N4 Collooney to Castlebaldwin, *Proposed Road Development*

APPENDIX NO. 13.4

Extracts from Preliminary Geotechnical Interpretive Report

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The information contained herein has been extracted by Sligo Councils Road Design Section from the geotechnical Interpretive Report prepared by AGL Consulting Engineers. The extracted text has been compiled solely to allow the reader gauge an overview of the Description of the Existing Environment Section of the Soils and Geology section of the EIA.

Where there are differing descriptions in the text of this document to text in the Soils and Geology Chapter, the contents of the Soils and Geology Chapter of the EIS will take precedence.

1.1 Existing Ground Conditions

1.1.1 DESIGN UNIT 1

Ch. 0-190 - 1+600

The 6" Drift maps from the GSI and the subsoils maps from the EPA indicate that the ground conditions along this section generally consist of shale and sandstone glacial till with some possible boggy alluvial deposits along the north shore of the Toberscanavan Loughs. The GSI drift maps indicate that rock is shallow in the area, and the OS background maps identify caves adjacent to the road at the north end of the scheme in Toberbride, which could be evidence of karstification. Between Ch. 0+000 and 0+130 the trial pits encountered 1.5 to 1.8 of made ground comprised of very soft boulder clay with some to many cobbles, organic material and pieces of waste material, bitumen and wooden beams, particularly at the roundabout at the north end of the scheme (TP-101). TP-101 and TP-102 were terminated at refusal on possible rock at a depth of 2.5 m and 1.5 m, respectively. There was 0.7 m of soft boulder clay over the rock in TP-101. The existing road is in a rock cut between about Ch. 130 and 355. Rock is exposed from a shallow depth on the cut slope on the east side of the road. (Photo No. 4.1.1). TP-104 refused on probable rock at a depth of 1.2 m at the top of the slope. The overburden consisted of very soft Boulder Clay (brown slightly gravelly CLAY with many cobbles and boulders). On the west side of the cut BH-101 and BH-101A reached refusal at a depth of 0.5-0.6 m on possible weathered rock and the overburden consisted of clayey, very gravelly SAND.

Photo No. 4.1.1 – Existing rock cut on east side of cut between Ch. 130 and 355

Competent rock was cored from a depth of 1.5 to 6.3 m in RC-101. The rock is classified as fresh to slightly weathered, strong to very strong grey medium-grained massive fossiliferous LIMESTONE with styolites and pyrite crystals. The total core recovery (TCR) ranged from 98-100% and the RQD was between 54% and 69%. There is a soft ground area between Ch. 355 and 605 where the existing road is constructed on an embankment with a stream crossing at Ch. 480. 2.5 m and 1.6 m of very soft PEAT was encountered in BH-102 and TP-105, respectively. In BH-102, which was adjacent to the stream, the peat was underlain by Cobbles with some gravel, which could be weathered/fractured rock, and the borehole reached refusal on possible rock at a depth of 3.45 m. At TP-105 the peat was underlain by very soft Boulder Clay (grey slightly sandy, slightly gravelly to gravelly SILT with many cobbles and some boulders) and the trial pit reached refusal on possible rock at a depth of 4.1 m. From Ch. 605 to Ch. 1+330 the existing road is in cut (Ch. 755-880 & Ch. 1+110-1+330) and at-grade or on shallow fill (Ch. 605-755 & Ch. 880 - 1+110) with two stream crossings (Ch. 905 and Ch.1+110). The trial pits in this area (TP-106 to TP-108) indicate that the ground conditions consist of topsoil over very soft and soft Boulder Clay (blue and brown slightly sandy gravelly CLAY with many cobbles and some boulders). The Boulder Clay was very stiff to hard below a depth of 1.8 to 2.1 m in TP-106, TP-107 & TP-109. TP-106 was terminated on possible rock at a depth of 3.4 m. TP-107 and TP- 109 were both advanced to a depth of 4.5 m without encountering rock. 0.9 m of boulder clay fill was encountered from a depth of 0.5 to 1.4 m in TP-108, adjacent to the stream.

Ch. 1+100 - 2+300

Along this section the existing road is at grade or on shallow fill. The proposed new road is in fill up to 4.5m over this section. Between Ch. 1+280 and 1+600 the road runs along the east side of Toberscanavan Loughs. The 6" drift map for the area would indicate that the road is constructed on fill over the eastern shore of the lake. This was confirmed with BH-103 and BH-104 were carried out in the wooded area on the west side of the road. At BH-103 there was 0.5 m of topsoil over Boulder Clay fill to a depth of 3.5 m (grey and brown slightly gravelly SILT with many cobbles). This was underlain by 1.0 m of PEAT and 1.5 m of ORGANIC SILT over dense silty, slightly sandy GRAVEL with some cobbles at a depth of 6.0m. SPT N-Values of 2 and 3 were recorded in the organic soils indicating that they are soft. At BH-104 there was 4.5 m of dark grey and brown slightly sandy, slightly gravelly organic SILT over dense silty sandy GRAVEL. The SILT had SPT N-Values of 12, which is relatively high and could indicate that the material is mixed with boulder clay. On the east side of the road in this area (TP-111) the ground conditions consist of 0.4 m of topsoil over very soft to soft Boulder Clay with very stiff Boulder Clay at a depth of 3.4 m. The trial pit was advanced to a depth of 4.5 m without encountering rock. There is an existing embankment over the poorly drained ground and stream crossing at Ch. 2+300. In general the ground conditions over much of this area consists of 0.4 to 0.5 m of topsoil or PEAT (TP-114) over soft and very soft Boulder Clay described as brown slightly sandy slightly gravelly or gravelly CLAY with many cobbles and occasional boulders. However, some of the material within a depth of 0.5 to 1.3 m in TP-116 and TP-117 had a low stone content and could be alluvial clay. There was 2.0 m of PEAT in BH-105 on the east side of the embankment at Ch. 2+230. Stiff and very stiff to hard brown or blue/grey Boulder Clay was encountered at a depth of 1.5 to 3.8 m in TP-112, TP-113, TP-116 and TP-117, although generally at depths >3.0 m. There was a blue sandy GRAVEL with many cobbles below the very soft Boulder Clay at a depth of 3.2 m in TP-115 and BH-105 was terminated in dense brown very clayey, very sandy GRAVEL with some cobbles at a depth of 3.5 m. TP-112, TP-115, TP-116 were terminated on possible rock at a depth of 3.2 to 4.1 m. Competent rock was cored from a depth of 6.0 to 11.4 m in RC-105. The rock is classified as slightly weathered, strong to very strong dark grey/black fine-grained, thinly bedded, fossiliferous LIMESTONE with extremely closely to closely spaced fractures. The total core recovery (TCR) ranged from 89-100% and the RQD was between 37% and 73%. There is no evidence of karstification in the rock.

Geophysical Investigations (Ch. 0-190 to 2+585):

A geophysical investigation was carried out along this section of the scheme in April and June 2011 to assess the general characteristics of the overburden, the depth to rock, and the degree of weathering and possible extent of karstification in the Limestone rock. The work was carried out by Waterwise Environmental and consisted of continuous 2D Resistivity profiles along the existing road between Ch. -0+070 and 2+585 and 8 No. 70 m long 2D Seismic Refraction profiles at selected locations based on the resistivity data. The locations of the surveys are summarised in Table No. 4.1.1. (Note the chainages have been adjusted from the values reported in the report by Waterwise to account for the most recent alignment of the scheme, as noted on Table No. 4.1.1. Ch. 0+070 on the Waterwise report corresponds to Ch. 0+000 along the new alignment) Table No. 4.1.1 gives a summary of the interpreted depth to rock along the length of the scheme between Ch. -0+070 and 2+585. The following are some other general conclusions on the characteristics of the overburden and rock within the study area:

- Rock is shallow at the north end of the scheme, as expected. There are somezones of concentrated weathering near the surface of the rock at Ch. -30 to 50, Ch. 180 & Ch.250 which may be due to karstification in the limestone rock. The seismic refraction survey at Ch. -30 to 50 indicates that there could be a layer of weathered/karstified rock up to about 5-8 m deep underlain by competent Limestone.

- Between Ch. 380 and 630 the overburden appears to be largely comprised of sandy/gravelly soils or made ground. This section of the road would be on an embankment. There is also a layer of argillaceous limestone rock or shale 5-10m thick at rockhead. Seismic Refraction profile S2 indicates competent rock with a seismic velocity of 2800 m/s;
- From Ch. 630 to 1+130 the overburden is generally clayey and it is underlain by competent Limestone rock. There is no strong evidence of karstification in the rock. However, there is a possible fault and sudden transition to shallow rock at Ch. 1+070. This could be a zone of concentrated weathering or karstification but Seismic Refraction profile S3 indicates that there is competent Limestone rock with a seismic velocity of 4000 m/s at a depth of 10-11 m at the fault.
- There is a transition to a more argillaceous Limestone or Shale between Ch. 1+130 and 1+180. This rock dominates for the remaining length of this survey up to Ch. 2+610 with only isolated zones of the cleaner Limestone rock within the depth of the survey between Ch. 1+780 and 1+900.
- The overburden along this length is generally clayey with layers of gravelly soil at rockhead (Ch. 1+330 - 1+730), which could be weathered rock, or at the ground surface (Ch. 1+210 - 1+590, Ch. 1+830 - 1+870 & Ch. 2+210 - 2+580), which could also be made ground.
- There are concentrated deep zones of low resistivity material within the rock from Ch. 2+030 to 2+100 and between Ch. 2+190 and 2+330, which would be characteristic of karstification or concentrated zones of weathering. However, the seismic refraction profiles at these locations (S6 & S7) indicate that there is competent strong rock with a seismic velocity of 4500 m/s below rockhead at a depth of 4-6 m.

Table No. 4.1.1 Summary of interpreted depth to rock along geophysical profiles.

Chainage	Depth to Rock (m)		Notes
	Range	Average	
-0+070 to 0+345	<1.0 m	1.0 m	Within rock cut Ch. 130-345.
0+345 to 0+380	3.0 m	3.0 m	
0+380 to 0+430	2.3 - 8.5 m	6.0 m	
0+430 to 0+470	6.0 - 13.8 m	10.0 m	
0+470 to 0+700	10.8 - 14.6 m	12.7 m	
0+700 to 0+730	7.7 - 13.8 m	10.8 m	
0+730 to 0+940	4.6 - 10.4 m	7.5 m	
0+940 to 1+010	4.6 - 8.8 m	6.0 m	Gap in profile Ch. 0+955 to 0+990
1+010 to 1+070	2.3 - 10.8 m	8.0 m	Possible fault at Ch. 1+070
1+070 to 1+120	2.3 - 8.6 m	5.5 m	
1+120 to 1+330	8.5 - 15.8 m	12.5 m	
1+330 to 1+580	6.1 - 12.7 m	10.0 m	Gap in profile Ch. 1+580 to 1+620
1+620 to 1+830	1.0 - 5.4 m	2.2 m	
1+830 to 1+890	2.7 - 8.5 m	5.4 m	
1+890 to 1+930	8.5 - 13.8 m	11.0 m	
1+930 to 2+100	3.5 - 10.8 m	7.0 m	
2+100 to 2+140	8.0 - 14.6 m	11.1 m	

1.1.2 DESIGN UNIT 2

Ch. 2+300 to 2+770

This is the embankment at the tie-in with the online upgrade section of the existing N4 in Design Unit 1 at the north end of the scheme. The section of existing road under the new road is at-grade or on a low embankment. There are no ground investigation points within the footprint of the new road. However trial pits TP-117, TP-118, TP-119 and TP-01 are along the west side of the existing road through this area, and BH/RC-105 is on the east side in the soft ground area at Ch. 2+230. The ground conditions encountered in the trial pits typically consisted of 1.6 to >4.3 m of very soft and soft fine-grained glacial till (slightly sandy, slightly gravelly CLAY or SILT) with some to many cobbles and boulders, 22-33% low-plasticity fines and a water content of 11-19%. However, the soil within a depth of 1.3 m-1.5 m in TP-119 and TP-117 had a higher water content (30%-34%), fines content (60% [TP-119]) and liquid limit (43%-52%: MI), suggesting that it may contain traces of organics, or could be alluvial in origin. The trial pits were excavated to a depth of 3.0 to 4.5 m. TP-119 reached refusal on rock at 3.7 mBGL. At Ch. 2+230 on the east side of the road there was up to 2.0 m of PEAT with a water content of 209% over the glacial till. An SPT N-Value of 15 was recorded in the underlying glacial till, which would be classified as a clayey, very sandy GRAVEL with some cobbles and 17% low plasticity fines. The borehole reached refusal at a depth of 3.5 m. Competent rock was cored from a depth of 6.0 to 11.4 m in RC-105. The rock is classified as slightly weathered, weak to strong dark grey/black fine-grained, thinly bedded, fossiliferous LIMESTONE with extremely closely to closely spaced fractures. The total core recovery (TCR) ranged from 89-100% and the RQD was between 37% and 73%. The point load index tests in the rock gave Is(50) values generally in the range of 1.29 to 3.81 MPa, with one low value of 0.2 MPa at a depth of 10.7 m. Using the approximate empirical relationship qu ≈ 20 x Is(50), this corresponds to a range in unconfined compressive strength, qu, of 25-76 MPa (moderately strong to strong), locally 0.4 MPa (very weak). There is no evidence of karstification in the rock. An SPT N-Value of 34 was recorded in the overlying gravel, which may be weathered rock.

Ch. 2+770 to 3+150

The ground conditions encountered in Cut 1 consist of 1.2 to 3.8 m of soft or soft to firm cohesive glacial till over firm to stiff, stiff or very stiff Boulder Clay (TP-200, TP-201, TP-202B, TP-203) weathered/fractured rock (TP-02, BH-01/RC-106, BH-02, TP-202, TP-202A). The upper soft and soft to firm cohesive glacial till ranges from soft brown sandy, slightly gravelly CLAY with rare or occasional cobbles, to soft brown sandy gravelly SILT or very silty/very clayey very sandy GRAVEL with some to many cobbles and occasional boulders. SPT N-values recorded within the upper 2.0 m in BH-01 and BH-02 ranged from 1 to 5. At the time of writing test results were not available for TP-200 to TP-204 along the revised alignment. However, water contents from the remaining boreholes and trial pits typically ranged from 11-25% with the higher values in the finer till in the upper 1.0 m. The fines content of two samples from BH-01 ranged from 24 to 29%. Firm to stiff, stiff or very stiff grey/brown or dark grey Boulder Clay (slightly sandy, gravelly SILT) was encountered at a depth of 1.2 to 3.8 m in TP-200, TP-201, TP-202B, TP-203 and TP-204. The soil contained many cobbles and occasional to some boulders up to 0.4 m in diameter, with the boulder content increasing with depth. The trial pits were excavated to depths of 3.0 - 4.9 m. TP-200, TP-201, TP-202B and TP-203 were terminated at refusal on obstructions. TP-02 was advanced 1.5 m into a layer of COBBLES and BOULDERS from 1.6-3. 1 mBGL, which is probably Weathered Rock. TP-202 and TP-202A were excavated in an old quarry to the rear of the farmhouse at about Ch. 3+000. The pits reached refusal at a depth of 0.9 to 1.0 m, probably on rock at the base of the quarry, although this is not noted on the logs. The glacial till overburden in this area could be Made Ground used to partially reinstate the quarry. BH-01 and BH-02 were terminated at refusal on Limestone obstructions at a depth of 2.7 m. BH-01 was advanced by rotary coring at RC-106. The corehole was advanced through fractured rock recovered as COBBLES from 2.8 to 5.2 mBGL. Competent rock was cored from a depth of 5.2 to 10.0 m. The rock is classified as slightly to moderately weathered, strong to very strong grey/dark grey fine-grained, very thinly bedded, fossiliferous LIMESTONE with extremely closely to closely spaced fractures and bedding dipping at shallow angles of 10-20º. The total core recovery (TCR) ranged from 56-88% and the RQD was between 20% and 49%. The point load index tests in the rock gave Is(50) values in the range of 2.72 to 4.81 MPa, which would correspond to a range in unconfined compressive strength, qu, of 54-96 MPa (Strong) using the empirical relationship qu ≈ 20 x Is(50),. One unconfined compressive strength test gave a qu of 115 MPa, which is Very Strong. The Limestone has a weathered/highly fractured profile from 2.8-5.2 mBGL and contains highly weathered seams of low recovery in the slightly to moderately weathered rock below this level. However, there are no recorded cavities or solution features due to karstification in the rock. SPT N-Values in the weathered/fractured rock were driven to refusal.

Ch. 3+150 to 3+870

Due to environmental constraints this section of the road has been re-aligned west of the original alignment through Lackagh Fen. Trial pits TP-204 to TP-201 were excavated along the revised alignment, which is at the edge of the soft ground area. Borehole BH- 03, trial pits TP-07 and TP-08, dynamic probes DP-102 and DP-103, and cobra probes PH-01 to PH-04 were carried out along the original alignment through the soft ground area to the east. The ground conditions in TP-204 to TP-210 generally consisted of 0.2 to 0.5 m of topsoil or peat over soft, locally firm (TP-210) slightly gravelly SILT or CLAY with occasional to some cobbles down to a depth of 1.0 - 1.2 m. At TP-207 (Ch. 3+500) the depth of peat increased to 2.1 m. The soft glacial till was underlain by a coarser till ranging from sandy, gravelly SILT to silty or very silty, very sandy GRAVEL with many cobbles and occasional to some boulders. The trial pits were generally excavated to refusal on obstructions in this deposit at a depth of 1.5 to 2.8 m, although TP-210, which is at the southern end of this section (Ch. 3+800) reached a depth of 4.2 m before collapsing. We understand that TP-205, at the north end (Ch. 3+300) was terminated on rock at a depth of 1.5 m. Table No. 4.2.2 summarises the depth of soft ground along the mainline carriageway. Along the original alignment through Lackagh Fen the probes, trial pits and boreholes indicate that the compressible soils are comprised of 1.7 to 4.1 m of very soft PEAT and organic SILT (MARL) over glacial till or possible rock (refusal on black gravel). The depth of soft ground was not fully penetrated at a depth of 2.6 m in TP-07. However, dynamic probe DPH-102 was driven through 3.8 m of very soft soil at the same location and reached refusal at 3.9 mBGL. Based on the available SI data, soft Peat and Marl could be encountered under the embankment between about Ch. 3+450 and 3+830. The depth of soft soil should increase from west to east across the width of the embankment but should be generally less than 3.0 m on the east side.

Table No. 4.2.2 – Summary of soft ground encountered along revised and original alignment of mainline carriageway embankment in Design Unit 2

Design Unit #	Probe No.	Depth of Soft *(m)*	Depth to Bottom of "Medium" (cobra probes*) *(m)*	Depth to Refusal *(m)*
2	**TP-206**	**0.25**		**1.8**
	TP-207	**2.1**		**2.8**
	TP-208	**0.2**		**2.6**
	TP-209	**0.45**		**2.8**
	PH-01	2.8		2.8
	BH-03	1.95		2.4
	DPH-102	3.8		3.9
	TP-07	>2.85		Soft ground not penetrated
	DPH-103	4.1		4.2
	PH-02	4		4
	PH-03	3.1		3.1
	PH-04	1.1		1.1
	TP-08	1.7		2.6

**refers to penetration resistance reported by operator, which is qualitative and open to interpretation.*

3+870 to 4+180

The ground conditions in Cut 2 consist of fine and coarse-grained glacial till over Limestone rock. At the north end of the cut (Ch. 3+910) BH-04 reached refusal at a depth of 1.55 m in stiff brown slightly sandy, slightly gravelly CLAY. However, trial pits TP-120 and TP- 210B were excavated to a depth of 4.0 to 5.1 m at the same location and the overburden is generally classified as soft grey slightly gravelly sandy SILT or very silty, very sandy GRAVEL with some to many cobbles and occasional boulders. TP-120 reached refusal on a possible rock obstruction at a depth of 4.0 m. SPT N-Values of 17 and refusal were recorded in the overburden and one PSD test gave a fines content of 20% in the gravel in TP-120. Over the rest of the cut boreholes BH-05 to BH-07 penetrated to a depth of 4.35-4.80 m into the glacial till reaching refusal on possible limestone obstructions. The ground conditions within that depth ranged from soft, firm and stiff brown Boulder Clay (sandy slightly gravelly and gravelly CLAY) to medium dense very silty, very sandy GRAVEL and clayey slightly gravelly SAND. SPT N-values of 1 and 6 were recorded in soft cohesive till within a depth of 1.0 and 2.0 m in BH-05 and BH-06, respectively. Below this level the N-Values ranged from 11 to 40 and refusal. Cobbles are noted on some of the logs and some of the SPT tests may have been influenced by the coarse content in the soil. There is some uncertainty in the ground conditions below the depth of refusal of the boreholes and it is open to interpretation. In RC-04 to RC-07 the material below this level is classified on the logs as strong grey fine-medium grained LIMESTONE rock. However, the Total Core Recovery (TCR) and Solid Core Recovery (SCR) down to a depth of 8.0 to 10.0 mBGL are very low, typically < 25-50%, and the RQD is 0% which would indicate that the rock could be very highly weathered highly fractured Limestone, possibly due to karstification, or possibly very stiff Boulder Clay or very dense granular till with numerous large cobbles and boulders where the finer material is washed out in the coring process, as found in some of the deep cuts elsewhere on the project. SPT tests carried out in the material gave N-Values between 43 and 78, with some refusals, which would suggest that glacial till at this level would be very stiff to hard or very dense. Formation level for the cut will be generally in this stratum. Some of the logs note cavities contributing to the poor core recovery (e.g. RC-04 & RC- 05). However, the high SPT N-Values do not indicate that the material within this depth has been loosened or softened due to karstification in the limestone. Below a depth of 8.0 to 10.0 m there was a distinct transition to better quality rock, although the classification on the logs is the same. The TCR and SCR range from 90- 100% and from 62-95%, respectively. The RQD ranges from 31 to 89%, but is generally > 50%. The rock at this depth also contains dark bands of thinly laminated rock within the Limestone. Fractures in the rock are closely to very closely spaced, dipping subhorizontal to 40-50°. [Note: the TCR is not reported on the logs for RC-04 and RC-05] Apex Geoservices carried out a series of 2-D Seismic Refraction profiles within this cut between Ch. 3+900 and 4+300 [S1 to S11 - Area 1]. The profiles generated by Apex show three distinct layers within the depth of cut. There is a thin layer (0.75-1.5 m) of soft to firm overburden with seismic velocities (vs) ranging from 261 – 667 m/s over a 2- 5 m thick band of firm to stiff/medium dense to dense overburden or highly to moderately weathered/broken rock with vs = 614 – 1043 m/s. This is underlain by a layer classified as competent slightly weathered to fresh rock with vs = 2623 – 5394 m/s at a depth of about 3.0 to 6.0 mBGL, generally <5.0 m. The surface of this layer is highly irregular but it is generally below the depth of excavation with the exception of a short section at the south end of the cut between Ch. 4+120 and 4+140 where it may be encountered within the box cut below sub-formation level at a depth of 3-4 mBGL. However, as noted above, the rotary coreholes indicate that competent rock is generally below a depth of 8.0-10.0 m. Therefore, the top of the layer classified as slightly weathered to fresh rock may coincide with the layer of highly weathered/highly fractured rock or very stiff/very dense glacial till above competent rock. [Note that the chainages referred to in the Apex report have been superceded by the new alignment of the single carriageway scheme]

1.1.3 DESIGN UNIT 3

Ch. 4+180 to 4+860

The embankment between Ch. 4+180 and 4+860 crosses the alluvial floodplain of a tributary of the River Arrow. The overburden in this area is described on the GSI 6” drift map as "thick bog, partly cultivated". To the south of this the road rises onto higher ground and the ground conditions consist of a thin cover of peaty topsoil over very soft boulder clay (sandy gravelly CLAY with occasional cobbles) (TP-09). The ground investigation in the soft ground area consisted of 1 No. DPH dynamic probe (PH/DP-05), 4 No. Cobra probes (PH-06 to PH-09), 2 No. trial pits (TP-122 and TP-123) and 1 No. borehole with an adjacent rotary corehole (BH/RC-107) BH/RC-107 was carried out adjacent to the river crossing at about Ch. 4+430. The ground conditions here consisted of 2.0 m of very soft PEAT (N=2) and alluvial SILT with lenses of MARL over fine and coarse-grained glacial till. The borehole reached refusal in the till at a depth of 2.5 m and was advanced by open hole drilling in RC-107 to the top of rock at 8.2 mBGL. SPT N-Values in the till below the depth of refusal of the borehole ranged from 31 to refusal, indicating very stiff to hard boulder clay and/or very dense granular material with cobbles and boulders. Strong to very strong thinly bedded fine and medium-grained LIMESTONE was cored from 8.2 to 12.9 mBGL. TCR ranged from 87-97%. RQD ranged from 69-84%. There was no evidence of karstification. Table No. 4.3.2 gives a summary of the logs of the probes in the area. They indicate that the depth of soft soil could be between 1.0 and 3.8 m deep along this section of the road. The probes reached refusal at depths of 3.1 to 5.5 m, although the resistance to penetration at depths > 4.0 m was classified as "hard", which should correspond to glacial till, indicating that the depth of alluvial and organic soils should be less than 4.0m. TP-122 and TP-123 were excavated adjacent to probes PH-07 and PH-08 at Ch. 4+520 and 4+620, respectively. Both trial pits were excavated to a depth of 4.5 m in very soft PEAT, MARL and ORGANIC SILT without penetrating the full depth of the soft ground. The corresponding probes reached refusal at a depth of 5.5 m and 3.8m, respectively.

Table No.4.3.2 – Summary of probe logs in Design Unit 3

Design Unit #	PH #	Depth to Bottom of "Soft*" (m)	Depth to Bottom of "Medium* " *(m)*	Depth to Refusal *(m)*
2	**PH/DP-05	0.5		2.8
	PH-06	1.0	3.1	3.1
	PH-07	2.0	4.0	5.5
	PH-08	3.8		3.8
	PH-09	2.0	4.5	4.5
	PH-10	1.8	2.7	1.8
	PH-11	1.0		2.7
	PH-12	4.5		4.5
	PH-13	3.0	4.5	4.5
	PH-14	4.3		4.3
	**PH-201	2.3		3.0
	PH-15	2.0	4.1	4.1
	**PH-202	2.6		3.5
	**PH-203	0.0		4.3
	**PH-204	2.6		3.7
	**PH-205	1.0		3.1

**for cobra probes, this refers to the interpreted resistance to penetration reported by the operator, which is based on experience and open to interpretation*

The cobra probes only give a very preliminary estimate of the depth of soft ground because there are no samples and the resistance to penetration reported on the logs is based on the experience of the operator, which is open to interpretation. It is possible that the depth of soft organic or alluvial soils is greater than the depth where the resistance to penetration is classified as "soft" on the logs. On the other hand, the depth of refusal should indicate where the probes reach refusal on an obstruction in the glacial till or rock.

Ch. 4+860 to 5+110

This is a short shallow cut section between the two soft ground areas. The ground conditions in this area consists of a thin cover of peaty topsoil over very soft boulder clay (sandy gravelly CLAY with occasional cobbles) (TP-09). Cobra Probes PH-10 and PH- 11 reached refusal on possible obstructions in the till at depths of 1.8 to 2.7 m.

Ch. 5+110 to 5+750

The embankment between Ch. 5+115 to 5+750 crosses an extension of the alluvial floodplain to the north of Lough Corran. The overburden in this area is described on the GSI 6" drift map as "thick bog, partly cultivated". The ground conditions in the soft ground area consist of 0.7 to >4.5 m of very soft PEAT, MARL and ORGANIC SILT over very soft/soft, firm and stiff Boulder Clay or medium dense and dense GRAVEL, which is possibly weathered rock. The total depth of soft ground from the probes ranged from 0.5 to 4.5 m (Table 4.3.2), including the depth of "soft" and "medium" penetration resistance from the cobra probes, which can be representative of peat, marl and organic silt, as noted in Fill 2. (Note: as an exception to this, the depth of soft in PH-12 was 4.5 m, but in the adjacent trial pit TP-124, the very soft PEAT and MARL were underlain by very soft/soft and soft/firm boulder clay from 2.2 to 4.5 mBGL. The total depth of soft ground was not penetrated in TP-125 at about Ch. 5+280. The trial pit was terminated in a layer of very soft Organic SILT at a depth of 4.5 m. Cobra probes PH-13 and PH-14, approximately 50 m to the northwest and southeast, respectively, reached refusal at a depth of 4.5 m. The alignment of the road has since been moved to the east of TP-125 and DPH probe PH-201 indicates that the depth of soft ground reduces in this direction. The total depth of soft ground at PH-201 was 2.3 m, whereas at PH-14, along the original alignment to the west, the depth of soft ground was 4.3 m. The depth of soft ground is <1.5 m south of the existing road at Ch. 5+550 (BH-10, TP- 10, BH-11) Strong grey light grey Limestone rock was encountered at a depth of 3.4 to 4.8 m in RC- 09 and RC-10 at Structure No.3. The TCR is not noted on the logs and there are some errors in the RQD. However, the Solid Core Recovery (SCR) in the rock typically ranged from 51 to 106% with RQD from 26% to 77%. Weathering is described as black discolouration or clay on fracture surfaces. There is no evidence of karstification in the rock.

1.1.4 DESIGN UNIT 4

Ch. 5+750 to 6+610

This section of the road has been realigned as a cut into the drumlin to the east of the original line of investigation points for Phase I and II of the preliminary SI. During Phase III of the preliminary SI rotary coreholes RC-301 and RC-302 were carried out within the deepest part of the cut at about Ch. 6+240 and 6+530, respectively. The trial pits, which are generally at a lower elevation to the west of the revised alignment, indicate that the ground conditions within a depth of 2.7 to 4.5 m generally consists of very soft and soft cohesive glacial till (very clayey very sandy GRAVEL to sandy slightly gravelly CLAY with occasional to many cobbles and boulders). The fines content of the samples typically ranged from 25% to 35% and the water contents ranged from 11%-23% but were generally <15% below a depth of 1.5 m. Stiff to hard boulder clay was encountered at a depth of 2.7 m and 3.0 m in TP-12 and TP-13 at the west end of the cut, and at a depth of 1.0 m in BH-12 at the east end of the cut, respectively. There was 1.0 m of PEAT over GRAVEL (12.2% fines) near the junction in TP-15. RC-301 and RC-302 were taken to a depth of 15.0 m in cohesive and granular glacial till in the deepest part of the cut at Ch. 6+240 and 6+530, respectively. No rock was encountered in the coreholes. The Geobore-S triple tube system was used with polymer gel drilling fluid to maximise core recovery in overburden. However the TCR was generally <25-50% with some zones of no recovery due to washout of granular soils. The strata descriptions may not be fully representative of the undisturbed ground conditions where the core recovery was low. Some zones of high recovery (60-100%) were recorded in very stiff to hard cohesive glacial till in RC-302. SPT tests were carried out below a depth of 9.0 m in RC-301 and from a depth of 3.0 m in RC-302. The NValues ranged from 20 to 50 and refusal indicating that the cohesive glacial tills are stiff to very stiff, and the granular till is medium dense to dense.

Ch. 6+610 to 7+690

This embankment crosses the Unshin Bog between Ch. 6+740 and about Ch. 7+450. The proposed alignment has been moved to the east of the original alignment in an effort to reduce the depth of soft ground along the mainline carriageway. Therefore, a number of the investigation points are to the southwest of the new alignment. Between Ch. 6+610 and 6+700 the ground conditions consisted of firm and soft Boulder Clay (slightly sandy to sandy, slightly gravelly CLAY) and medium dense to dense silty, very sandy GRAVEL over weathered and competent LIMESTONE rock. Low blow counts (N=0-2) within a depth of 1.0 to 3.0 m in BH-13 and BH-14 adjacent to the watercourse to the west of the current alignment indicate the presence of very soft glacial till or possibly very soft alluvial or organic soils in that area. The sample descriptions and classification tests would indicate that the material is generally glacial till, possibly mixed with organics near the ground surface. Strong grey fossiliferous LIMESTONE with irregular bands of black material was cored from a depth of 3.0 m and 2.6 m in RC-13 and RC-14, respectively. However, the core recovery was <25% down to a depth of 6.1 m and 4.2 m, which could be highly weathered, highly fractured rock, or possibly glacial till with cobbles and boulders. Below this depth the TCR generally ranged from 50-112%. The quality of the rock in RC-13 was very poor down to a depth of 17.6 m [TCR = 30%-80%, SCR = 0%-74%, RQD gen = 0%, locally up to 35%], whereas there was better quality rock below a depth of 5.3 m in RC-14 [TCR > 100% (?), SCR = 82%-98%, RQD = 48% - 79%]. Low core recovery could occur in highly weathered and fractured rock, and the variable weathering between the two cores would indicate that the rock could be karstified with concentrated weathering, although no voids or cavities were noted on the logs. SPT N-Values recorded in the weathered highly fractured rock in RC-13 ranged from 40 to 48, which does not indicate the presence of a solution feature. Figure No. 4.4.1 shows the possible depth of soft ground interpreted from the probes and boreholes that were carried out across the Unshin Bog. The probes include a combination of hand held Cobra Probes and DPL Mackintosh Probes (5 kg), as well as DPSH and DPH dynamic probes, as noted on Table 4.4.1. No samples are collected with these probes so the results are open to interpretation. The penetration resistance of the Cobra probes is also based on the experience and judgement of the operator. Therefore, in some cases the possible depth of soft ground has been expressed as a range. The hand held mackintosh probes may not penetrate the full depth of soft ground and the distinction between the soft compressible soils and the underlying glacial till is less distinct in the DPSH probes. The depth of soft ground determined from the boreholes is the most reliable. The probes and boreholes indicate that the depth of soft ground is shallower along the revised alignment of the road, particularly along the east side, where it is generally <2.7 m. The total depth of soft ground in the probes along the road ranges from 1.0 to 4.5 m, possibly increasing up to 5.0 to 6.0 m along the west side of the embankment between Ch. 4+640 and 7+040. At BH-109 (Ch. 7+420) the soft ground adjacent to the River Arrow consisted of 6.0 m of very soft PEAT and Organic sandy SILT, possibly MARL, over medium dense to dense slightly silty, very sandy GRAVEL and dense silty very gravelly SAND. SPT N-Values in the peat and organic soils were between 0 and 1. The water content of the samples ranged from 475% in the peat, to 82% - 214% in the organic sandy silt, which reflects a high organic content. SPT N-Values in the sand and gravel below the soft soils ranged from 30-35 and refusal, indicating that they are generally dense. The fines content in the gravel was 7.2%. The borehole reached refusal on an obstruction at a depth of 8.2 m, possibly on weathered/highly fractured rock.

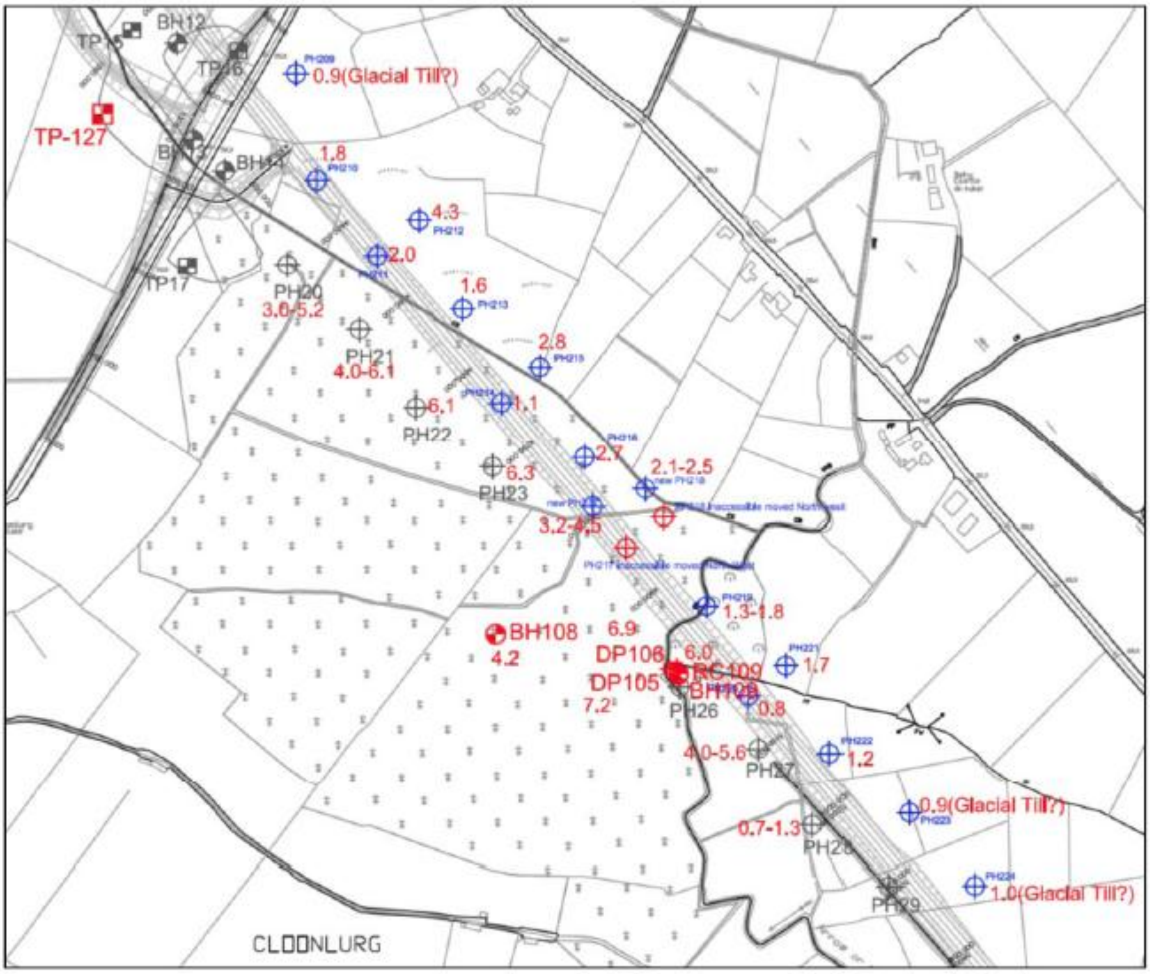

Figure No. 4.4.1 - possible depth of soft ground from the investigation points between Ch. 6+640 and 7+640

Strong grey medium-grained fossilferous LIMESTONE was cored from a depth of 9.0 to 14.1 m in RC-109. The TCR ranged from 89-100% and the RQD was between 63% and 93%, indicating good quality rock. The point load index, Is(50) of the intact rock ranged from 3.69 - 6.86 MPa. Using the approximate empirical relationship qu = 23 Is(50), the unconfined compressive strength of the rock, qu, ranged from 85 to 158 MPa, which is strong to very strong in accordance with BS5930:1999. At the east end of this embankment the ground rises up out of the soft ground and the ground conditions consist of fine and coarse-grained glacial till deposits of slightly sandy, slightly gravelly CLAY (wn = 19%) over silt, very sandy GRAVEL (18.4% fines, wn = 9.4%). The probes indicate that the upper 1.0 m could be soft.

1.1.5 DESIGN UNIT 5

Ch. 7+690 to 8+140

The ground conditions in this area consist of glacial till overburden ranging from soft, firm and stiff Boulder Clay (brown slightly sandy, slightly gravelly CLAY with large cobbles) to silty very sandy GRAVEL with numerous cobbles and boulders. Table No. 4.5.2 gives a summary of the probes that were carried out in the short atgrade/ shallow cut section between Ch. 7+690 and 7+800. The probes were driven to a depth of 2.7 m in soft and firm boulder clay.

Table No. 4.5.2 - Summary of probe results for Design Unit 5

Design Unit #	PH #	Depth to Bottom of Soft* *(m)*	Depth to Bottom of "Medium*" (Cobra Probe only) *m*	Depth to Refusal *m*
4	PH-29 (Cobra)		2.7	2.7
	PH-224 (DPH)	1.0		2.7

** Refers to reported penetration resistance from cobra probe or interpreted depth of soft ground from DPH probe.*

TP-18 and TP-19 were excavated to depths of 3.0 m and 2.6 m, respectively in silty, very sandy GRAVEL with numerous cobbles and boulders and a fines content of 16.5% to 18.4%. TP-19 was terminated on a solid sheet of rock. Boreholes BH-15, BH-16 and BH-17 reached refusal on a possible boulder or rock at a depth of 2.5 m and 0.6 m, respectively. SPT N-Values in the stiff to very stiff Boulder Clay overburden ranged from 18 to 78 and refusal. Rotary coreholes were advanced to depths of 16.3 to 25.9 m at RC-15, RC-16 and RC-17 between Ch. 8+040 and 8+165. In general the quality of the core recovery in this area was very poor and there was evidence of karstification in the Limestone. The total core recovery within a depth of 15.0 to 18.0 m typically ranged from 15% to 65% is shown on Figure 4.4.1 and the RQD was generally 0%. Cavities were also recorded in RC-16 and RC-17. In RC-15 the core recovery was described as "boulders and gravel", and "fabric infill of cavities with gravelly clay and boulders". The poor quality of the core was attributed to weathering and the presence of cavities. In RC-16 the core recovery is described as gravelly CLAY down to a depth of 5.4 m, over strong light grey fine to medium grained LIMESTONE with no discernable bedding and clay smearing on fracture surfaces from 5.4 m to 18.4 mBGL. There was a cavity recorded at 14.1 to 16.0 mBGL, although the TCR in this zone ranged from 32% to 59%. A seam of strong fine to medium grained SANDSTONE with TCR of 62% to >100% and RQD of 0-45% was encountered between 18.4 and 21.1 mBGL. This was underlain by competent grey fine to coarse LIMESTONE with TCR of 92 to >100% and RQD of 11- 49%. [Note: TCR > 100% can occur where sections of core from adjacent runs are recovered in the core barrel, but high values >>100% are unusual and possibly indicate errors in the logging]

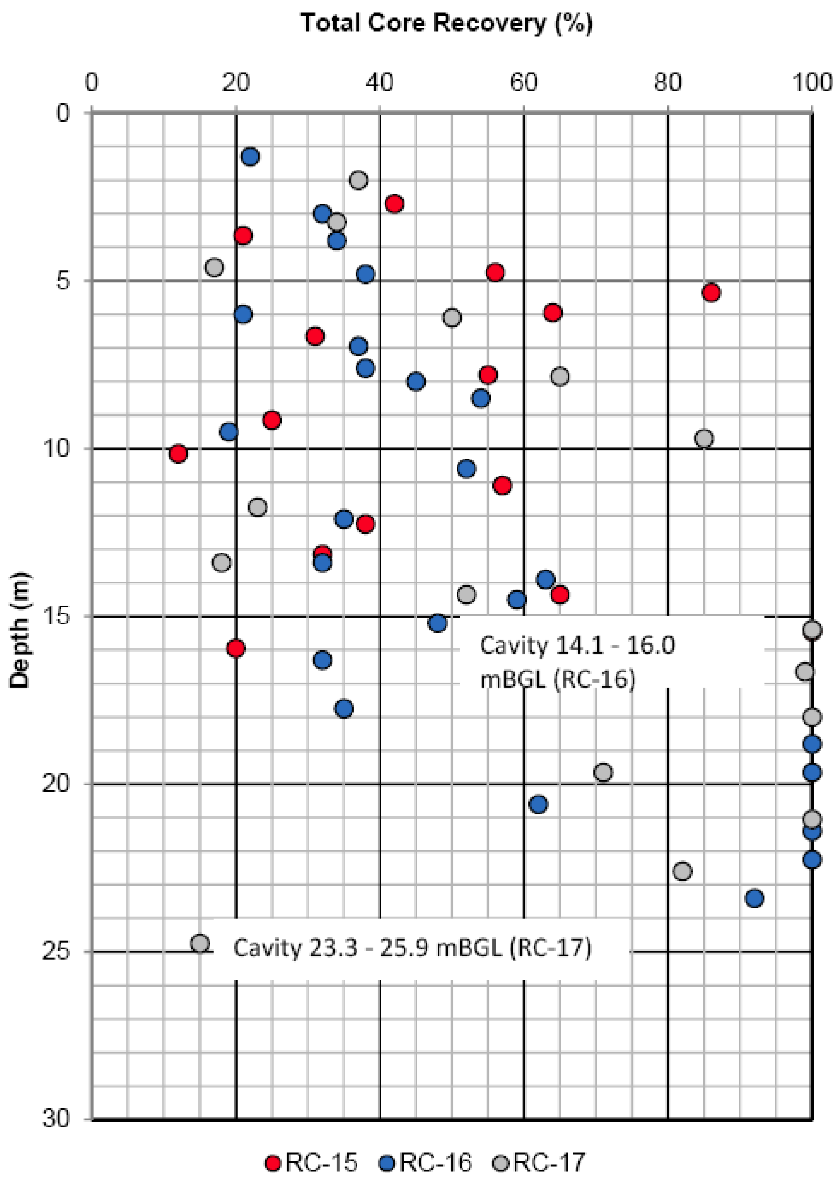

Figure 4.5.1 - Total Core Recovery (TCR) in rotary coreholes between Ch. 7+725 and 8+165.

In RC-17 about 8 m of solid but non-intact core was recovered between a depth of 1.5 m and 14.7 m. The TCR ranged from 17% to up to 85%, but the RQD was 0%. The core is described as strong light grey LIMESTONE but the log notes that the non intact core is due to infill of voids with black gravelly CLAY. A layer of strong grey marbled finegrained SANDSTONE with minor layers of silty Limestone was encountered from 14.7 to 23.3 mBGL. The TCR ranged from 71 to >100%, and the RQD was between 22% and 95%. The corehole was terminated in a cavity below the Sandstone from 23.3 to 25.9 mBGL. It is not stated if the base of the cavity was reached. Apex Geoservices carried out a series of 2-D Seismic Refraction profiles within this area [S12 to S18 - Section 2]. The profiles generated by Apex show three distinct layers. There is a thin layer (1.0-1.5 m) of soft to firm overburden with seismic velocities (vs) ranging from 253 – 923 m/s (Gen. < 700 m/s) over a 1.0-5.5 m thick band of firm to stiff/medium dense to dense overburden or highly to moderately weathered/broken rock with vs = 600 – 1521 m/s (Gen < 1350 m/s). This is underlain by competent slightly weathered to fresh rock with vs = 2237 – 6160 m/s at a depth of about 2.0 to 7.5 m. The surface of the rock is highly irregular. The seismic velocity of the competent rock layer was >3600 m/s to the north of Ch. 7+940, and <3000 m/s to the south of Ch. 7+940, indicating a transition in the quality of the rock between Ch. 7+940 and 7+740. The 2-D resistivity profiles produced by Minerex indicate that clean Limestone rock is relatively shallow at a depth of about 5-7 m up to Ch. 7+920 and then drops off to depths of 10-20 m to the south of this, which is consistent with the seismic refraction profiles. The material above the clean Limestone south of Ch. 7+920 is described as Gravelly Clay, Clayey Gravel, or Gravel overburden, or very karstified Limestone rock becoming slightly karstified with depth. [Note that the chainages referred to in the Apex and Minerex reports have been modified in this report to reflect the new alignment of the single carriageway scheme] In summary, the geophysical profiles and rotary coreholes would indicate that the quality of the rock to the south of Ch. 7+920 is very poor with low TCR in non intact rock down to a depth of about 15.0 to 18.5 m. However, due to the low core recovery (gen. 15- 65%), there is some uncertainty in the characteristics of the material within this depth, probably due to washout of finer material in the coring process. It is possible that the material within this depth is highly fractured/highly weathered possibly karstified LIMESTONE rock, or very stiff/very dense fine and coarse-grained glacial till with numerous large cobbles and boulders, as found in some of the deep cuts in the drumlins elsewhere on the project. SPT tests carried out in the material gave N-Values between 45 and 99, with many refusals, which would suggest that fractured rock or glacial till at this level would be very dense or very stiff to hard, probably with numerous cobble and boulder obstructions. If it is karstified limestone rock, the SPT tests do not indicate that the material has been loosened due to solution features in the rock. An N-value of 57 was even recorded 0.5 m-1.0 m above the cavity in RC-16. The quality of the rock improves in the Sandstone and Limestone rock below a depth of 15.0 to 18.5 m. However, there was still a cavity at the base of the Sandstone in RC-17.

Ch. 8+165 to 8+430

The boreholes in this area all reached refusal on possible Limestone boulders or rock in the glacial till overburden at a depth of 1.7 m to 3.65 m. The overburden within this depth consisted of cohesive glacial till deposits of orange brown and grey brown slightly sandy, slightly gravelly CLAY and very silty, very sandy GRAVEL with occasional cobbles and a fines content of 30.5-32.5%. The strength of the cohesive material ranged from soft (N<8) in the top 0.5 to 2.5 m, to firm, stiff and very stiff below that level. SPT N-Values ranged from 4 to 24 with some refusals, possibly on boulder obstructions (Figure 4.4.2).

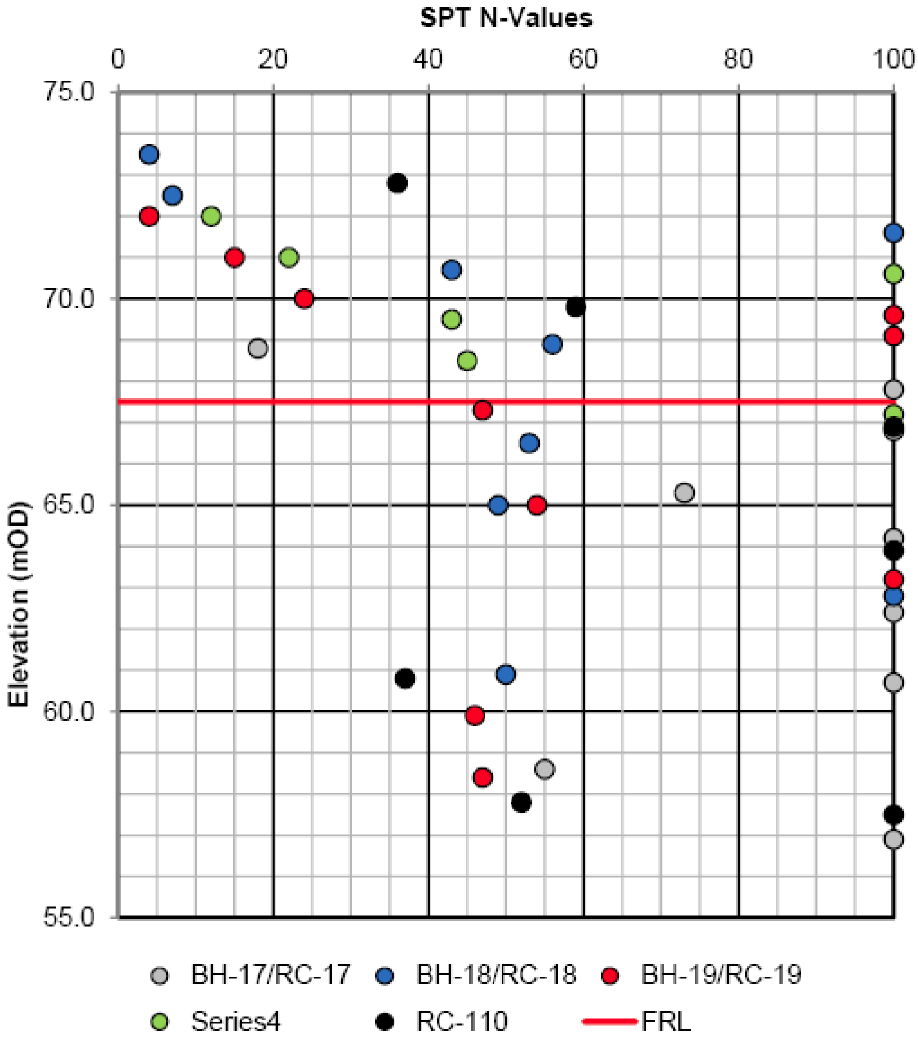

Figure 4.5.2- SPT N-Values from the boreholes and rotary coreholes between Ch. 8+165 and 8+430.

Rotary coreholes were advanced to depths of 11.4 to 25.9 m at RC-17 to RC-20 and RC- 110. In general the quality of the core recovery in this area was very poor down to a depth of 14-19 m (approx. Elev. +55 to +60 mOD) and there was evidence of karstification in the Limestone. The TCR within this depth typically ranged from 5% to 75% as shown on Figure 4.4.3 and the RQD was generally 0%. A cavity was recorded in RC-17 at a depth of 23.3-25.9 mOD.

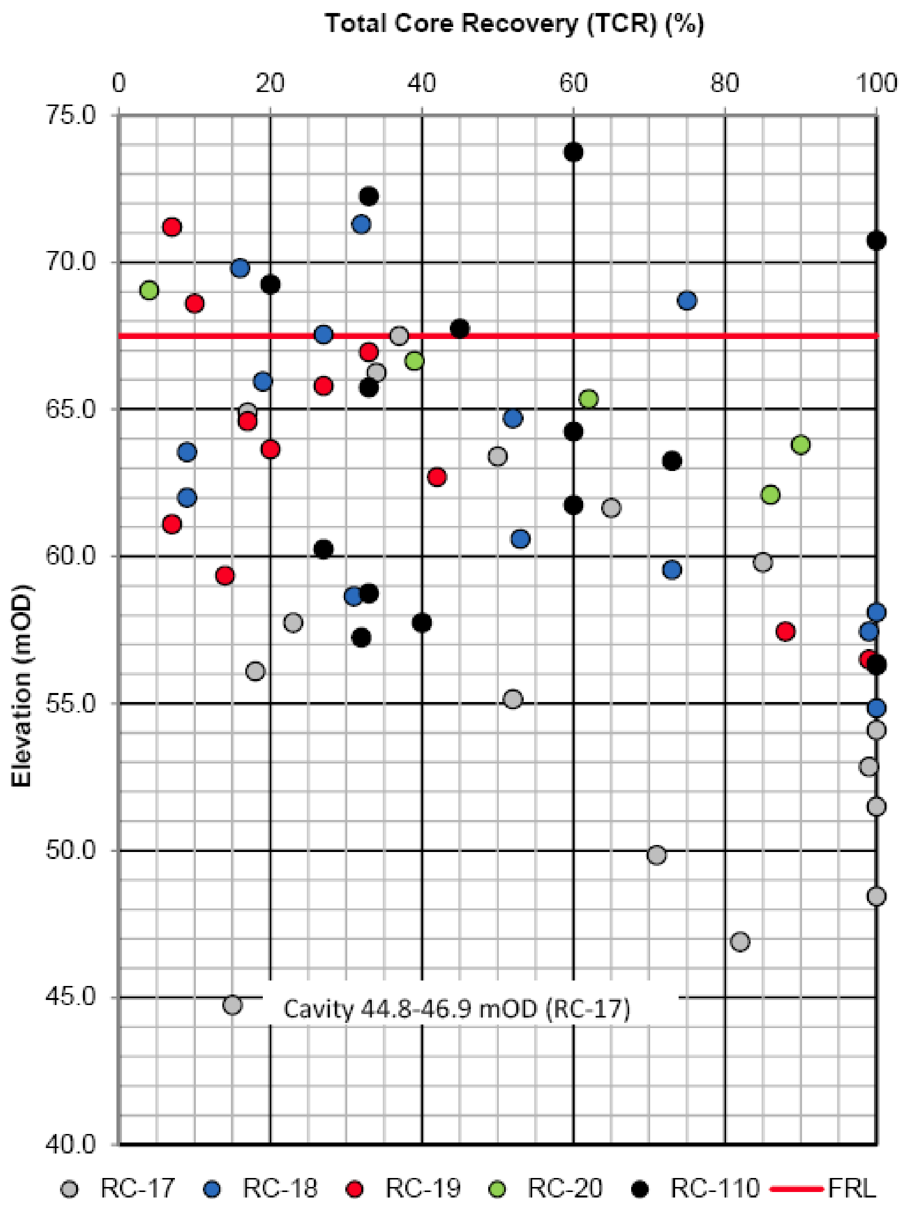

Figure 4.5.3 - Total Core Recovery (TCR) in rotary coreholes between Ch. 8+165 and 8+430.

In RC-17, at the north end of the cut, about 8 m of solid but non-intact core was recovered between a depth of 1.5 m and 14.7 m. The TCR ranged from 17% to up to 85%, but the RQD was 0%. The core is described as strong light grey LIMESTONE but the log notes that the non intact core is due to infill of voids with black gravelly CLAY. A layer of strong grey marbled fine-grained SANDSTONE with minor layers of silty Limestone was encountered from 14.7 to 23.3 mBGL. The TCR ranged from 71 to >100%, and the RQD was between 22% and 95%. The corehole was terminated in a cavity below the Sandstone from 23.3 to 25.9 mBGL. It is not stated if the base of the cavity was reached. Sandstone would not be karst susceptible so it would have to be in the underlying Limestone. In RC-18 and RC-19, at the centre of the cut, the core recovery down to a depth of 14.1 to 14.7 m (Elev. 60.6 mOD to +58.3 mOD, respectively) is described as Boulder Clay or clayey GRAVEL overburden. The TCR generally ranged from 10-50%, probably due to washout of finer material in the coring process, so the samples may not be representative of the undisturbed soil. SPT N-Values ranged from 40 to 56 with some refusal, indicating that the cohesive soils would be very stiff and the granular soils would be dense to very dense with cobble and boulder obstructions. Strong light grey LIMESTONE with some thinly laminated dark grey beds was cored from a depth of 14.7 m in both coreholes. The TCR was between 75 and 100% and the RQD was between 0% and 68%. There was a weathered rock layer from 14.1 to 14.7 m in RC-18. During Phase II of the preliminary site investigation RC-110 was cored to a depth of 20.3m near RC-18 using the

Geobore-S triple tube system with a polymer gel drilling mud to maximise core recovery in the overburden and weathered rock. The core recovery within a depth of 18.5 m consisted of very stiff and hard brown and grey Boulder Clay (slightly sandy gravelly CLAY) with occasional to some cobbles, and nested layers of COBBLES and BOULDERS from 7.5-11.5 mBGL, and 13.5 - 16.5 mBGL, which may have been infilled with finer material washed out in the coring process. No cavities are noted and SPT N-Values ranged from 36 to 59 with some refusals. Strong to very strong, fresh to slightly weathered grey massive medium grained fossiliferous LIMESTONE was cored from 18.5 to 20.3 mBGL. The TCR and RQD below the fractured layer at rockhead were 100% and 61%, respectively. RC-20 was cored at the cut/fill line at the south end of the cut. Limestone is reported from a depth of 1.9 m but the core recovery is only 4% down to a depth of 5.4 m, so this could be fine or coarse grained overburden with limestone cobbles and boulders. Grey SANDSTONE with a TCR of 39 to 86% was cored from 5.4 to 11.4 mBGL. The RQD in the rock ranged from 11 to 47%, increasing with depth. Apex Geoservices carried out a series of 2-D Seismic Refraction profiles within this area [S19 to S22 - Section 3]. The profiles generated by Apex show three distinct layers. There is a thin layer (1.0-2.0 m) of soft to firm overburden with seismic velocities (vs) ranging from 465 – 608 m/s over a 2.5-10.5 m thick band of firm to stiff/medium dense to dense overburden or highly to moderately weathered/broken rock with vs = 1222 – 1959 m/s. This is underlain by competent slightly weathered to fresh rock with vs = 2149 – 4128 m/s at a depth of about 4.0 to 12.5 m. The profiles indicate that the "rock" with seismic velocity of 2419-2686 m/s could be encountered within the depth of excavation to sub-formation level between Ch. 8+240 and 8+340. However, this is not consistent with the corehole data and it is likely that this layer includes the very stiff to hard boulder clay, or the very dense gravel with cobbles and boulders encountered at this level in the coreholes. The 2-D resistivity profiles produced by Minerex indicate that clean Limestone rock is at a depth of about 10 m to >20 m in this area. The overlying material is classified as Gravelly Clay, Clayey Gravel or Gravel overburden, or very karstified Limestone rock becoming slightly karstified with depth. [Note that the chainages referred to in the Apex and Minerex reports have been modified in this report to reflect the new alignment of the single carriageway scheme]

1.1.6 DESIGN UNIT 6

Ch. 8+410 to 8+970

The ground conditions in this area consist of deposits of glacial till overburden over shallow Limestone bedrock. The overburden is classified as firm (?) grey brown clayey SAND, or stiff brown slightly sandy or sandy gravelly CLAY with cobbles and boulders. The trial pits, boreholes and cobra probes reached refusal on possible rock or boulders at a depth of 0.3 to 2.1 m. Note: between about Ch. 8+640 and 8+990 the embankment runs along the west side of a soft ground area adjacent to Culleencroobagh Lough. No soft organic or alluvial soil was encountered in the boreholes, trial pits or cobra probes. However, none of these were carried out in the low-lying area along the east side of the embankment. It is possible that some soft ground may be encountered on this side. Rock was proven in RC-20, RC-21 and RC-22. At the north end of the embankment, BH-20 was terminated at refusal on a limestone obstruction at a depth of 2.1 m and LIMESTONE rock is reported in RC-20 from 1.9 to 5.4 mBGL. However, the total core recovery was only 4% so this may not be a reliable indicator of rock, and it could be a continuation of the overlying very stiff boulder clay encountered in the borehole. SPT NValues of 43 and 45 were recorded at a depth of 3.0 and 4.0 m in the corehole, which would indicate very stiff boulder clay, dense granular till or highly weathered/highly fractured rock. Sandstone bedrock with a TCR of 39-86% and an RQD of 11-47% was recorded from 5.4 to 11.4 mBGL in RC-20. (Note one TCR value of 9% would appear to be an error as the solid core recovery (SCR) at the same depth was 88%). Strong light grey fine-grained LIMESTONE with no obvious bedding was encountered at a depth of 0.0 to 0.8 m in RC-21 and RC-22. A seam of strong grey SANDSTONE was also encountered from 3.5 to 5.3 mBGL in RC-22. The total core recovery in the rock generally ranged from 75% to >100% below the weathered surface layer. The RQD ranged from 22% to 61% but was generally < 35%. There is an error in the TCR (Total Core Recovery) or SCR (Solid Core Recovery) in RC-22 from 2.0 to 3.5 mBGL. The SCR should always be less than the TCR, but the TCR is reported as 35% and the SCR is reported as 95%. Assuming that the SCR is correct the Limestone rock does not appear to be karstified in this area. However, Culleencroobagh Lough may have formed in a swallow hole in the Limestone, and there appears to be a spring feeding into the watercourse in the shallow rock area on the south side of the road at Ch.8+660. Figure 4.6.1 shows an aerial photo of the area and Figure 4.6.2 shows the surface hydrology. The Sandstone rock is not karst susceptible but karst features are known to occur at the boundary between Limestone and other types of rocks.

Figure 4.6.1 - Aerial photo of soft ground area around Culleencroobagh Lough, which is a possible swallow hole (Google Maps, 2012)

At the north end of this section the 2D-Resistivity profiles by Minerex show a deep profile (>25 m) of gravel overburden or slightly karstified Limestone Rock with a sudden transition to shallow Limestone rock at a possible fault at Ch. 8+490. Between Ch. 8+490 and about 8+890 the profiles show clean Limestone rock at or close to ground surface. There is a concentrated zone of possibly very karstified Limetone between Ch. 8+950 and 9+065 bounded by faults at either end. This could also represent a change in lithology to a fine-grained rock such as a Shale. However, it corresponds to the location of Culleencroobagh Lough, which could be a swallow hole, so there is a risk of concentrated karstification in the Limestone rock in this area. 2D seismic refraction profiles S23 and S24 by APEX are at the north end of this section. The profiles show a thin layer (0.5-1.5 m) of soft to firm overburden with seismic velocities (vs) ranging from 476 – 1312 m/s over firm to stiff/medium dense to dense overburden or highly to moderately weathered/broken rock with vs = 600 – 2250 m/s. This is underlain by competent slightly weathered to fresh rock with vs = 3691 – 4613 m/s at a depth of about 2.5 m to greater than 12.5 m. Rock level drops off significantly to the south of Ch. 8+515.

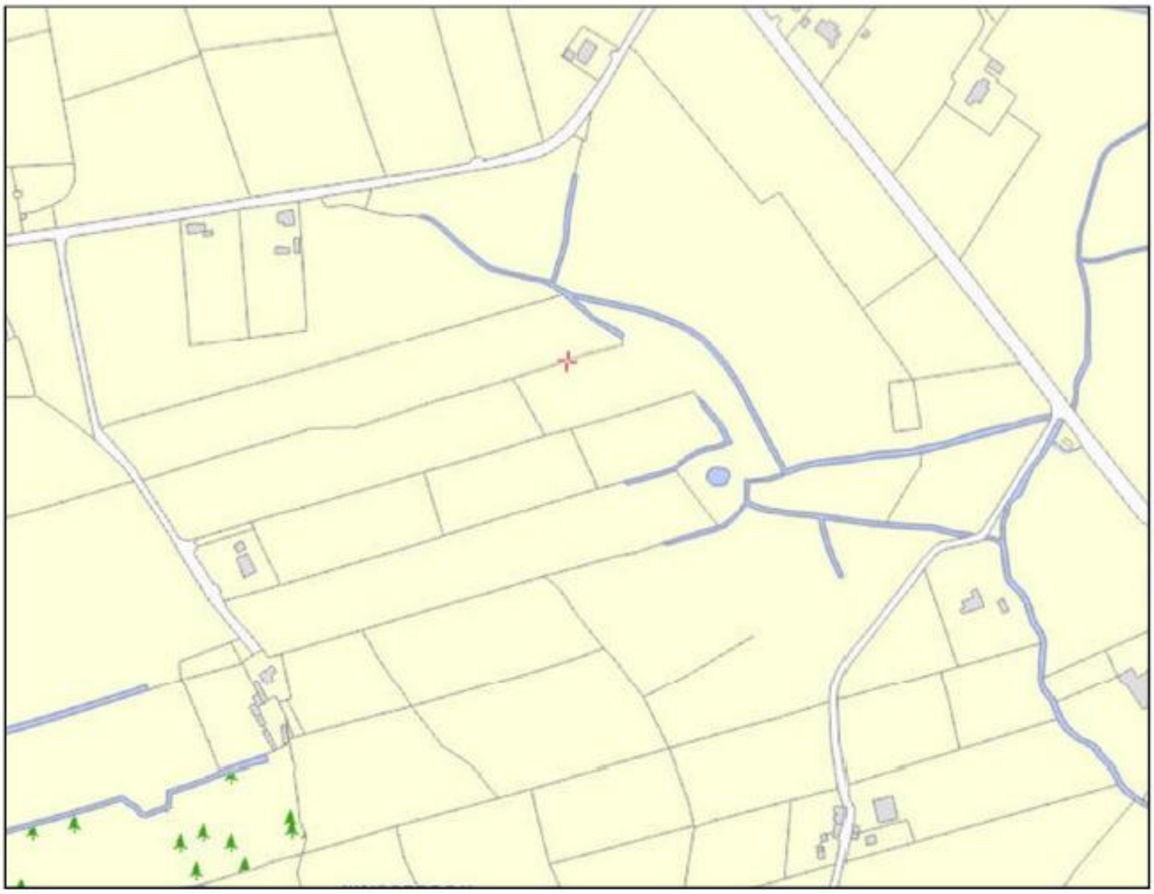

Figure 4.6.2 - Surface hydrology between Ch.8+540 and 9+240 (OSI Street Mapping - 2012)

Ch. 8+970 to 9+230

This section of the mainline carriageway is cut into the east side of a drumlin with steep slopes so that the depth of cut is significantly greater on the west side of the road. RC- 111 was carried out on the west side at Ch. 9+160, where the depth of cut is approximately 10.8 m. The corehole was advanced using the Geobore S triple tube system with polymer gel drilling fluid to maximise core recovery in overburden and weathered or karstified rock. The ground conditions encountered within the depth of cut consisted of stiff and very stiff deposits of fine-grained glacial till which would generally be classified as slightly sandy, gravelly CLAY with occasional to many cobbles and occasional boulders. The TCR in the till ranged from 20% to 93% so there could be some granular layers that could have been washed out in the coring process. Unconsolidated undrained triaxial compression tests gave undrained shear strengths, cu, of 60 kPa and 144 kPa at a depth of 7.5 m and 12.0 m, respectively. SPT N-Values below a depth of 3.0 m ranged from 21-47, with some refusals, possibly on cobble or boulder obstructions. Using the approximate empirical relationship cu = 5 N, this would correspond to a cu of 100-250 kPa, which is stiff to very stiff. Water contents ranged from 6-15%. The nearby cobra probe PH-31 reached refusal at a depth of 3.0 m and indicated that there could be 1.0 to 3.0 m of soft and firm Boulder Clay above this level. TP-128 and TP-22 were excavated at the north and south ends of the cut, respectively. On the higher ground at the north end of the cut the Boulder Clay within a depth of 2.4 m in TP-128 was classified as very soft to soft (n = 18-27%, 37.1% fines, l=26%, Ip = 10, CL). Below this the water content of the Boulder clay was lower and it was classified as very stiff (n = 8.9%, 40.1% fines, l=25%, Ip = 11, CL). This is in the area of possibly highly karstified Limestone opposite Culleencroobagh Lough. At the south end of the cut (TP-22) there was 2.4 m of possible glacial till which is described as orange brown and brown slightly sandy, slightly gravelly CLAY or SILT (n = 17-21%, 63.7% fines) with occasional cobbles below a depth of 1.2 m, where the material is described as firm. These deposits were underlain by a brown thinly laminated CLAY with sand lenses from 2.4 to 2.8 mBGL (n = 17-24%), which is possibly a finegrained fluvioglacial soil. Stiff dark grey Boulder Clay was encountered at 2.8 mBGL. The 2D Seismic Refraction profile produced through this cut by APEX indicates that slightly weathered to fresh rock with a seismic velocity, vs of 2265-2674 m/s, could be encountered at a depth of 1-3 m, locally up to 5.4 m. However, based on the trial pits and rotary corehole in the area rock is below the depth of excavation and the boundary shown on the APEX profiles may actually correspond to the top of the very stiff Boulder Clay. The 2D-Resistivity profiles by Minerex show a concentrated zone of possibly very karstified Limetone between Ch. 8+950 and 9+065, which is bounded by faults at either end. The very karstified Limestone is also shown to extend from ground surface over the full length of the cut to Ch. 9+280. Again, the trial pits and coreholes in this area indicate that this would actually correspond to very stiff deposits of fine-grained glacial till within a depth of 3-15.0 mBGL. The Minerex profiles show clean Limestone at a depth of about 12-20 m between Ch. 9+065 and 9+280.

Ch. 9+230 to 9+780

Between Ch. 9+490 and 9+740 the embankment crosses a soft ground area along the southern shores of Aghalenane Lough. The ground conditions in the area consist of 1.5 to >3.4 m of very soft PEAT and MARL over very soft to soft fine-grained glacial till (slightly sandy gravelly CLAY with some cobbles and many boulders). The total depth of soft ground was not penetrated at a depth of 3.4 m in TP-129 at Ch. 7+100, but the adjacent cobra probe PH-32 reached refusal at a depth of 3.4 m. BH-28 and TP-130 were terminated on obstructions at a depth of 3.4 m and 2.4 m, respectively. Rock is noted at this depth in TP-130, although not proven by rotary coring. The 3 No. Mackintosh probes to the southwest of the current alignment (PH-225 to PH-227) seem to indicate that there is no soft ground on this side of the embankment. Outside the soft ground area the boreholes (BH-25, BH-26, BH-27 and BH-29) reached refusal in very stiff Boulder Clay at depths of 1.2 to 2.1 m. SPT N-values in the overburden within this depth ranged from 8 to 41 and refusal, which corresponds to an undrained shear strength, cu, of 40-200 kPa using the approximate empirical relationship cu ≈ 5 N. The soft to firm boulder clay with an SPT N-Value of 8 was recorded at a depth of 0.5 m in BH-27 at the edge of the soft ground area. BH-25 and BH-26, at the north end of the embankment at Structure No.6 where advanced into rock by rotary coring. Strong grey LIMESTONE with dark grey wavy bedding and close to medium spaced fractures was recorded below a depth of 1.0 to 2.9 m. TCR was generally >97-100% below a depth of 2.6 to 2.8 m, indicating that competent rock is below this level. There was no evidence of karstification in the rock. The 2D-Resistivity profiles by Minerex show a zone of possibly karstified limestone rock between Ch.9+450 and about 9+790 with a possible fault at either end. This could also correspond to a change in lithology to an argillaceous rock such as a Shale, which would have a significantly lower resistivity. There are no rotary coreholes within this zone. Bh- 27 and BH-28 were taken to refusal at depths of 2.1 to 3.4 m. BH-27 was terminated in dense grey clayey sandy GRAVEL, which could be highly fractured rock. BH-28 was terminated at the base of a layer of very soft slightly gravelly, sandy SILT, which may be an alluvial deposit. The Aghalenane and Ardloy Loughs on the north side of the road in this area may have been formed in swallow holes or from subsidence due to karstification in the underlying Limestone.

1.1.7 DESIGN UNIT 7

Ch. 9+780 to 10+280

The ground conditions along the section between Ch. 9+780 and about 10+070 consist of 0.2 to 0.3 m of topsoil over firm Boulder Clay (sandy, slightly gravelly to gravelly CLAY) and medium dense to dense grey silty to very silty, very sandy GRAVEL with occasional to numerous cobbles and boulders. Strong light grey LIMESTONE rock was cored from a depth of 1.2 m in RC-30. TCR in the weathered rock layer from 1.2 to 3.2 mBGL was 22-50%. In the competent rock below this the TCR was >95% and the RQD ranged from 0-33%. The embankment crosses a soft ground area between about Ch. 10+070 and 10+220, particularly on the north side of the embankment close to the stream flowing into Ardloy Lough. 1.0 and 2.9 m of soft PEAT and MARL was encountered in BH-31 and BH-B, respectively, on the west side of the existing N4. These were underlain by firm, stiff and very stiff Boulder Clay (sandy gravelly CLAY and slightly sandy, slightly gravelly SILT/CLAY with many angular cobbles). SPT N-Values in the Boulder Clay ranged from 10 to 40 with some refusals. The boreholes reached refusal at depths of 3.9 to 4.6 m. In the poorly drained area on the east side of the existing N4 there was 1.0 to 2.6 m of topsoil and organic SILT or CLAY over soft to firm and firm Boulder Clay, clayey sandy GRAVEL, or possible rock. The Organic CLAY from 1.8 to 2.6 mBGL in TP-D had a relatively low water content of 21.9%, which would indicate that it is probably only slightly organic. It was also interbedded with lenses of gravelly SAND. BH-32 reached refusal at a depth of 4.1 m in possible weathered/karstified Limestone, which was recovered as Cobbles smeared with grey sandy CLAY from 3.5 to 4.1 m. SPT N-Values ranged from 12 to 27 in the overlying Boulder Clay, which is firm to very stiff. N-Values of 30 were recorded in the weathered rock. RC-31 and RC-32 were carried out at the junction with the existing N4. The core log for RC-31 shows rock from a depth of 1.2 m. However, the borehole at this location recorded firm boulder clay down to a depth of 4.6 m, so the rock should be below this level. From 4.9 -9.6 m in RC-31 there was Strong grey wavy bedded Limestone with calcite veining with a TCR of 56-100% and RQD of 23-54%. The quality of the rock was considerably poorer on the east side of the junction in BH/RC-32. Cobbles smeared with grey sandy clay were encountered in the borehole at a depth of 3.5 m. In RC-32 the TCR between 2.6 and 10.6 mBGL generally ranged from 10-27% with 0% RQD. This would indicate that the rock is highly fractured or possibly karstified. The SPT test results are non-standard but all of the tests appeared to reach refusal at depths of penetration <300 mm after the seating blow. Below a depth of 10.6 m in RC-32 the quality of the Limestone improves with TCR in the range of 50-100%. However the RQD is typically 0% indicating that the rock is highly fractured. Some dissolution is noted on the logs for the zones of assumed core loss. However, no voids or cavities are recorded in the rock and the SPT test results would indicate that the overburden or weathered rock has not been loosened or softened by karstification in the Limestone. The 2D Seismic Refraction profile by APEX indicates that slightly weathered to fresh rock with a seismic velocity, vs of 2234-3624 m/s, could be encountered with a variable rockhead at a depth of 1.0 to 5.5 m between Ch. 9+750 and 10+090, locally dropping off to depths of over 10 m at Ch. 9+930. This may be evidence of karstification, possibly paleokarst. However, RC-30 was carried out at this location and competent Limestone was encountered at a depth of 3.2 m. The resistivity profiles by Minerex also identify a sudden increase in the depth to rock to the south of about Ch. 10+115, indicating that the rock to the south of this may be slightly karstified to karstified, although it could also represent a change in lithology to a more argillaceous rock such as a shaley Limestone.

Ch. 10+280 to 10+530

The ground conditions within the depth of the boreholes consisted of 1.0 to 1.5 m of soft brown Boulder Clay (slightly sandy, slightly gravelly CLAY) over firm to stiff and stiff grey Boulder Clay (sandy, slightly gravelly and gravelly CLAY). SPT N-Values ranged from 2 to 5 at a depth of 0.5 m, to 44 and refusal below a depth of 1.5 m. Using the approximate empirical relationship, cu≈5 N, the undrained shear strength, cu, of the soil could range from 10 to 25 kPa (very soft to soft) in the top 1.0 to 1.5 m, to >200 kPa (very stiff) below this level. The boreholes reached refusal on limestone obstructions at a depth of 2.9 to 3.1m. There is some uncertainty in the ground conditions below this level. RC-33 and RC-34 were advanced by conventional rotary coring to a depth of 33.5 m and 20.8 m, respectively. The material recovered in the coreholes is classified as strong grey Limestone, or fossiliferous Limestone, with closely spaced undulating rough or planar smooth fractures and orange colouring and clay smearing along fracture surfaces. Some Sandstone and clay bands were also noted. However, the total core recovery (TCR) down to a depth of 17.0 to 23.0 m was very low, typically 10-50% (Figure 4.7.1), and the RQD was 0%. Therefore, the material could be very stiff to hard cohesive glacial till with some to many cobbles and boulders, very dense coarse granular till, or highly weathered, highly fractured and karstified Limestone. SPT tests were carried out at a depth of 3.5 to 18.5 m in the coreholes. The reported values are non-standard but most of the tests appeared to reach refusal at depths of penetration <300 mm after the seating blow (Figure 4.7.2). N-Values of 38 to 45 were recorded between 5.6 and 11.2 mBGL in RC-33. These values are representative of very stiff to hard cohesive soil, or dense to very dense granular soil, which does not indicate that the material has been loosened or softened by karstification in the underlying rock. More competent LIMESTONE rock (TCR 50-100%, RQD 0-40%) was encountered below a depth of 23.0 m (+62.4 mOD) in RC-33 and at 17.0 m (+68.8 mOD) in RC-34. However, a cavity was noted at a depth of 29.0 - 30.5 mBGL in RC-33. RC-112 was advanced to a depth of 25.0 m near RC-34 using the Geobore-S triple tube system with polymer gel drilling fluid to maximise core recovery in overburden and highly weathered rock. The ground conditions within a depth of 19.0 m generally consisted of stiff, very stiff and hard brown and grey Boulder Clay (slightly sandy gravelly CLAY with occasional to some cobbles and boulders). The TCR ranged from 0-100% (Figure 4.7.1) which would indicate that there could be some layers or pockets of granular material within the cohesive till that were washed out in the coring process. Layers of cobbles and occasional boulders up to 0.9 m are also recorded on the logs. SPT N-Values ranged from 32 at a depth of 3.0 m, to refusal below this level. Moderately strong to very strong grey fossiliferous LIMESTONE was encountered at a depth of 19.9 m (67.4 mOD). The TCR in the rock ranged from 53% to 93% with an RQD of 24% to 66%. The unconfined compressive strength of the rock from UCS and point load index tests ranged from 21 MPa to 197 MPa, which is moderately strong (12.5-50 MPa) to very strong (100-200 MPa).

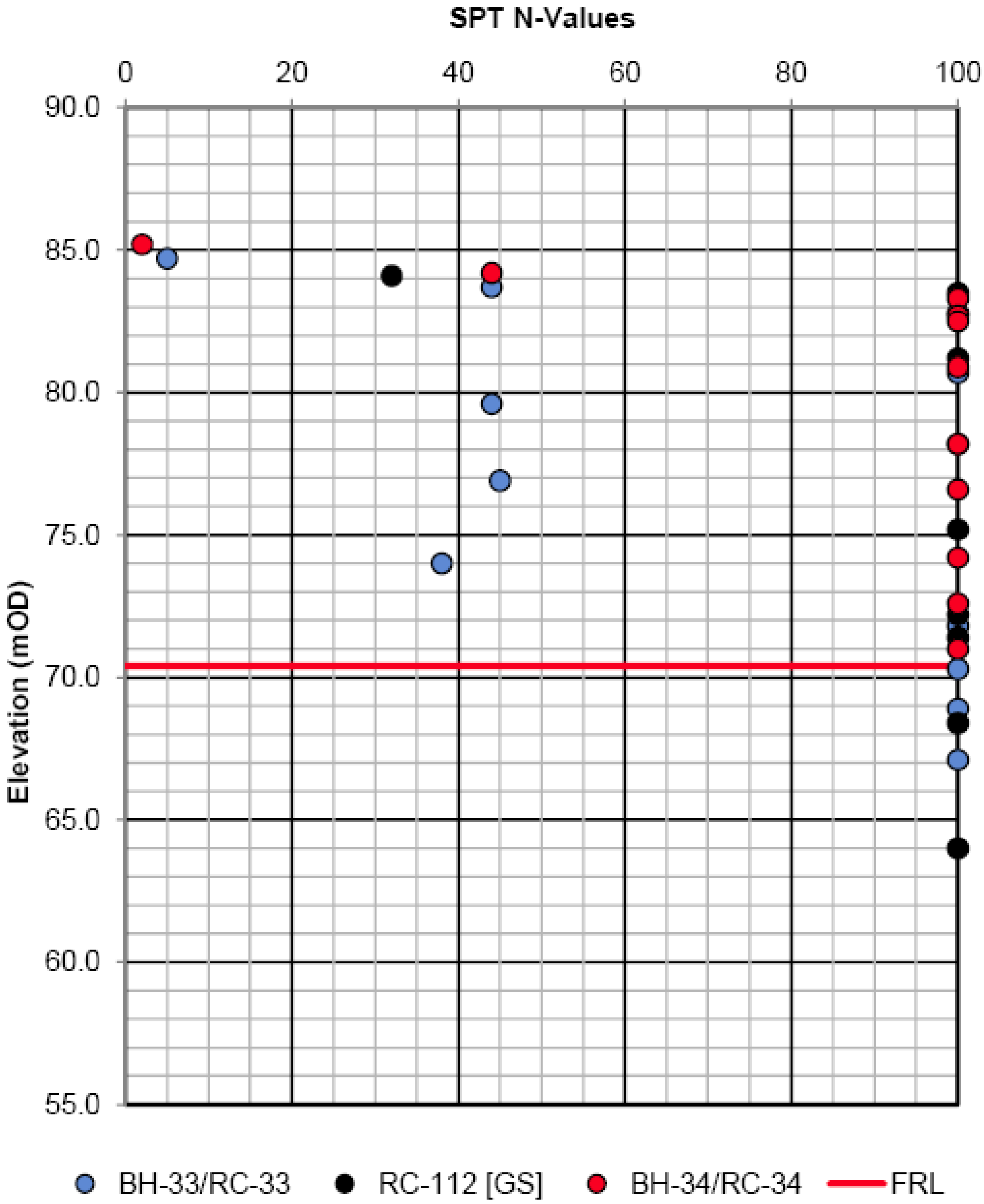

Figure 4.7.1 - SPT N-Values in boreholes and rotary coreholes between Ch.10+280 and 10+530 (Cut 8) - Refusal plotted at N=100

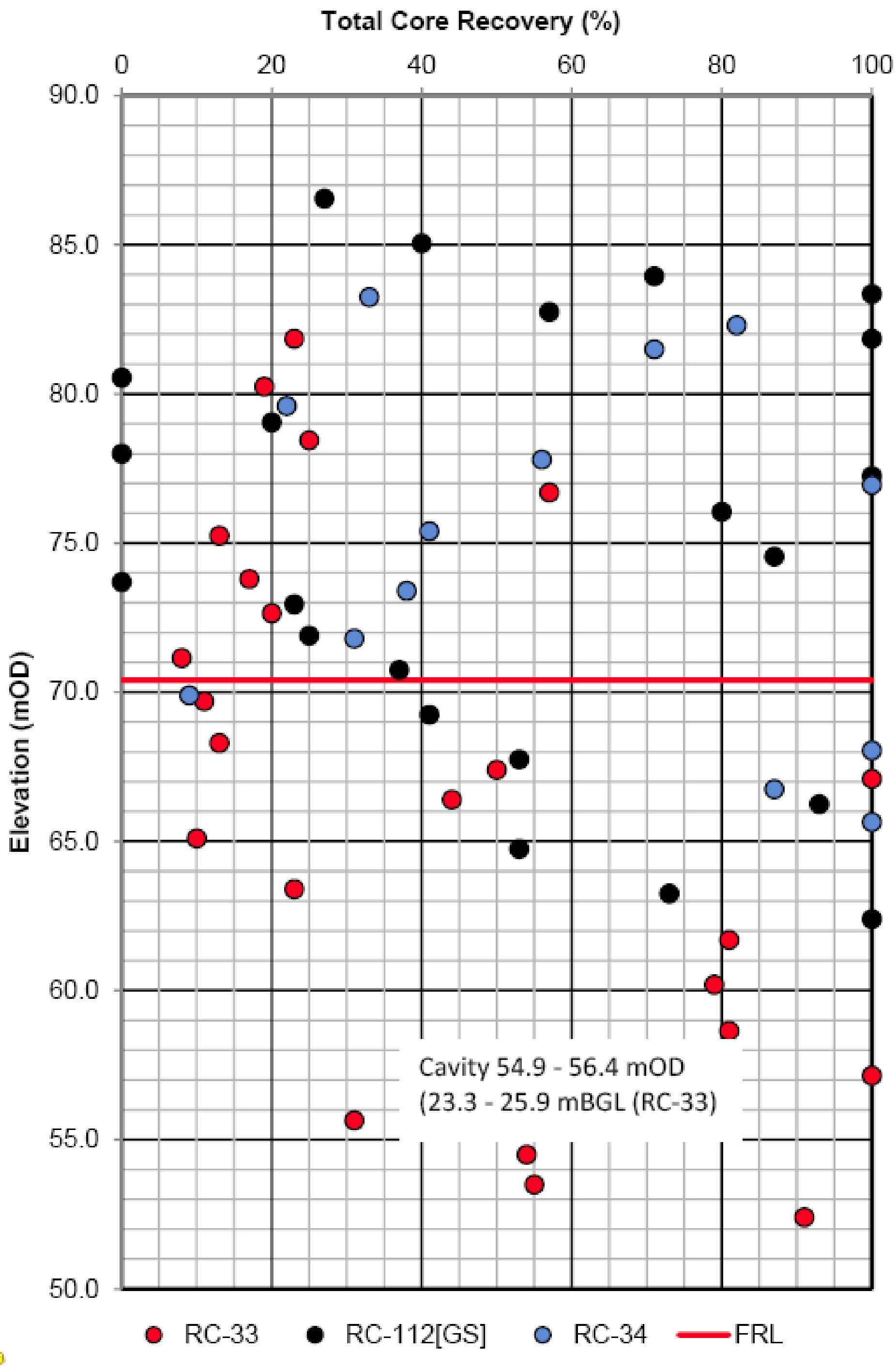

Figure 4.6.2 - Total Core Recovery (TCR) in rotary coreholes between Ch.10+280 and 10+530 (Cut 8)

The 2D resistivity profiles by Minerex indicate that the depth of clayey gravel or gravelly clay overburden is >15-25 m between Ch. 10+280 and 10+395. South of this clean Limestone rock is shown to be at a depth of 15.0 -17.0 m. This would indicate that comptent rock is below excavation level, which is consistent with the coreholes.

Ch. 10+530 to 10+900

The embankment crosses soft ground in the low lying area between Ch. 10+715 and 10+900. To the west of this (BH-35) the ground conditions consist of soft, soft to firm and stiff brown and grey-brown slightly sandy, slightly gravelly CLAY, which is probably glacial till, although some of the water contents are high (?n = 22-

38%). SPT NValues in the overburden range from 5-8 in the top 0.5 – 2.0 m, which would correspond to a cu of about 25 to 40 kPa (soft to firm), increasing to 17 and refusal in the underlying stiff Boulder Clay. The borehole reached refusal at a depth of 3.85 m. Strong dark grey LIMESTONE was recorded below a depth of 3.85 m in RC-35. However, total core recovery (TCR) in the rock generally ranged from 25% to 54% with some values of 77% to >100% in short core runs. The RQD was 0% which indicates the rock would be highly fractured, highly weathered, possibly due to karstification. However, the 2D resistivity profile from Minerex could also indicate that there is a deep profile of gravelly CLAY overburden at this location. Based on the conditions encountered in the adjacent cut to the west, it is possible that the corehole was advanced through very stiff to hard Boulder Clay with some to many cobbles and boulders and possibly layers or pockets of coarse granular till. No SPT's were carried out in the corehole but the overlying borehole does not indicate that the overburden is softened by karstification in the underlying Limestone rock. The Minerex resistivity profiles show a transition to shallow clean Limestone rock at Ch. 10+665. 3.3 to 6.3 m of very soft and soft to firm PEAT, MARL and Organic CLAY was encountered in the boreholes between Ch. 10+715 and 10+900. BH-36 and BH-38 were terminated at refusal at the base of the organic soils. A layer of soft and firm slightly sandy CLAY was encountered below the peat from a depth of 4.2 to 7.5 m in BH-37. SPT N-Values in the clay ranged from 5 to 11, which would correspond to an undrained shear strength of about 25 kPa (Soft) to 55 kPa (Firm). This was underlain by dense Limestone GRAVEL from 7.5 to 8.0 mBGL, which could be weathered rock. The depth of very soft PEAT and MARL was up to 6.3 m at BH-113, which was put down adjacent to BH-37. The organic soils were underlain by firm to stiff Boulder Clay (dark grey slightly sandy, slightly gravelly CLAY, N=15, □n = 18%, CL) from 6.3 to 7.5 mBGL, and dense brown clayey sandy GRAVEL with some cobbles below a depth of 7.5 m, which could be weathered rock(N=34 & refusal). The borehole was terminated on an obstruction in the gravel at a depth of 8.5 m. Strong light grey thinly laminated LIMESTONE rock was reported from a depth of 2.3 m in RC-38. Total core recovery (TCR) in the rock was low down to a depth of 4.8 m (32%), which could be weathered rock or very stiff/very dense glacial till with cobbles and boulders. Competent rock was encountered below a depth of 4.8 m where the TCR ranged from 76% to >100%. The RQD ranged from 0% to 76% but was greater than 54% below a depth of 5.3 m. The resistivity profiles from Minerex show that the level of clean Limestone rock drops off to the east of Ch. 10+740 and the profiles show overburden of gravelly clay, clayey gravel over possible slightly karstified clean LIMESTONE at a depth of about 5-15m.

Ch. 10+900 to 11+220

This section of the road is cut into the west side of a drumlin so that there is a steep transverse slope from east to west across the cut. TP-26 and TP-27 were excavated along the shallow side of the cut on the west side of the road. The trial pits were excavated to refusal on boulders at a depth of 2.5 to 2.9 m. The overburden within that depth consisted of soft and firm brown slightly sandy and sandy, slightly gravelly CLAY with occasional to many cobbles and boulders (Boulder Clay) (wn = 11-27%, 39.3-47.8% fines, CL). RC-40 was cored from ground level in the deepest part of the cut at Ch.11+090. Strong light grey, thinly laminated LIMESTONE was reported from ground level. However, the total core recovery (TCR) down to a depth of 15.9 m was typically 10-40% with an RQD of 0-15%, which could be highly weathered, highly fractured rock, dense to very dense coarse granular till, or very stiff to hard cohesive glacial till with occasional to many cobbles and boulders. SPT N-Values of 45-54 and refusal were recorded in the corehole, which does not indicate that the material has been loosened or softened due to karstification in the Limestone. Competent strong dark grey, thinly laminated LIMESTONE was encountered below a depth of 15.9 m. TCR in the rock was >92-100% and the RQD ranged from 48-66%. RC-114 was advanced to a depth of 15.0 m near RC-40 using the Geobore-S triple tube system with polymer gel drilling fluid to maximise core recovery in overburden and highly weathered rock. The core recovery from 1.5 to 7.5 mBGL ranged from 0-52% and consisted of Cobbles and Boulders, which could be granular glacial till after washout of finer material. Very stiff Boulder Clay (slightly sandy, slightly gravelly CLAY with occasional cobbles) was encountered from 7.5-15.0 mBGL. No rock was encountered within a depth of 15.0 m. TCR in the Boulder Clay ranged from 13-73%. SPT N-Values in the overburden ranged from 20-43 and refusal. The 2D Seismic Refraction profile by APEX indicates that slightly weathered to fresh rock with a seismic velocity, vs of 2526-2749 m/s, could be encountered 0.5 to 1.0 m below finished road level between Ch. 11+080 - 11+130 in the shallow cut along the west side of the road. However, RC-114 would indicate that this could be the top of the very stiff or very dense glacial till. The 2-D Resistivity profiles by Minerex do not show competent rock within a depth of 10-25 m in the cut, but indicate that the material within the depth of excavation could consist of gravelly clay and clayey gravel overburden, which is consistent with RC-114, or possibly karstified Limestone.

Ch. 11+220 to 11+360

This is a short section of embankment that crosses a watercourse at Ch. 11+310. The overburden in borehole BH-41, adjacent to the stream, consisted of firm and stiff boulder clay over clay-smeared angular cobbles at a depth of 3.5 m, which could be weathered rock. The boulder clay is classified as orange brown or grey slightly sandy, slightly gravelly CLAY with occasional boulders. SPT N-Values in the clay range from 6 at a depth of 0.5 m, to 16-26 and refusal below this. The borehole reached refusal in the cobbles at a depth of 4.6 m. In contrast the boulder clay below 0.9 m of topsoil in TP-28 was classified as very soft orange brown and mottled light and dark brown slightly sandy, slightly gravelly and gravelly SILT with numerous cobbles and boudlers, which could indicate that the overburden has been softened due to karstification in the underlying rock. No rotary coreholes were carried out in this section, but the 2-D Resistivity profiles from Minerex do not show competent rock within a depth of 10-25 m, but indicate that the material within that depth could consist of glacial till overburden (clayey gravel/gravelly clay) or karstified limestone rock.

DESIGN UNIT 8 Ch. 11+360 to 11+860

The ground conditions encountered in the boreholes within this cut (BH-42 & BH-43) consisted of 0.5 m of topsoil over firm, firm to stiff and stiff Boulder Clay (orange brown slightly sandy, slightly gravelly CLAY and grey slightly sandy gravelly CLAY) down to a depth of 2.8 m. SPT N-Values ranged from 9 to 42 and refusal. BH-43 reached refusal at a depth of 2.8 m. BH-42 was advanced 1.0 m into a layer of brown slightly sandy clay smeared angular gravelly COBBLES from 2.8 to 3.8 mBGL before reaching refusal. TP-29 to TP-31 give a contrasting view of the strength of the Boulder Clay. The ground conditions that were encountered within a depth of 3.0 m consisted of 0.3 m of topsoil over firm, soft and very soft Boulder Clay ranging from orange brown slightly sandy, slightly gravelly SILT or CLAY within a depth of 1.2-1.3 m, to a grey or brown slightly sandy, gravelly SILT or CLAY with occasional to numerous cobbles and boulders below this level. The upper layer was classified as firm in TP-29 and TP-31 at either end of the cut. Water contents in the Boulder Clay ranged from 21-33% in the upper 1.2 -1.3 m, to 11-25% below a depth of 1.3 m. The fines content was between 31% and 34%, and the Atterberg Limits would indicate that the material would generally be classified as a low plasticity CLAY (⍰l = 24-34, Ip = 11-14). TP-29 was terminated on rock or a boulder at a depth of 2.9 m. BH-43 was advanced by rotary coring. Strong grey Limestone rock is reported at RC-43 from a depth of 2.2 m, but the adjacent borehole reached a depth of 2.8 m in Boulder Clay, and the TCR in the corehole was very low (17-50%) down to a depth of 5.9 m and from 9.1 to 13.5 m. Below a depth of 13.5 m the TCR ranged from 70-100% and the RQD was 0-76% in more competent LIMESTONE bedrock. A high TCR (60-91%) was also recorded from 5.9 to 9.1 mBGL (Figure 4.7.1) During Phase III of the preliminary SI RC-303 was advanced to a depth of 13.5 m at the location of RC-43 using the Geobore-S system to maximise the recovery in overburden and weathered rock. The ground conditions encountered within the corehole consisted of layers of granular and cohesive glacial till typically ranging from slightly sandy, slightly gravelly SILT or CLAY, to clayey sandy GRAVEL, both containing some to many cobbles and boulders. The TCR below a depth of 3.0 m ranged from 35% to 100%. Zones of low core recovery would probably indicate where finer material has been washed out in the coring process, particularly in granular soils. The coreholes would indicate that Limestone rock is below the depth of excavation in the cut, at about 13.5 mBGL or Elev. +67.2 mOD at Ch. 9+200 (FRL = +70.5 mOD). SPT N-Values from the boreholes and rotary coreholes are plotted against depth in Figure 4.8.2. The N-Values in the overburden range from 9-10 in the Boulder Clay in the top 0.5 to 1.0 m, which is Firm (cu ≈ 45-50 kPa) to 21 - 54 and refusal below this, which would correspond to stiff to very stiff and hard cohesive glacial till (cu ≈ 100 to >250 kPa), or medium dense to very dense granular till with cobble and boulder obstructions.

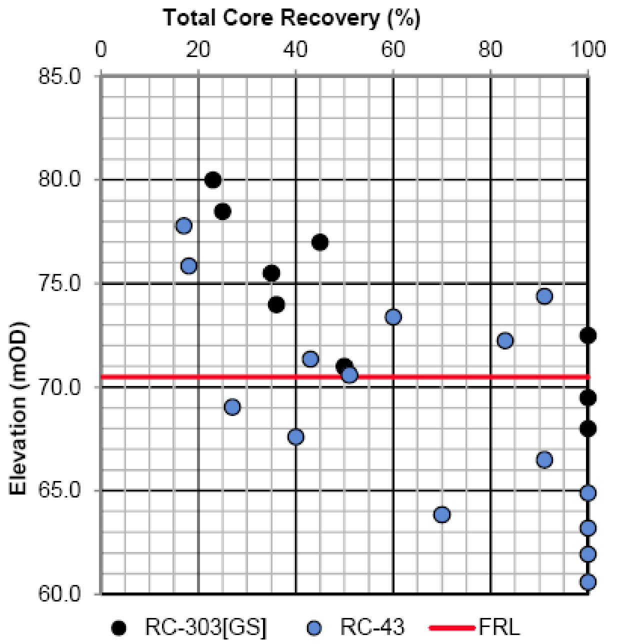

Figure 4.8.1 - Total Core Recovery (TCR) vs Depth in Cut 10

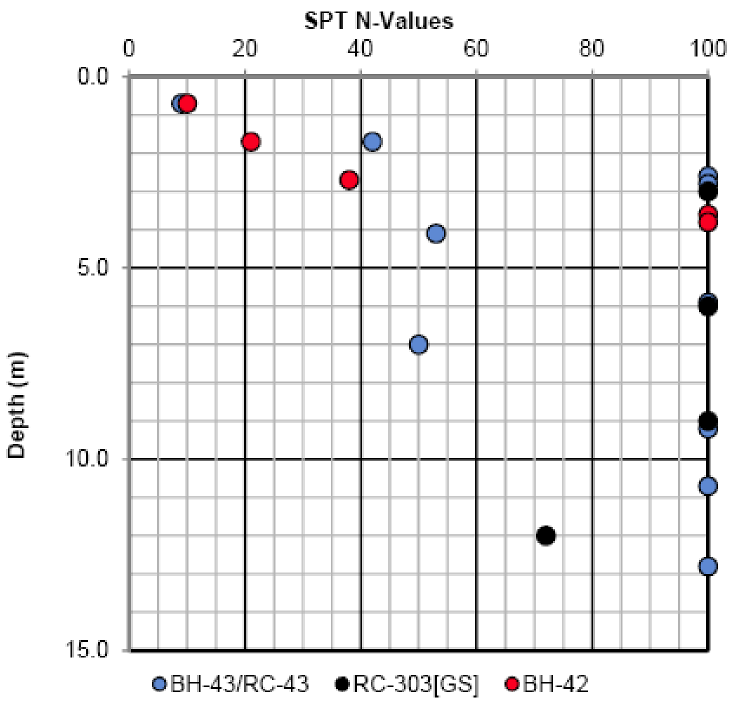

Figure 4.8.2 - SPT N-Values from boreholes and coreholes in Cut 10 (Refusal plotted at N=100)

The 2D Seismic Refraction profile produced through this cut by APEX indicates that slightly weathered to fresh rock with a seismic velocity, vs of 2307-3107 m/s, could be encountered at a depth of 1.5-6.5 m, generally at 3-5 mBGL. However, based on RC- 303, rock is below the depth of cut and the top of the rock profile shown on the Apex report actually seems to correspond to the top of the stiff or very stiff Boulder clay, or dense to very dense coarse granular till, which could give similar seismic velocities. The 2D-Resistivity profiles by Minerex show clayey Gravel overburden possibly underlain by slightly karstified Limestone at a depth of 5-20 m at the north and south ends of the cut, with a pocket of very karstified Limestone or Shale at a depth of 13-15 m at the centre of the cut, which would correspond to the depth of competent rock in RC-43 at Ch. 11+640.

Ch. 11+860 to 12+600

This section of the embankment crosses a soft ground area between Ch. 11+990 and about 12+390. The ground conditions encountered in the boreholes and trial pits in this area consisted of 1.3 to 3.1 m of soft PEAT over very soft to soft Boulder Clay (TP-131: n = 9.0-9.4%, 27.1% fines, l = 19-20, IP=5-7: CL/ML), or stiff grey/beige organic CLAY mixed with sand, gravel and cobbles (BH-45). There are no laboratory test results for the organic Clay below the peat in BH-45. However, SPT N-Values of 36-47 were recorded at a depth of 3.5 and 4.5 m, which would indicate that it is very stiff and of low compressibility - possibly glacial till with traces of organics at the interface with the peat. The cobra probes indicate that the depth of soft ground in the area ranges from 1.7 m to 3.1 m based on the interpreted resistance to penetration, which is open to interpretation by the operator. We note that the depth of soft compressible soil at TP-131 was only 1.3 m whereas the cobra probe at the same location indicates that it could be up to 3.1 m deep. The trial pits are more reliable in this case. Outside the soft ground area the trial pits indicate that the ground conditions consist of 0.1 to 0.6 m of Topsoil or PEAT over very soft and soft fine and coarse-grained glacial till typically ranging from slightly sandy, gravelly SILT, to silty sandy GRAVEL with occasional to many cobbles and boulders. Cobra probe PH-37, which was adjacent to the stream at Ch. 10+000 indicates that there could be up to 3.9 m soft ground at this location. However, the adjacent trial pit TP-132 only encountered 0.1 m of PEAT over very soft fine-grained glacial till with many cobbles and boulders, although the laboratory classification test results from a depth of 0.5-1.0 m indicate that there could be some mixing of organics at the interface (43.2% fines, n = 276%, l = 226, IP=98). Strong light grey thinly laminated fossiliferous Limestone with closely spaced smooth undulating fractures was cored from 5.7 to 10.4 mBGL in RC-45 at Ch. 12+340. There was a low core recovery down to a depth of 7.7 m, which could be weathered rock or possibly glacial till, but below this level the TCR was between 88 and 114% and the RQD ranged from 36-45% in competent Limestone. Water loss was recorded at a depth of 6.5m in RC-45 in a possible cavity, or in the glacial till overburden at this depth. There is no evidence of karstification in the competent rock below a depth of 7.7 m.

1.1.8 **DESIGN UNIT 9**

Ch. 12+600 to 13+625

The ground conditions encountered in the boreholes within this cut (BH-47 to BH-52) consisted of 0.5 m of topsoil over soft, firm, firm to stiff and stiff Boulder Clay (brown and grey brown slightly sandy to sandy, slightly gravelly CLAY with cobbles and boulders). The boreholes reached refusal on obstructions at a depth of 1.3 to 3.0 m. The trial pits within the cut indicate that the material within a depth of 2.0 to 4.5 m was generally comprised of soft and very soft Boulder Clay (orange brown and light brown slightly sandy to sandy gravelly CLAY) and clayey to very clayey, very sandy GRAVEL or gravelly SAND, with occasional to many cobbles and boulders throughout. Very stiff grey Boulder Clay was encountered at a depth of 2.4 m in TP-135 near the deepest part of the cut at Ch. 13+360. TP-39, near the cut/fill line at the south end, was excavated into a layer of angular COBBLES and BOULDERS with silty sandy GRAVEL from 0.5 to 2.4 mBGL before reaching refusal on probable rock. Water contents in the Boulder Clay generally ranged from 14% to 26% and the fines content was between 25.7% and 44%. Based on the Atterberg Limits, the fines would generally be classified as a low plasticity CLAY (l = 20-35, Ip = 7-14), although the sample from a depth of2.0 m in TP-35 was non-plastic. The Gravel had water contents of 5.8% to 13.7% and a fines content of 9.1% to 27.5%. Strong grey fossiliferous LIMESTONE is reported from a depth of 1.2 to 2.2 mBGL in rotary coreholes RC-47 to RC-52. However, the Total Core Recovery down to a depth of 4.2 to 10.0 m was very low (typically 0-35%) with SPT N-Values of 51 to 77 and refusal. Therefore, the material within this depth could be highly weathered/highly fractured or karstified Limestone rock, or very stiff/very dense glacial till with cobbles and boulders where the finer matrix material has been washed out during coring. Low core recovery due to dissolution or a cavity is noted from a depth of 4.8-5.9 m in RC-47 but the SPT NValues do not indicate any softening or loosening of the overburden or weathered rock due to active karstification in the Limestone. The TCR and SPT N-Values from the coreholes are plotted against depth in Figures 4.9.1 and 4.9.2, respectively. Table 4.9.2 shows the depth and elevation of the top of competent rock in the coreholes. TCR in the LIMESTONE below this level ranged from 78-100% and the RQD was between 0% and 47%. The rock is described as thinly bedded in RC-47, and thinly laminated in RC-50. Competent rock should generally be below cut level, although some rock may be encountered within the box cut to sub-formation level near Ch.13+040.

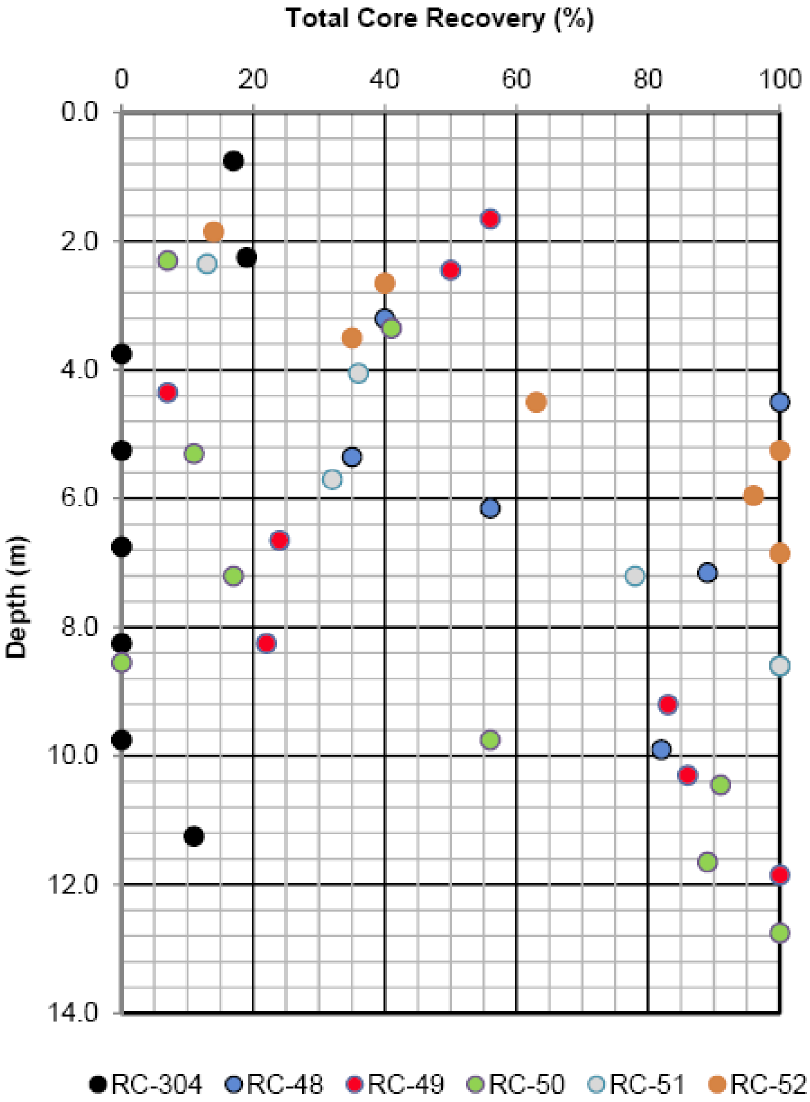

Figure 4.9.1 - Total Core Recovery (TCR) vs Depth in Cut 11

Table 4.9.2 - Level of competent Limestone rock in the coreholes in Cut 11

Rotary Corehole	Chainage (m)	Depth to Competent Rock (m)	Elevation of Competent Rock (mOD)	Finished Road Level (mOD)
RC-47	13+040	6.4	77.4	75.3
RC-49	13+300	8.9	75.3	75.2
RC-50	13+340	10	74.8	74.8
RC-304	13+360	>12.0	<74.5	74.6
RC-51	13+490	6.5	71.9	72.7
RC-52	13+640	4.8	66.2	70.5

[Note: There is an error on the log for RC-50. The TCR is reported as 0% but the Solid Core Recovery is reported as 7-104% with RQD of 0-99%. For the purpose of this report we have quoted the SCR as TCR and neglected the high RQD in the thinly laminated LIMESTONE below a depth of 10.0 m]. During Phase III of the preliminary SI RC-304 was advanced to a depth of 12.0 m near the location of RC-50 using the Geobore-S system to maximise the recovery in overburden and weathered rock. The recovery in the corehole was still very low, ranging from 17-19% in the cohesive soils in the top 3.0 m, to 0% from 3.0-10.5 m in material where the driller noted SAND, and 11% in the underlying GRAVEL from 10.5-12.0 m. The sample descriptions may not be representative of the undisturbed soil due to the low core recovery, but they do suggest that the soils form 9-12 mBGL could be predominately granular. The particle size distribution tests on samples of the granular soils from the trial pits in the area would indicate that these soils may still classify as Class 2C materials with >15% fines. No rock was encountered within the depth of the corehole.

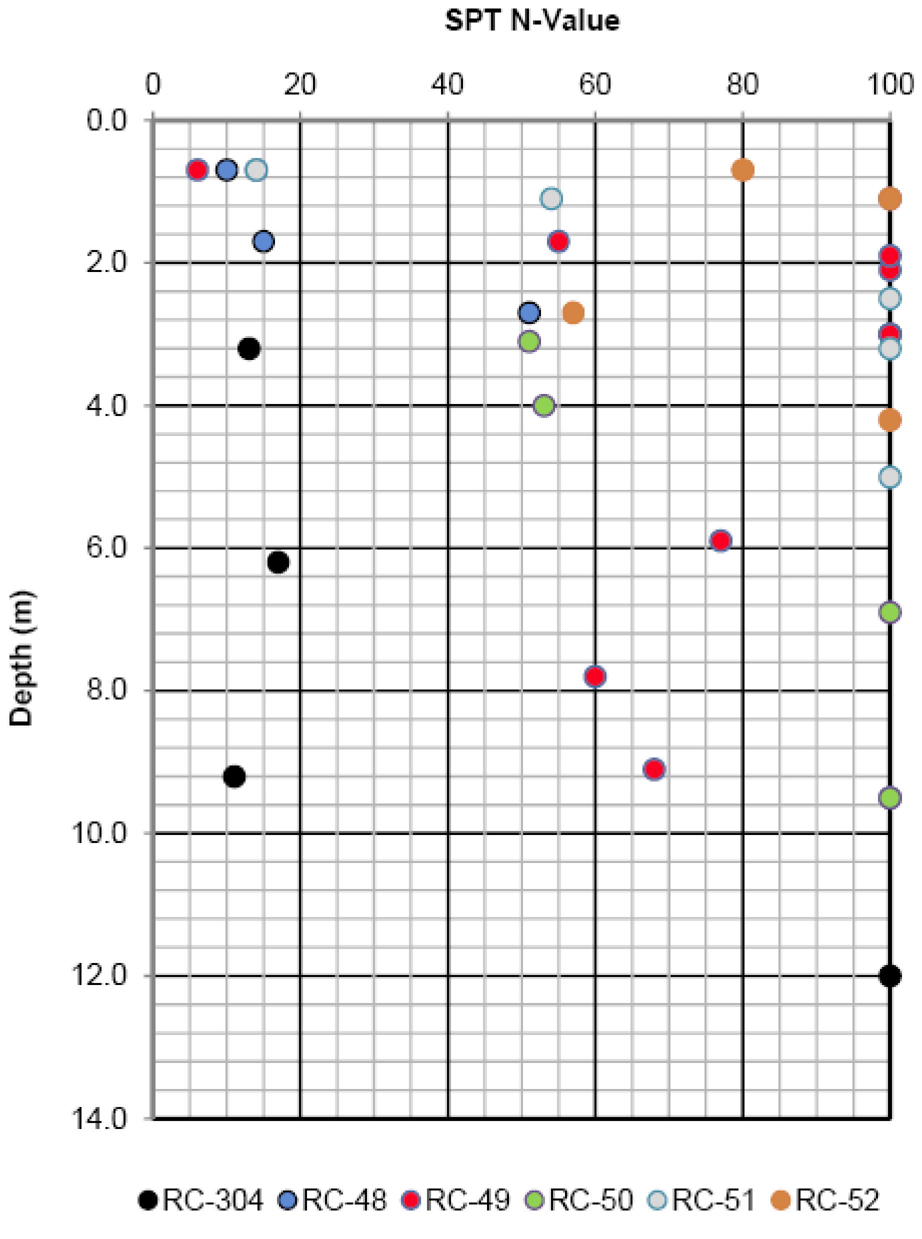

Figure 4.9.2 - SPT N-Values from boreholes and coreholes in Cut 11 (Refusal plotted at N=100)

SPT N-Values from the boreholes and rotary coreholes are plotted against depth in Figure 4.8.2. The N-Values in the overburden range from 6-14 in the Boulder Clay in the top 0.5 to 1.0 m, which ranges from soft to firm (cu ≈ 30-70 kPa) to 15 - 80 and refusal below this, which would correspond to stiff to very stiff and hard cohesive glacial till (cu ≈ 100 to >250 kPa), or medium dense to very dense granular till with cobble and boulder obstructions. Lower N-Values of 11 to 17 were recorded in the sandy soil from 3-10 mBGL in RC-304, which would indicate that the soils are medium dense, possibly as a result of karstification in the underlying Limestone. The 2-D Seismic Refraction surveys by APEX indicate that slightly weathered to fresh rock with a seismic velocity, vs, of 2293 to 4805 m/s occurs at a depth of 2.0 m to 12.0 m, but generally between 4.0 m and 8.0 mBGL. The interpreted profile of the top of rock is highly irregular with pinnacles and deep troughs.

The profile indicates that the rock may be encountered within the depth of cut to sub-formation level between Ch. 12+640 and 13+500. However, the rotary coreholes generally indicate that competent rock is at a lower level so some of the rock levels interpreted in the seismic refraction survey may actually correspond to areas where there is a distinct change in strata to very stiff to hard boulder clay or very dense coarse granular till with many cobbles and boulders. The 2D resistivity profile from Minerex shows a more uniform profile through slightly karstified rock at a depth of 2.8 to 9.7 m between Ch. 13+150 and 13+500. The profile indicates that clean limestone is at a shallow depth of 2-5 m south of this to the end of the cut at Ch. 13+500. The rock is overlain by gravel or slightly karstified Limestone. Based on the resistivity profile, rock may be encountered within the depth of cut to subformation level between Ch. 13+150 and 13+500, and locally at the base of the cut to the south of this.

Ch. 13+625 to 14+260

This section of embankment crosses a soft ground area of organic, alluvial and possibly fine-grained fluvioglacial soils between Ch. 13+740 and 13+990, which is adjacent to the watercourse that crosses the mainline carriageway at Ch. 13+865. On the north side of the stream the DPSH dynamic probes (DP-110 & DP-111) and trial pits (TP-43) indicate that there is 0.5-1.7 m of soft topsoil, clay, or possibly peat over soft to firm and firm fine-grained compressible alluvial or fluvioglacial soils. The probes reached refusal at depths of 4.6 m and 6.1 m. From 0.3 to 1.5 m in TP-43 there was a layer of soft-firm sandy, slightly gravelly CLAY ($\square_n$ = 33% & 50%, 48% fines, $\square_l$ = 47, I_p = 17, MI) with a large boulder. This was underlain by firm grey slightly sandy CLAY interbedded with thin lenses of fine SAND ($\square_n$ = 27% & 41.4%, $\square_l$ = 37, I_p = 13, CI/MI). The strength descriptions on the logs would indicate that these soils are overconsolidated, possibly fine-grained fluvioglacial soils. The natural water content from the classification tests was 27-33%, which would indicate that the soils are inorganic. However, higher water contents of 41-50% were recorded for the MCV tests, which would indicate a higher compressibility material, possible with traces of organics, although this is not noted on the logs. The main soft ground area is on the south side of the stream. The ground conditions in TP-44 and BH-115 at Ch. 13+940 consisted of 4.0 m of very soft PEAT and organic SILT over soft, firm and stiff slightly sandy CLAY. SPT N-Values ranged from 1 in the peat and organic soils, to 7, 12, and 24 increasing with depth in the sandy CLAY below a depth of 4.0 m. The borehole reached refusal at a depth of 9.1 m. Water contents ranged from 150-450% in the peat and from 66-111% in the organic silt. Lab vanes in the piston samples gave undrained shear strengths, c_u, of 10-26 kPa, which is very soft (<20 kPa) to soft (20-40 kPa). The slightly sandy CLAY below a depth of 4.0 m is possibly an over-consolidated finegrained fluvioglacial soil. The water contents ranged from 23-30%, which would indicate that it is not organic. The soil had 96-97% fines and would be classified as a low to intermediate plasticity CLAY based on the Atterberg Limits ($\square_l$ = 34-38, I_p = 13-17, CL/CI). The SPT N-Values of 7, 12 and 24 would correspond to c_u of about 35 kPa (Soft-Firm), 60 kPa (Firm) and 120 kPa (Stiff) at depths of 4.5 m, 6.0 m and 8.5 m, respectively. Unconsolidated undrained triaxial compression tests gave shear strengths, c_u, of 57 kPa at a depth of 5.2 m and 7.2 m. To the south of Ch. 13+990 DPSH dynamic probes (DP-112/112A and DP-113/113A would indicate that there is no soft ground along this section of the road. The probes reached refusal at shallow depths of 0.3 to 0.6 m. Additional investigations should be carried out in this area during the detailed site investigation stage to confirm that the probes have not reached refusal on obstructions in made ground. The is up to 1.7 m of very soft soil, possibly peat adjacent to the watercourse at Ch. 14+220 (DP-114). At the southern tie-in (TP-136) the topsoil is underlain by clayeysandy GRAVEL (5% fines) and gravelly SAND. The significance of the ground conditions is that where the proposed road realignment is underlain by soft ground unsuitable for road construction purposes, this material will require removal and appropriate re-use or disposal. The soft ground is likely to be sensitive to drying out and to compaction.