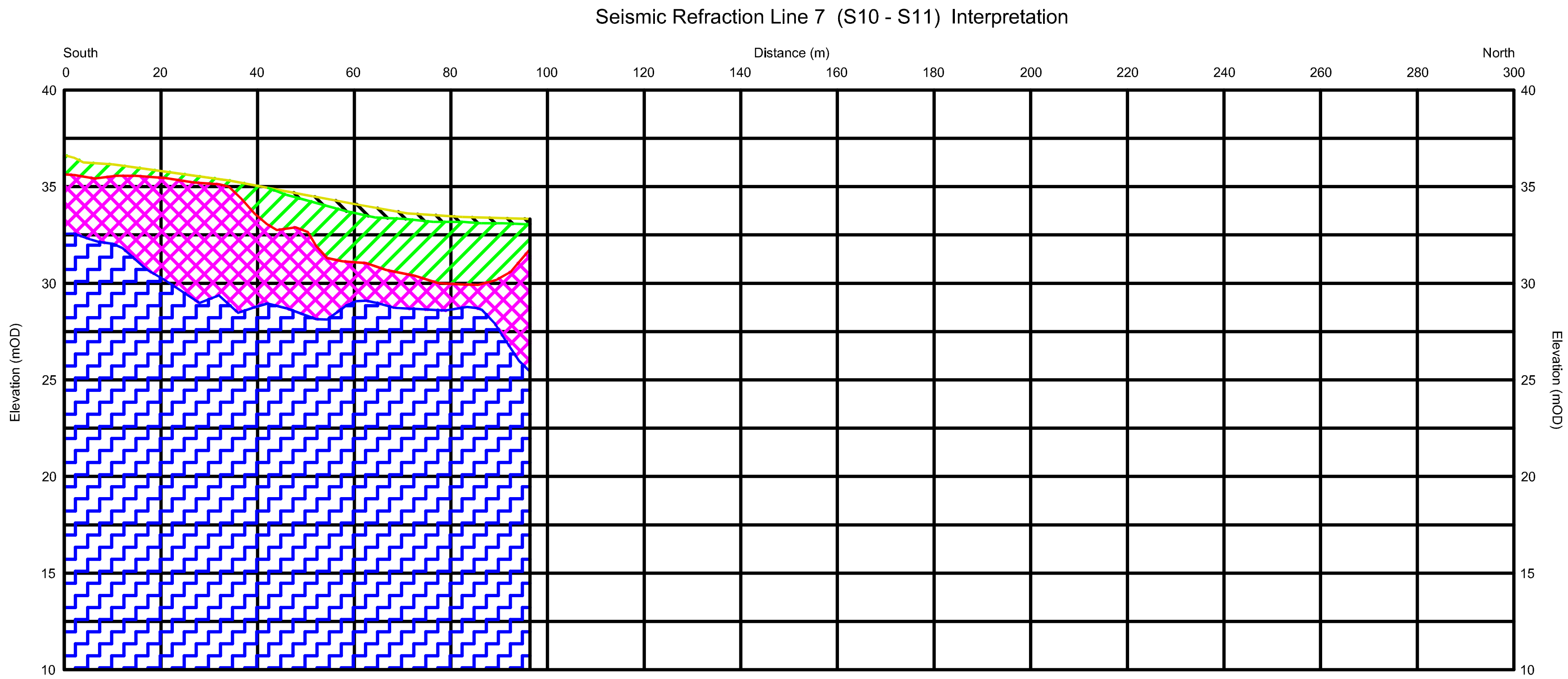
Integrated Combined Interpretation:

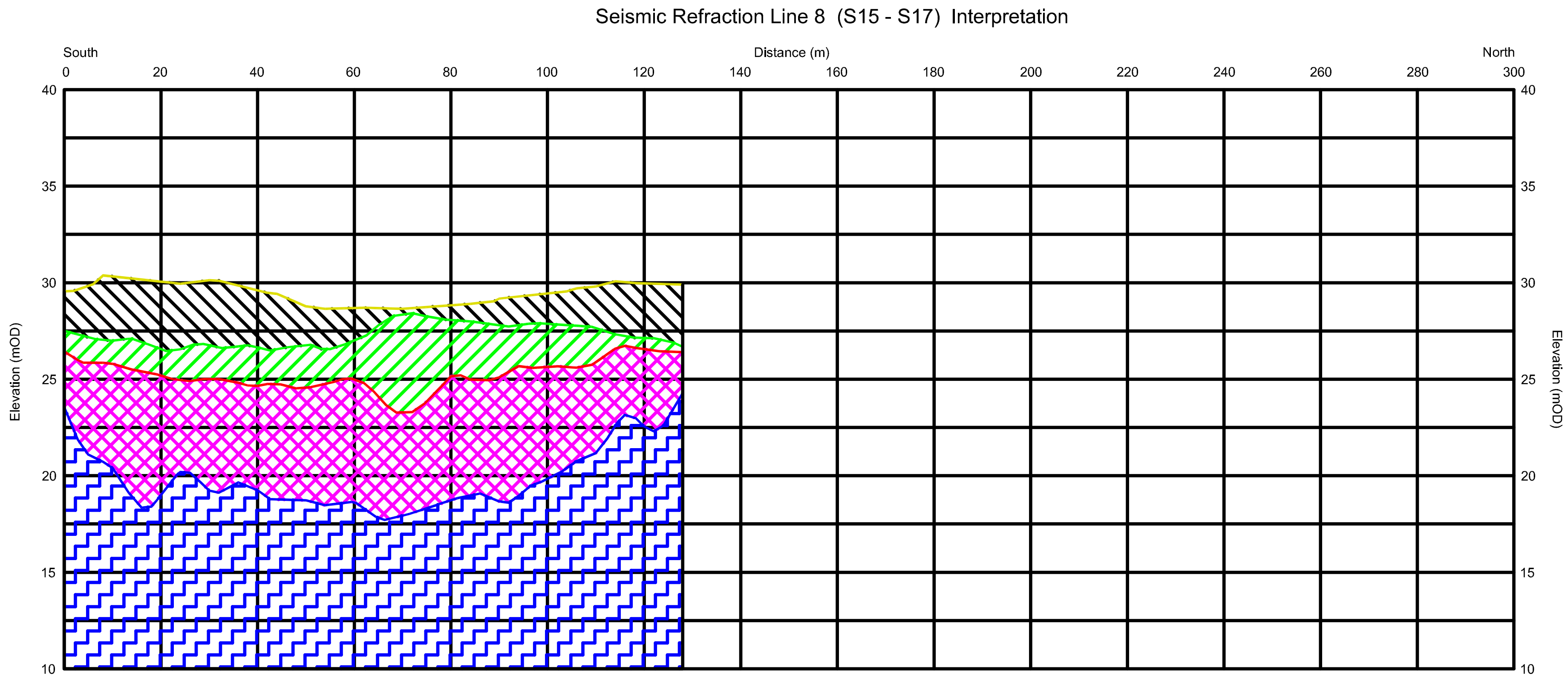
1 Soft/loose Topsoil/Overburden/Pavement Layers

2 Firm to Stiff/Dense Overburden or very weathered Granite

3 Poor to Fair Weathered Granite or hard/very dense Overbruden

4 Strong Granite





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CLIENT	Irish Drilling Ltd.
PROJECT	Galway City Outer Bypass Phase 1 Geophysical Survey
TITLE	Figure 2d: Interpretation of Geophysical Survey

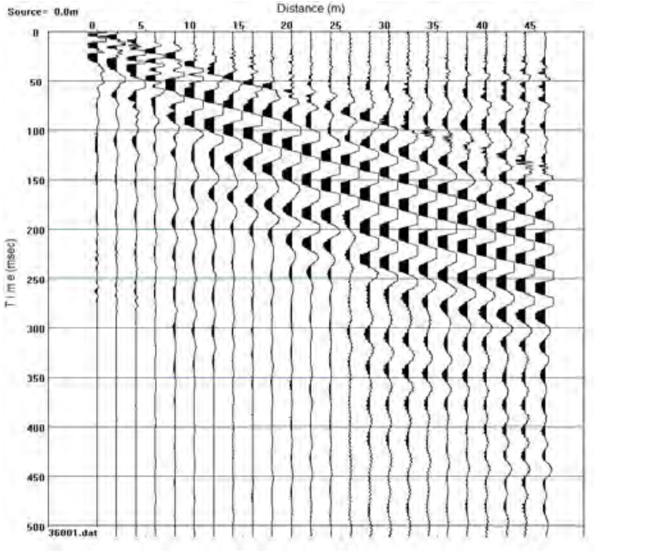
SCALE:	NTS, V.E. 1:4
PROJECT:	5820
DRAWN:	RJ
DATE:	14/07/2014
MGX FILE:	5820d_MapsFig.dwg
STATUS:	Draft

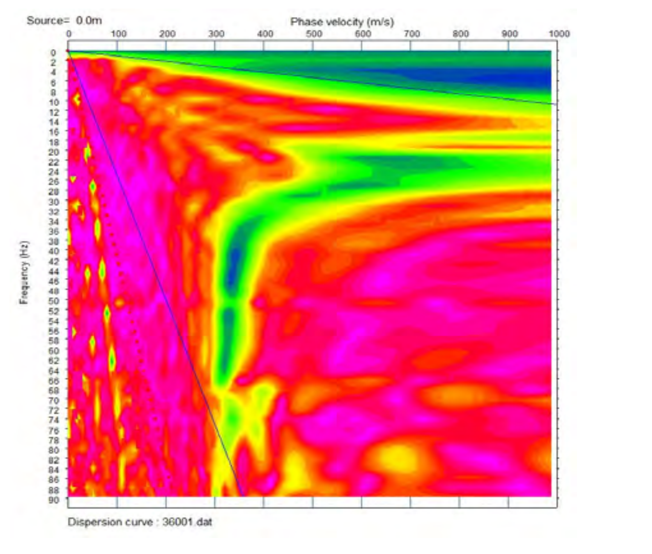
LEGEND:

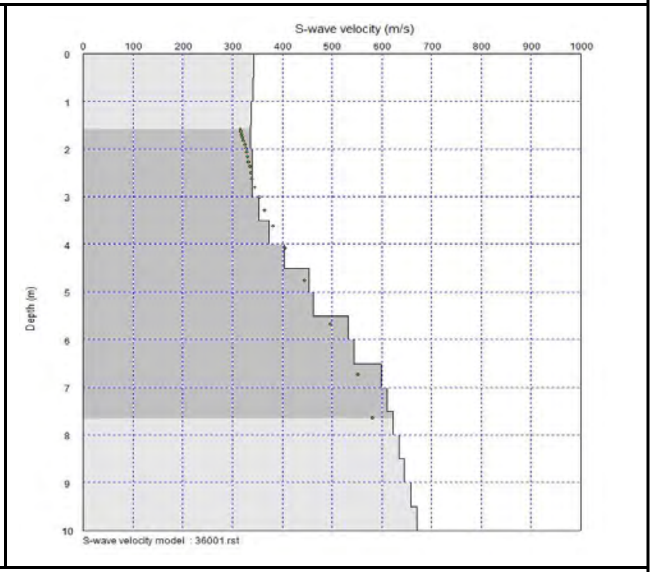
Integrated Combined Interpretation:
1 Soft/loose Topsoil/Overburden/Pavement Layers
2 Firm to Stiff/Dense Overburden or very weathered Granite
3 Poor to Fair Weathered Granite or hard/very dense Overbruden
4 Strong Granite

Appendix A: Results of MASW Survey

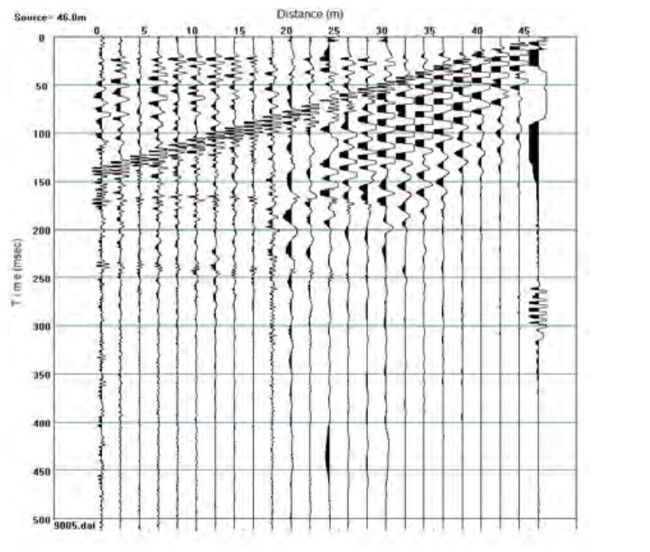
MASW Results from Line 1, Profile 36, Shot 1. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.

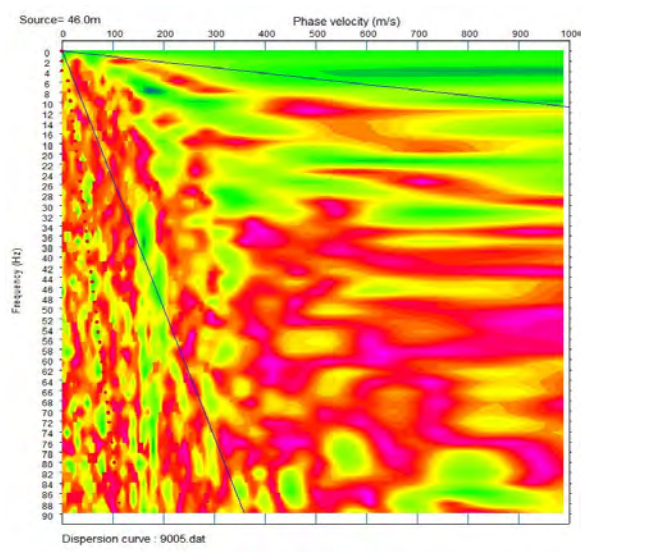


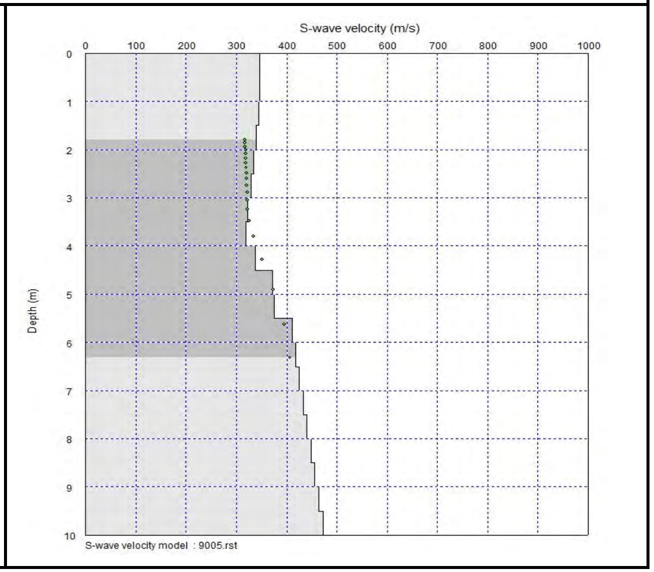




MASW Results from Line 2, Profile 9, Shot 5. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.

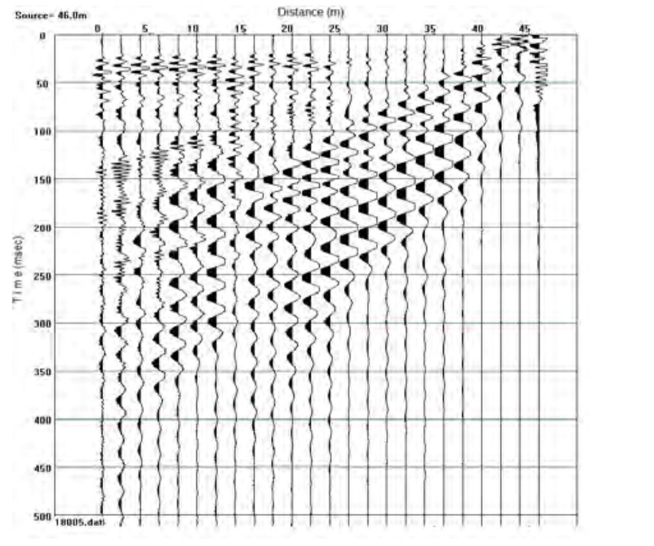


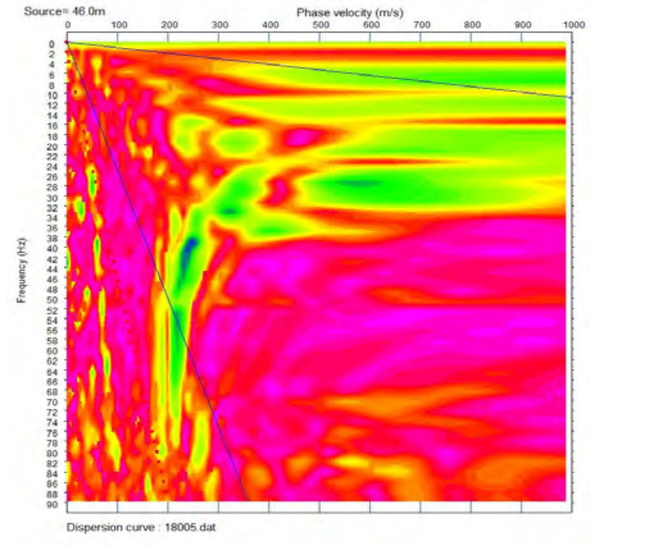


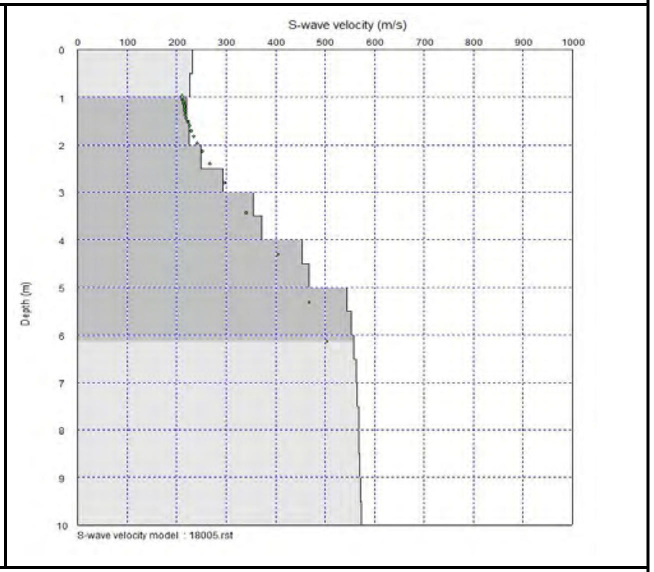


Appendix A: Results of MASW Survey

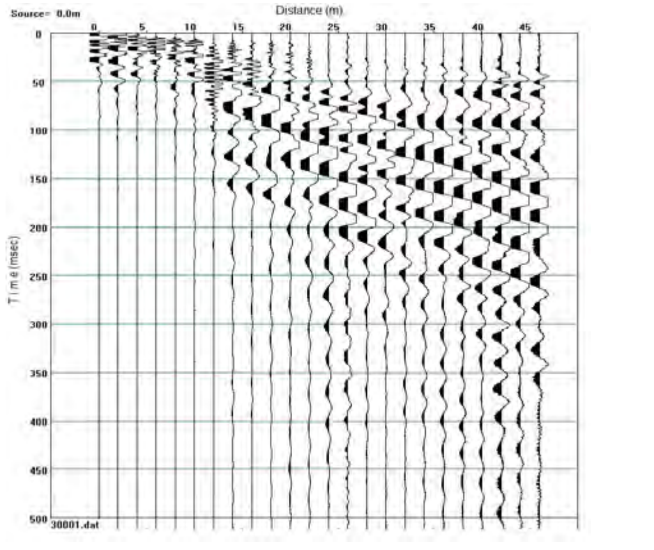
MASW Results from Line 3, Profile 18, Shot 5. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.

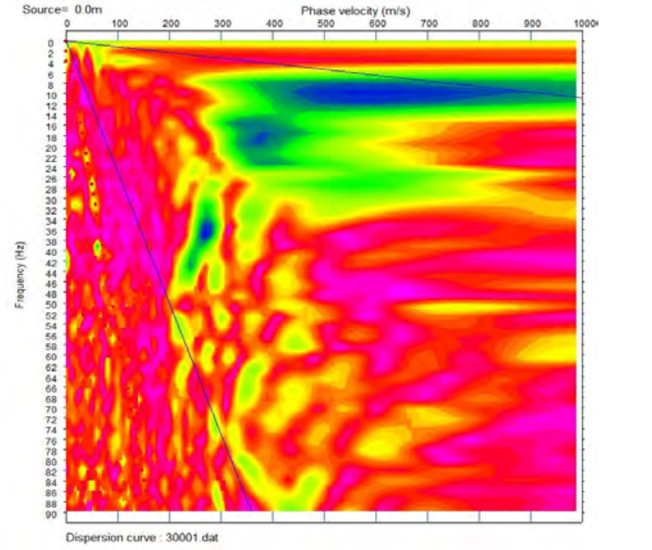


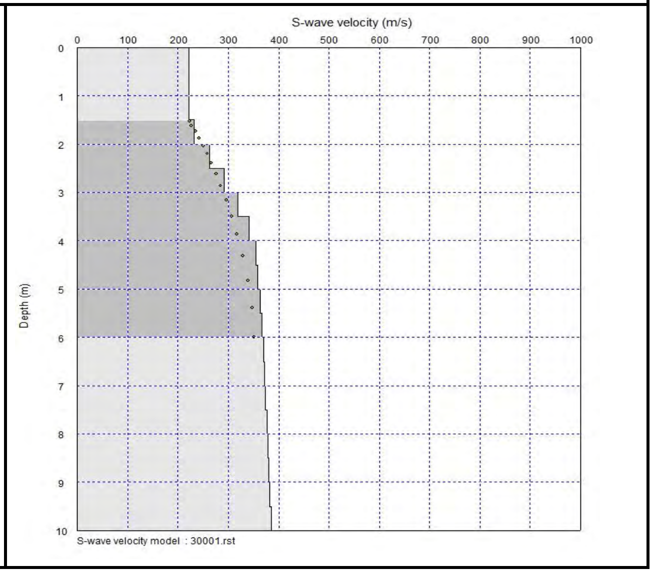




MASW Results from Line 4, Profile 30, Shot 1. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.

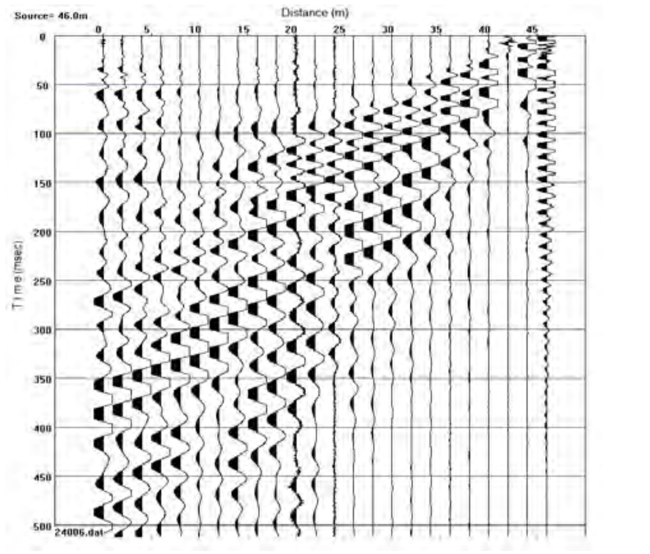


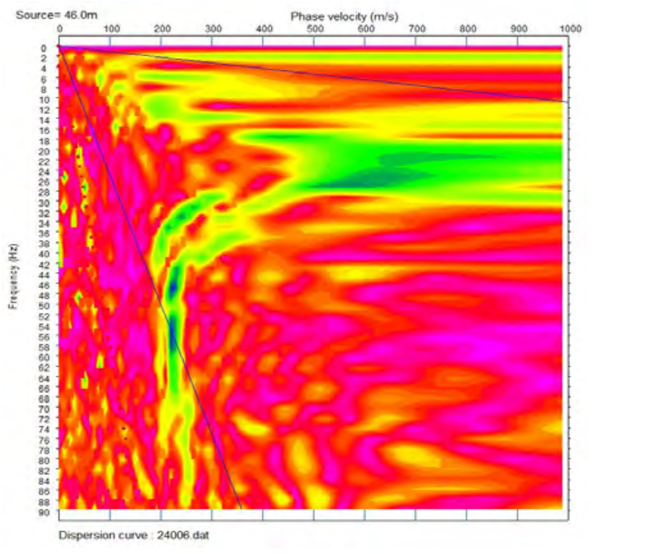


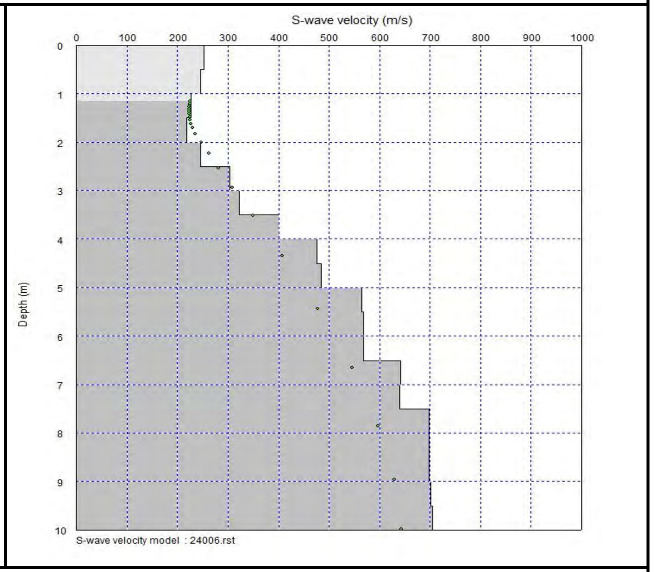


Appendix A: Results of MASW Survey

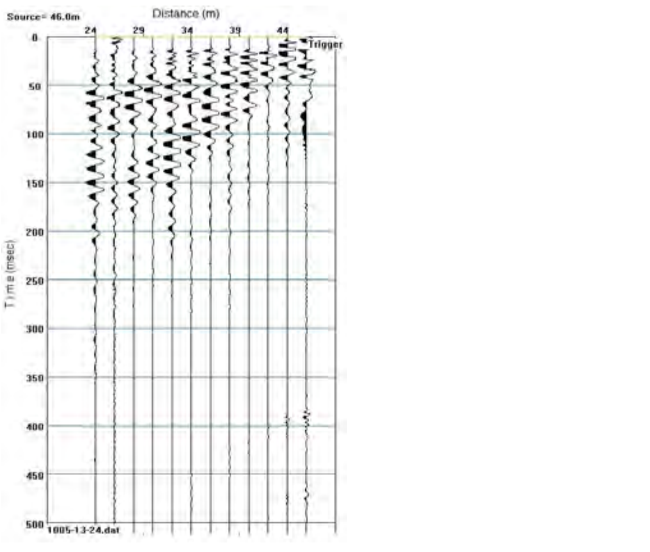
MASW Results from Line 5, Profile 24, Shot 6. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.

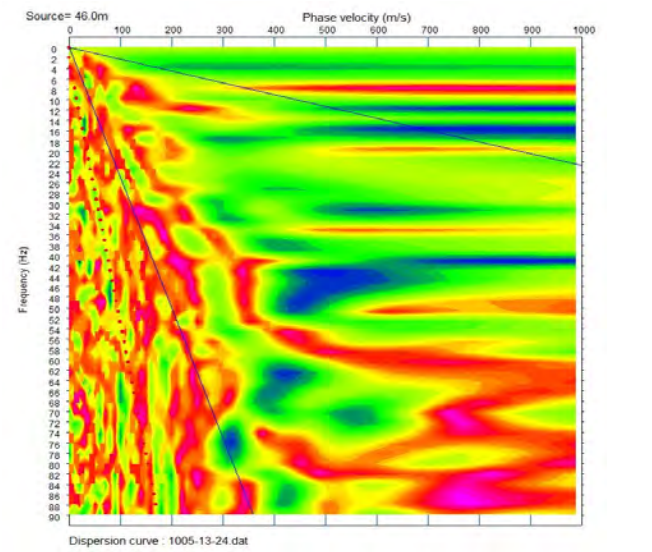


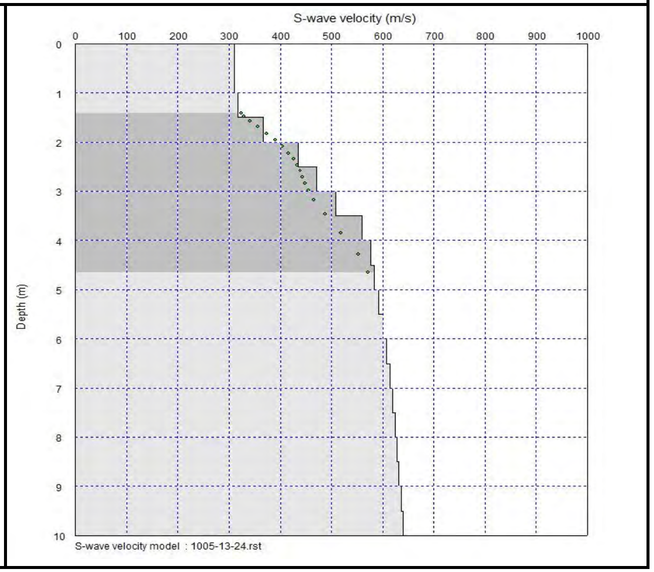




MASW Results from Line 6, Profile 1, Shot 5, Traces 13-24. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.

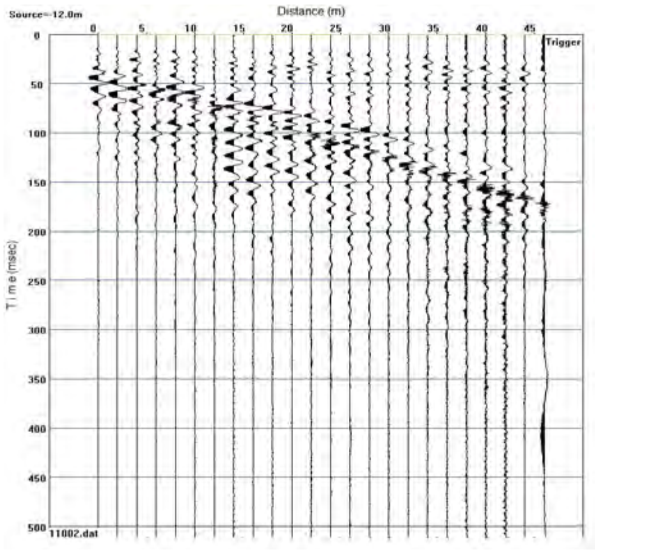


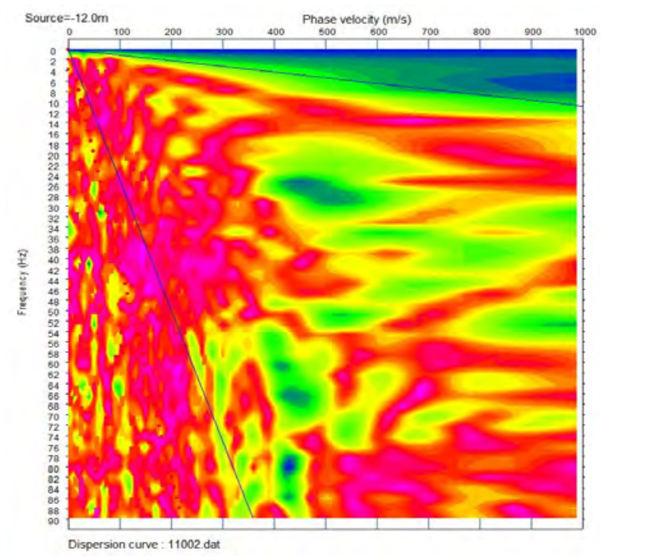


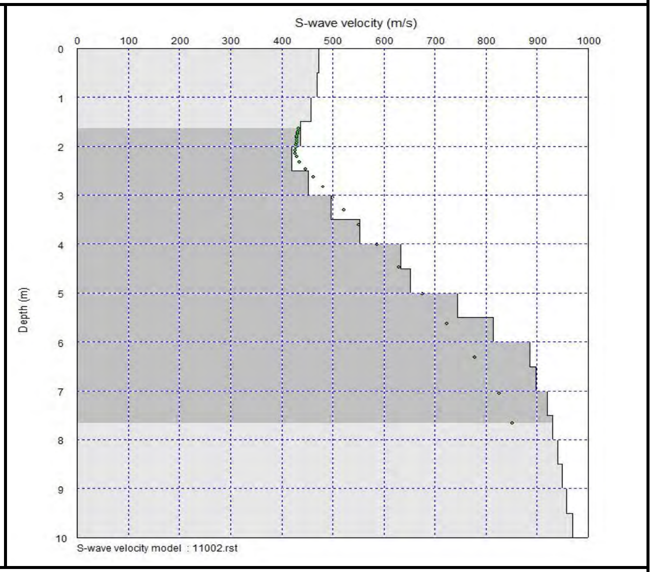


Appendix A: Results of MASW Survey

MASW Results from Line 7, Profile 11, Shot 2. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.







MASW Results from Line 8, Profile 16, Shot 6. From left to right images show the seismic shot record, the dispersion curve and the shear wave velocity - versus depth model.