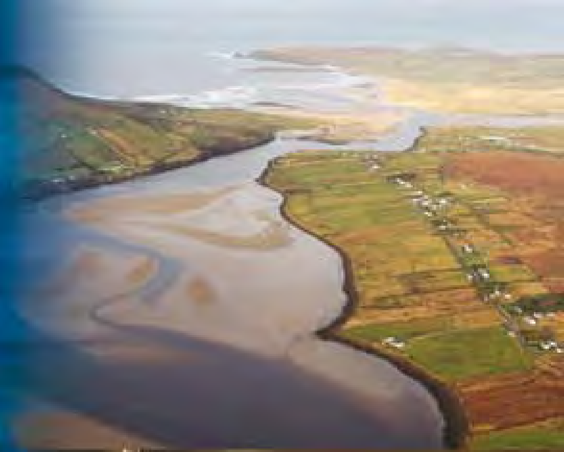
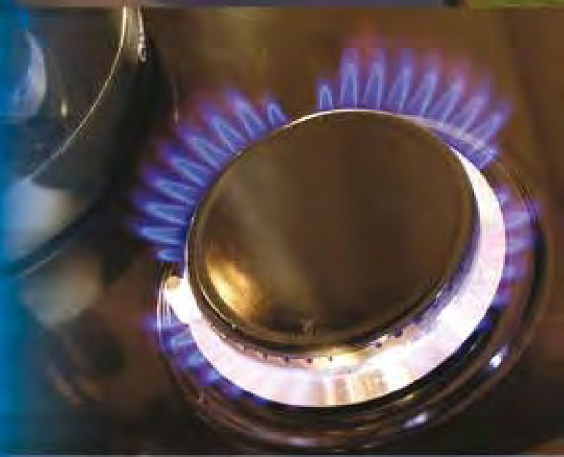
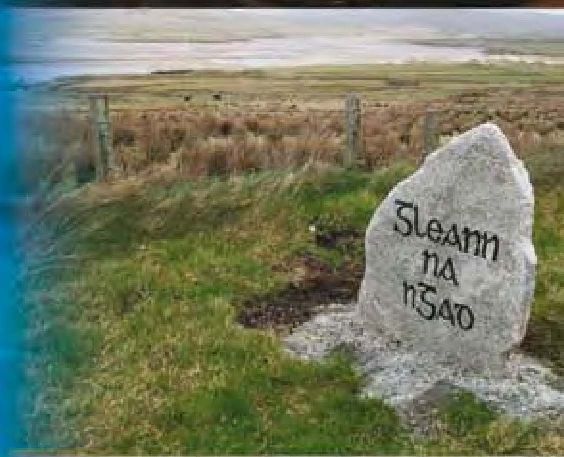
Corrib
natural gas





Corrib Onshore Pipeline

Environmental Impact Statement



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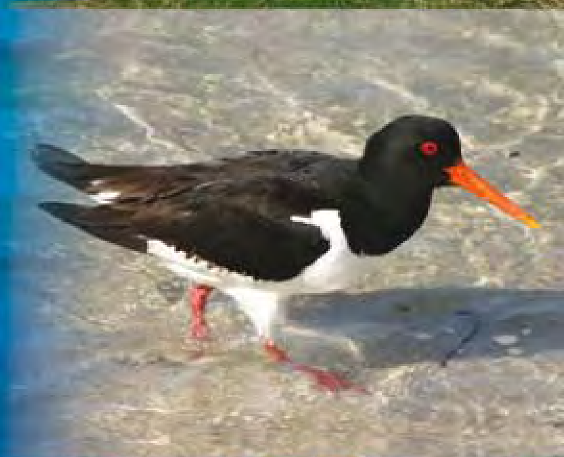

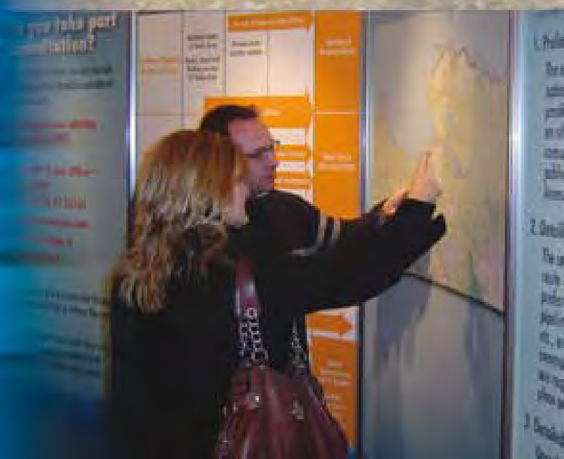

RPS

FEBRUARY 2009

Appendix M

Soils and Geology

M2: Peat Stability Assessment
M3: Geotechnical Assessment of Stone Road Construction in Peat Areas
M4: Geotechnical Risk Register
M5: Hydrological Impact Assessment
M6: Eco-Hydrological and Eco-Hydrogeological Impact Assessment of Proposed Corrib Onshore Pipeline

Appendix M2

Peat Stability Assessment

REPORT ON

CORRIB ONSHORE PIPELINE

PEAT STABILITY ASSESSMENT

Prepared for:

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January 2009

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DOCUMENT APPROVAL FORM

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EXECUTIVE SUMMARY

Approximately 5.7km of the proposed Corrib Onshore Pipeline is to be constructed within peat areas. The peat varies in depth along the route between 0.25 and 5m with approximately 63% of the peat area less than 3m deep.

Applied Ground Engineering Consultants Limited (AGEC) was commissioned on behalf on behalf Shell E&P (Ireland) Ltd (SEPIL) to prepare a peat stability assessment report for the proposed Corrib Onshore Pipeline route from the landfall at Glengad Headland to the Bellanaboy gas terminal site. This involved the assessment of the stability of natural peat slopes along the proposed pipeline route. The assessment was based on a walkover survey, geomorphology derived from the walkover survey and review and interpretation of the ground investigation (GI) data compiled along the proposed pipeline route.

There are three areas where the proposed pipeline route passes through peat areas namely Ross Port (Commonage) (ch. 85,960 to ch. 88,600), South of Sruwaddacon Bay to L-1202 (ch. 89,500 to ch. 91,000), and L-1202 to Terminal Site (ch. 91,000 to 92,560).

A summary of the findings of the assessment of the stability of natural peat slopes along the proposed pipeline route are as follows:

(1) The walkover survey of the pipeline route, carried out to identify salient ground conditions and in particular evidence of peat instability, identified no evidence of peat failure that would pose a risk to the pipeline route.

(2) Results of a stability analysis showed that the natural peat slopes along the proposed pipeline route have an acceptable Factor of Safety. The high calculated Factor of Safety for the route corresponds to the findings of the walkover survey of the route which identified no evidence of peat failure.

(3) Several localised areas of weaker peat were identified along the route. These areas are not considered to represent a significant risk to the pipeline construction, particularly taking into account the use of a stone road construction method in the peat.

(4) Taking into account the findings of the walkover survey, the results of the stability assessment and the proposed stone road construction method it is considered that the pipeline can be safely constructed along the proposed pipeline route.

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1 INTRODUCTION

1.1 Background

Applied Ground Engineering Consultants Ltd (AGEC) was requested by Shell E&P (Ireland) Ltd (SEPIL) in November 2008 to prepare a peat stability assessment report for the proposed Corrib Onshore Pipeline route from the landfall at Glengad Headland to the Bellanaboy gas terminal site (Drawing 864_01_001).

This assessment report examines the stability of natural peat slopes along the route of the proposed pipeline. The assessment is based on the findings of a walkover carried out by AGEC in December 2008, geomorphology derived from the walkover and review and interpretation of the ground investigation (GI) data compiled along the proposed pipeline route.

The proposed onshore pipeline route is approximately 9.2km long, from the landfall at Glengad Headland (ch. 83,400) to the terminal (ch. 92,560). The onshore pipeline crosses approximately 5.7km of deeper peatland, with peat depths ranging from 0.25 to locally 5m. The three sections where the pipeline crosses over peat land are: Rossport (Commonage) (ch. 85,960 to 88,600); South of Sruwaddacon Bay to L-1202 (ch. 89,500 to 91,000); and L-1202 to Terminal Site (ch. 91,000 to 92,560).

1.2 This Report

This report includes the following key sections:

(1) Description of route and geomorphology

(2) Review of ground investigation

(3) Interpretation of ground conditions along the route, principally within peat areas

(4) Characterisation of ground conditions and design parameters

(5) Peat stability assessment of natural peat slopes with respect to:

   (a) Stability within the peat and at the basal interface

   (b) Stability within the immediate underlying mineral soil

   (c) Stability assessment with and without construction loading

For reporting purposes the proposed onshore pipeline route has been divided up into seven sections based on the ground conditions encountered as shown below.

Section		Chainage	Peatland
1	Glengad Headland	83,400 to 84,065	No
2	Sruwaddacon Bay Lower Crossing	84,065 to 84,470	No
3	Rossport (West)	84,470 to 85,960	No
4	Rossport (Commonage)	85,960 to 88,600	Yes
5	Sruwaddacon Bay Upper Crossing	88,600 to 89,500	No
6	South of Sruwaddacon Bay to L-1202	89,500 to 91,000	Yes
7	L-1202 to Terminal Site	91,000 to 92,560	Yes

The chainages used to determine the extent of the individual sections are based on the ground conditions and do not relate to land boundaries.

The peat sections of the proposed onshore pipeline route are described as follows:

(1) Rossport (Commonage). The route passes through an area of generally open peat land which rises to a maximum elevation of 26m OD between Ch 86,950 to Ch 87,250. The route essentially follows the watershed divide (ridge line) through most of this section.

Local access tracks are encountered at Ch 86,400 and 86,830. These tracks are used to access peat cutting areas within the commonage and are areas where peat cutting is concentrated.

Public roads are encountered at Ch 87,540 and 88,350 before the route re-enters Sruwaddacon Bay estuary at Ch 88,600. Further areas of peat cuttings are located around the public roads and adjacent to the estuary.

(2) South of Sruwaddacon Bay to L-1202. This section of proposed onshore pipeline is located on gentle sloping ground. The ground comprised a section of grassland with most of the route consisting of blanket peat overlying mineral soil, with an area of forestry.

South of the estuary the pipeline route is also within a peat area which extends from the landfall at the estuary to the Bellanaboy terminal site. At about Ch 90,100 the route passes across a stream, where there is some reclaimed agricultural land. There is a peat cutting adjacent to the reclaimed agricultural land at Ch 90,200, which also marks the start of an area of open peat land that extends to ch. 90,400.

From ch. 90,400 the route is essentially within forestry until the terminal site. A stream is crossed at about ch. 91,000 where a local road is crossed.

(3) L-1202 to Terminal Site. This section of the proposed onshore pipeline route is located on gentle sloping ground. The ground comprised blanket peat overlying mineral soil.

The route is within forestry and intersects some areas of dense forestry comprising both juvenile and mature trees and open land. The forested areas contain a network of open drainage channels.

The topography initially falls from the local road (Ch 90,400) to an elevation of 19m OD at about Ch 91,530 where a minor stream is encountered before rising in elevation to about 36m OD at the terminal.

2 ROUTE DESCRIPTION AND GEOMORPHOLOGY

2.1 General

As part of the peat stability assessment for the proposed onshore pipeline, AGEC undertook a walkover survey of the route in December 2008 together with a review of available records of peat failures within the area.

The purpose of the walkover survey was to provide a record of the salient geomorphological features of the route and to provide an assessment of ground conditions, particularly peat conditions and evidence of peat instability that may pose a risk to the pipeline route.

At the time of survey the weather was clear, with no rainfall. The weather preceding the survey was typical for the time of the year. The survey was carried out by geotechnical engineers/engineering geologists experienced in peatland assessment.

The following salient geomorphological features included in the survey, as appropriate:

(1) Morphology, such as slope inclination and break in slope

(2) General ground conditions

(3) Indications of active, incipient or relict instability particularly within the peat

(4) Drainage conditions and wet areas

(5) General land use, such as agriculture, peat cutting

(6) General peat conditions including description, thickness, strength

The survey covered all reasonably accessible areas along the route.

The method adopted for carrying out the survey relied on the survey team carrying out a visual assessment of the site with peat depth probing and recording of salient geomorphological features. Aerial photographic interpretation was also used to supplement the field survey.

The results of the survey were used to compile the geomorphological plans (Drawing 864_01_002 to 004).

2.2 Review of Reported Peat Failures within the Area

The Geological Survey of Ireland (GSI 2006), Irish landslides Working Group report a number of peat failure events within Mayo, some of which are historical events. There are some 120 landslide events recorded in the GSI database for Ireland to date with 12 of these events occurring in County Mayo.

In recent times there have been a number of recorded peat failure events within the vicinity of the pipeline route. Details of some of the recent relevant events are given below.

(1) Dooncarton mountain landslides, September 2003.

On 19 September 2003 a cluster of 40 separate shallow landslides, including significant peat failures, occurred on Dooncarton Mountain during an exceptional rainfall event (Dykes and Warburton, 2008).

The trigger for landslides was the exceptional rainfall (in excess of 100 year return period) in combination with steep topography (generally greater than 20 degrees and up to 40 degrees) and local soil characteristics.

The mountain slopes are covered in blanket peat which thins gradationally upslope. The peat was underlain by a dominantly sandy mineral material, including a buried topsoil horizon, derived from weathering of the mainly schist bedrock, and bedrock at shallow depth.

Most of the landslide scars are coincident with the upper slope area where the peat cover gives way to thin peaty soil, and the slope is at its steepest and greatest convexity. It is considered that rapid ingress of water into the upper slope caused a build-up of a perched water table below the thin peat/soil cover that resulted in loss of effective stress leading to a reduction in shear resistance and ultimately failure.

Analysis of the upper part of the slope (Dykes and Warburton, 2007) showed that the slope convexity, where the peat cover gives way to thin peaty soil, defined the zone of minimum stability. Failure of the slope segment immediately above the convexity was controlled by the depth of peat and the build-up of water pressure within the slope.

The prevailing topographic and soil conditions on Dooncarton Mountain are notably different from the conditions that exist along the pipeline route. A notable pre-condition of failures on Dooncarton Mountain was the combination of steep slopes (generally greater than 20 degrees and up to 40 degrees) and thin peat cover.

In contrast to Dooncarton Mountain, the slope inclinations within the peat areas along the proposed pipeline route are gentle with inclinations not exceeding about 5 degrees, furthermore the peat cover generally exceeds 2m, see below for details.

(2) Peat landslip on L-1202 road, Aughoose, Erris, May 2008.

In comparison to the above events, this landslip incident was relatively minor in nature. The incident was located adjacent to a minor public road (L-1202), approximately 1.25 km from the junction with the R314 in Aughoose. The incident occurred during widening works for the road by Mayo County Council on 8 May 2008.

The incident comprised movement of peat over a length of over 40m along the north side of the road. The movement appeared to extend some 15 to 20m distance away from the road, and affected an area possibly up to 800m^2 with peat depth estimated at 2 to 3m. Total affected volume was estimated at up to 2400m^3.

The upper section (about 1m thick) of the failed peat appeared to be fibrous and was underlain by more amorphous peat. The incident area was vegetated by coarse grass, reeds with occasional bushes, trees and tree stumps with forestry some 30 to 50m from edge of the road. The lateral extent of the landslip was possibly controlled by the presence of drainage ditches that run perpendicular to the road.

The existing road is a floating road and appeared to be undamaged by the incident.

The reasons for the incident are not known in detail but based on descriptions of the event and an inspection of the site the possible cause of the landslip was bearing failure of the insitu peat due to excessive loading. The loading was as a result of placement of excavated peat and quarry stone placed during the road widening. This loading likely caused a bearing failure within the insitu peat that would have initially failed as rotational movement resulting in heave followed by limited translational movement.

The inadvertent loading of weak peat has been identified in a number of peat failures. For the construction of the pipeline it is proposed to limit placing of load onto the peat surface by the construction of a stone road through the peat areas.

Stone road construction within peat areas is a recognised construction method for access in particularly deep peat areas and has been used for example on the Mayo-Galway gas pipeline. The constructed stone road provides a stable platform for subsequent construction work, so reducing construction impact on the surrounding peat, and provides secure ground in which to install the pipeline.

2.3 Route Description and Geomorphology

Detail description of the route is provided in Appendix A and shown on the geomorphological plans (Drawing 864_01_002 to 004) with a summary of the route and the geomorphology given below. For chainage location of features described below refer to the geomorphological plans.

Photographs associated with the geomorphological plans are presented in Appendix B. The details given below are those identified or/and recorded from the walkover, further sub-surface ground details are given in the section on Ground Conditions.

2.4 Glengad Headland

The pipeline landfall is on the northeast coast of the headland (ch. 83,400). At the landfall the sea cliff was some 2.5 to 3m high with bedrock exposed at the base of the cliff. The route passes through mostly agricultural land where the topography is relatively uniform with slope inclinations about 1 degree.

Areas of sand hills are present to the north and it is possible that sand underlies part of the route.

Several significant drains, carrying streams from Dooncarton Mountain to the south cross the route.

Overall there was little peat cover in the area with typically peaty topsoil present with a thickness of about 0.5m.

2.5 Sruwaddacon Bay Lower Crossing

This section of proposed works crosses below Sruwaddacon Bay. The foreshore area on the Glengad Headland comprised a shallow beach terrace comprised of fine sediments.

The foreshore area on the Rossport side comprised more rocks with occasional bedrock exposures with sand gravel and angular cobbles and boulders. A minor cliff is present which comprised overburden with some bedrock exposures.

2.6 Rossport (West)

The pipeline route follows the shoreline of Sruwaddacon Bay and is located within agricultural fields. The topography generally comprised side-long ground with uniform slopes up to typically 5 degrees but with locally steeper slopes closer to the shoreline, where there is a cliff that varies in height from less than 1m up to 5m.

Ground conditions generally comprised overburden in the upper few metres with rock near surface in the north but generally at depth.

A number of ditches located within the field boundaries cross the route. Ditches were typically less than a metre deep and carried surface run-off from the ground upslope and discharged onto the foreshore.

Overall there was little peat cover in the area with typically peaty topsoil present with a thickness of about 0.5m.

2.7 Rossport (Commonage)

This section contains extensive areas of blanket peat.

The route essentially follows the watershed divide (ridge line) through most of this section. The route passes through an area of generally open peat land which comprised gentle slopes with inclinations from 0 to 3 degrees increasing to about 4.5 degrees as the route approaches the shoreline in the south, where there are peat cuttings. The route rises to a maximum elevation of 26m OD between Ch 86,950 to Ch 87,250.

Peat cover through the commonage varies from about 1m to about 5m. There are extensive areas of cuttings where the peat has been completely removed together with areas of machine cut peat. Where the underlying mineral soil is exposed this was described as firm greenish/brown sandy gravely silt.

Drainage within the area comprised large ditches adjacent local access tracks and public roads. Elsewhere there was shallow standing water in irregular surfaces and flat lying areas.

In general, the peat condition in the area varied from locally waterlogged, where peat levels have been reduced by cutting/grazing and in flat lying areas, to drier conditions and firmer peat underfoot above cutting faces.

Extensive areas of peat cut by machine and localised areas of steep sided peat banks (commonly about 1m high) where peat has been removed are concentrated around the local access tracks and public roads. Machine cuts in peat are spaced at 0.5 to 1m centres with areas of multiple cross cutting common. Depth of cuts is about 1m with cuts commonly water filled, which results in quaking peat.

2.8 Sruwaddacon Bay Upper Crossing

This section of proposed works crosses below Sruwaddacon Bay. The foreshore area at Rossport comprised a small cliff about 1.5 to 2m high with a shallow beach terrace comprised of silty sand with many cobbles.

The foreshore area on the South of Sruwaddacon Bay also comprised a shallow beach terrace formed dominantly of slightly gravelly silt with occasional tree roots. There is a small cliff formed dominantly in peat about 2.4m high.

2.9 South of Sruwaddacon Bay to L-1202 Ch 89,500 to Ch 91,000

This section contains extensive areas of blanket peat.

South of the estuary the pipeline route is also within a peat area which extends from the landfall at the estuary to the terminal site at Bellanaboy. Immediately adjacent to the foreshore there is a minor cliff formed mostly in peat some 2 to 2.4m high. The peat thickness for the entire section typical ranged from about 2 to about 4.2m, except where a stream is crossed (Leenamore Inlet) where peat is absent.

At about Ch 90,100 the route passes across the Leenamore Inlet, where there is some reclaimed agricultural land. There is a peat cutting adjacent to the reclaimed agricultural land, which also marks the start of an area of open peat land that extends to an area of forestry.

Drainage within the area comprised a stream and some ditches on property boundaries or adjacent local access tracks.

The route is on typically gentle peat slopes with inclinations from 2 to 3 degrees increasing to about 8.5 degrees as the route crosses a steam and peat thickness becomes thinner.

In general, the peat condition in the area varied from surface hummocks with some waterlogging, where the peat surface was disturbed by grazing, to reclaimed peatland. Close to cuttings the peat was drier and firmer underfoot.

2.10 L-1202 to Terminal Ch 91,000 to Ch 92,560

This section contains extensive areas of blanket peat.

The topography initially falls from the local road at about ch. 91,000 to an elevation of 19m OD at about Ch 91,530 where a minor stream is encountered before rising in elevation to about 36m OD at the terminal.

The peat thickness for the section typical ranged from about 2 to about 4.6m, except where a stream is crossed.

The route is on typically gentle peat slopes with inclinations typically from 0.5 to 3 degrees increasing to about locally 4 to 8 degrees as the route crosses a steam and peat thickness becomes thinner.

Drainage within the area comprised a stream and regularly spaced forestry drainage.

Generally the route is within breaks that run through the forestry plantation.

In general, the peat condition in the area varied from some local waterlogging to well-drained peat in parts of the forestry. A stone road was present for part of the pipeline route near the terminal.

3 GROUND INVESTIGATION

3.1 General

The purpose of the ground investigations (GI) was to define the subsurface conditions along the proposed onshore pipeline route for the construction of the proposed onshore pipeline. The ground conditions investigated were as follows;

(1) Overburden (granular and cohesive soils) and bedrock.

(2) Ground conditions beneath the Glenamoy River Estuary.

(3) Peat conditions.

In this report particular attention is given to the peat areas, with data from GI used to determine particularly thickness and strength of the peat for assessment of peat stability.

3.2 Ground Investigations

The following ground investigations have been carried out along the proposed onshore pipeline route from the Glengad Headland Landfall to Terminal Site, namely:

(1) IDL (2002). Included percussion boring, trial pits and pipe bearing tests along the entire proposed onshore pipeline route from the landfall at Glengad Headland to the terminal.

(2) AGEC (July 2004). Included peat probing, peat sample logging, trial pits and in situ shear vane testing in peat along proposed onshore pipeline route from Glenamoy River Estuary to terminal site.

(3) AGEC (September 2004). Included trial pits either side of the Glenamoy River where the proposed onshore pipeline crosses at the west of the estuary, Sruwaddacon Bay Lower Crossing.

(4) Osiris Projects (2004). This included a geophysical marine survey at the Sruwaddacon Bay Lower Crossing.

(5) GES (2007). Included percussion boring with follow-on rotary drilling along the proposed onshore pipeline route carried out on the Glengad Headland and Rossport (West).

(6) Osiris Projects (2007). This included a hydrographic and geophysical survey across Sruwaddacon Bay and its close environs.

(7) IDL (2008). Included percussion boring with follow-on rotary within Sruwaddacon Bay at the two crossing points, that is between Glengad Headland and Rossport (West), and between Rossport (Commonage) and South of Sruwaddacon Bay.

(8) RPS (2008). Included peat probing and shear vane testing of the peat along the proposed onshore pipeline route through the blanket peat area in Rossport (Commonage) and along part of the route south of Sruwaddacon Bay.

3.2.1 IDL (2002)

A summary of ground investigations carried out along proposed onshore pipeline route from the landfall at Glengad Headland to the terminal site is outlined as follows:

There were cable percussion boreholes, trial pits and pipe bearing tests with associated laboratory testing carried out along the relevant onshore pipeline route. The boreholes were taken to depths between 2.1m (BH1) and 6.0m (BH2) below ground level (bgl).

The trial pits were excavated to depths between 3.2m (TP9) and 3.7m (TP1) bgl.

Pipe bearing tests were carried out in a shallow trench. A sealed length of pipe was placed on in situ ground within base of trench and settlement with time recorded.

3.2.2 AGEC (July 2004)

A summary of ground investigations carried out along proposed onshore pipeline route from Leenamore to the Terminal Site is outlined as follows:

The depth of peat was determined along the proposed onshore pipeline route by way of probing. The probes were carried out along the centre-line with a probe off-set at 20m either side of the centre-line. For all probe records peat was depth between 2.10m and 5.40m.

Trial pitting was carried out along the proposed onshore pipeline route with a total of 8 trial pits (TP-01 to TP-08). Trial pits were excavated to depths between 2.30m (TP-06) and 5.10m (TP-03) using either a Hitachi EX60 or JCB JS130 excavator. Bulk samples were taken of all underlying mineral soil.

Peat sample logging was carried out and samples were retrieved using a Russian Peat Borer (RPB). The samples were logged in accordance with the von Post Classification.

Mechanical vane testing was carried out using a Geonor H-10 mechanical vane. Testing was carried out at typically 0.5m depth intervals.

3.2.3 AGEC (September 2004)

A summary of ground investigations carried out along proposed onshore pipeline route at the estuary crossing between Glengad Headland and Rossport (West) is outlined as follows:

Trial pitting was carried out along the foreshore on the proposed onshore pipeline route with a total of 12 trial pits (TPW-1 to TPW-6 and TPE-1 to TPE6). Trial pits were excavated to depths between 1.2m (TPE-5) and 3.0m (TPW-1, TPW-2, TPE-2 and TPE-6) bgl. Samples were taken for rock strength testing.

3.2.4 Osiris Projects (2004)

This non-intrusive geophysical marine survey was carried out to ascertain the bedrock level for the proposed onshore pipeline between the Glengad Headland and south of the Rossport jetty.

3.2.5 GES (2007)

A summary of ground investigations carried out along proposed onshore pipeline route by GES between the Glengad Headland and Rossport (West) is outlined as follows:

A total of 15 number cable percussion boreholes with rotary core follow on was carried out for the proposed onshore pipeline route, with 7 number exploratory holes in the vicinity of the current onshore pipeline layout. The exploratory holes were taken to depths between 19.9m (BH003-07) and 25.1m (BH016-07) bgl. Soil and rock samples were taken for laboratory testing.

Furthermore, acoustic and optical televiewer surveys were carried out in a number of exploratory holes, these surveys indicated bedrock features such as rock dip angle, rock orientations, fractures and faults.

3.2.6 Osiris Projects (2004)

The main objectives of the marine geophysical survey were to produce detailed bathymetric charts, which showed the distribution of all of the main channels within the area and to map sediment thicknesses/depth of bedrock, in order to provide information for a possible directional drill/tunnel or open cut/drag box solution to the proposed onshore pipeline route.

3.2.7 IDL (2008)

A summary of ground investigation carried out at the two estuary crossings, with the first between Glengad Headland and Rossport (West), and the second between Rossport (Commonage) and South of Sruwaddacon Bay, the GI is outlined as follows:

There were a total of 14 cable percussion boreholes with rotary core follow on carried out for the proposed onshore pipeline route over the Glenamoy River Estuary. These exploratory holes were carried out from a jack-up rig at locations shown on Drawings 864_01_005 to 864_01_010. The exploratory holes were taken to depths between about 25 and 35m bgl. Soil and rock samples were taken for laboratory testing.

3.2.8 RPS (2008)

A summary of the ground investigations carried out by RPS at Rossport (Commonage) across the blanket peat area is as follows;

The depth of peat was probed along the onshore pipeline route with a total of about 53 probes in Rossport (Commonage) and some 80 probes in total. The probes were carried out approximately on the centre-line at varying spacings along the proposed pipeline route. From probe records peat was recorded at a depth between 0.25m and 5.00m. Vane testing within the peat was also carried out.

Within the section South of Sruwaddacon Bay to the L-1202 a number of probes were also carried out together with vane testing in the peat.

Insitu vane testing was carried out using a SL800 hand vane. Testing was carried out at various depth intervals.

4 GROUND CONDITIONS

4.1 General

The ground conditions along the proposed onshore pipeline route vary considerably and include blanket peat, cohesive and granular mineral soil beneath the blanket peat, and marine deposits within the crossings.

Interpreted ground conditions along the proposed onshore pipeline route are shown in Drawing Nos. 864_01_005 to 010.

The ground conditions of importance to peat stability and which are primarily considered below are as follows:

(1) Peat conditions, and

(2) Mineral soil conditions immediately below peat.

The ground conditions for each section are reported below with only outline ground conditions provided for non-peat areas.

4.2 Glengad Headland

This section of proposed onshore pipeline crosses Glengad Headland between ch. 83,400 and 84,065. There was one ground investigation carried out on the headland. This investigation consisted of cable percussion boreholes with rotary core follow-on, a summary of the investigations are as follows;

- BH016-07 and BH016-07A, (GES, 2007).

The overburden material on Glengad Headland was described as generally granular deposits over bedrock. The granular deposits ranged between typically 4m and 5.0m below ground level (bgl).

The granular deposits were described as medium dense to very dense sandy gravel or gravelly sand.

The bedrock underlying the granular deposits was described as moderately strong to very strong psammite and semi-pelite with moderate weathering.

A groundwater strike was encountered in one borehole between about 3m and 4m bgl and is not necessarily representative of the true groundwater level.

There is no significant peat cover in this section and as such this section is not considered further in this report.

4.3 Sruwaddacon Bay Lower Crossing

This section of proposed onshore pipeline crosses Sruwaddacon Bay between ch. 84,065 and ch. 84,470. There were two ground investigations carried out in this section of the bay. These investigations included exploratory holes which were carried out from a jack-up rig at locations across the bay, and trial pits on the west and east shores. A summary of the investigations is as follows;

- BHF001-08 to BHF004-08, (IDL, 2008).
- TPW-1 to TPW6 and TPE-1 to TPE-6, (AGEC, Sept. 2004).

The above investigations were carried out to indentify rockhead beneath the bay crossing and associated rock properties. The rock beneath the bay crossing consisted of typically very strong psammite with moderate weathering.

This section is not considered further in this report.

4.4 Rossport (West)

This section of proposed onshore pipeline crosses Rossport (West) between ch. 84,470 and ch. 85,960. There were two ground investigations carried out at Rossport (West). These investigations consisted of cable percussion boreholes, rotary core drilling and trial pitting, a summary of the investigations are as follows;

- BH001-07 to BH004-07 including BH001A-07 (GES, 2007).
- BH1, BH2, TP1, (IDL, 2002).

The overburden material at Rossport (West) was described typically as granular deposits over bedrock with some exploratory holes showing cohesive deposits below the granular deposits and over the bedrock. Localised areas of organic and cohesive soil were recorded over the granular deposits. It should be noted that there was no ground investigation carried out between ch. 85,600 and ch. 85,960.

The granular deposits ranged between 1.4m and 8.1m bgl, with the cohesive deposits ranging between about 5m and 10m bgl. The localised areas of organic and cohesive soil over the granular deposits ranged from 0.45m to 0.9m bgl.

The granular deposits were described as medium dense to dense silty sandy gravel or gravelly sand with occasional to some cobbles and boulders, locally very soft to soft (very loose to loose) sand was encountered in one trial pit.

The cohesive deposits were described as very stiff sandy gravelly clay with occasional cobbles and boulders (BH002-07), and stiff slightly gravelly sandy silt with some cobbles (BH2).

The localised organic and cohesive soils would be considered as topsoil and were described as very soft to soft slightly sandy slightly gravelly clay and silt with areas of shallow peat.

The bedrock was described as moderately strong to extremely strong psammite, with one local description of very weak to moderately strong pelite schist.

Groundwater was struck in exploratory holes between about 1m and 4m bgl.

There is no significant peat cover in this section and as such this section is not considered further in this report.

4.5 Rossport (Commonage)

This section of proposed onshore pipeline is between ch. 85,960 and ch. 88,600. The overburden material at Rossport (Commonage) is typically peat over mineral soil; this sequence of lithology was confirmed from walkover survey carried out by AGEC in December 2008.

The ground investigation along this section of proposed onshore pipeline included probing in peat and hand vane testing. It should be noted that no trial pitting or boreholes were carried out in this area. Exposures of insitu peat and underlying mineral soil and rock were however logged during the AGEC walkover survey.

Vane testing was used to determine the insitu undrained shear strength of the peat along this section of onshore pipeline; this testing was carried out using an SL800 hand vane (RPS, 2008). Hand vanes are considered to give indicative results for undrained shear strength in peat and generally may not reflect true insitu peat strengths. Therefore, to establish design peat strengths a comparison between hand vane strengths from Rossport (Commonage) and mechanical vane strengths (AGEC, July 2004) from L-1202 to Terminal Site was carried out, see Figure 1.

From the comparison between the hand and mechanical vane results (Figure 1) there are similarities between both sets of results, particularly for lower peat strength. Some of the lower strength values for the hand vane results at shallow depth are not considered representative as the vane testing was carried out in water-filled depressions.

Peat depth along this section of proposed onshore pipeline was determined by way of probing. The probes were carried out along the centre line of the proposed onshore pipeline, with probe depths varying from about 0.25m to 5m, with an average thickness of 2.8m (Drawings 864_01_006 and 007).

The undrained strengths from the SL800 hand vane range between 1 and 25kPa with a mean of 8kPa. Variation of shear strength along onshore pipeline route is shown in Figure 3.

For the purpose of peat stability assessment at Rossport (Commonage) hand vane undrained strengths recorded along this section will be adopted. A summary of engineering properties of peat is given in Table 1.

Parameter	Typical Range of Values	Design Values	Comments
Bulk unit weight (kN/m^3)	10 to 11	10.5	Assumed based on experience of ground investigation of blanket peat.
Undrained shear strength, c_u (kN/m^2)	1 to 25	1 to 25	Based on strength measured by insitu shear vane along this section, see Figures 2.

Table 1 Geotechnical Properties of Peat at Rossport (Commonage)

There is a variation of peat c_u both laterally and with depth. The peat has a relatively stronger and more fibrous upper layer which is typically about a metre thick.

Allowing for a margin of safety, and in the absence of further specific ground investigation results, lower bound peat strength values are used at specific locations, see Figure 3.

Geotechnical Properties of Mineral Soil

Geotechnical properties of the mineral soil below the peat have been determined by examination of exposures identified and logged during the walkover survey. Mineral soil was exposed in the cliffs on the foreshore of Sruwaddacon Bay and also in peat cuttings within the commonage.

Descriptions of the mineral soil are generally firm to locally soft grey/brown to reddish brown slightly sandy to sandy slightly gravelly to gravelly silt. Locally the mineral soil was granular and described as silty gravelly sand.

Geotechnical properties of mineral soil are given in Table 2.

Parameter	Typical Range of Values	Design Values	Comments
Effective angle of friction, ϕ' (°)	-	30	Assumed based on description and experience
Effective cohesion, c' (kPa)	-	1	Assumed based on description and experience
Undrained shear strength, c_u (kPa)	Soft to firm	40kPa[(1)]	Typical design value. Worst case value.

Notes
(1) Tomlinson (2001)

Table 2 Geotechnical Properties of Mineral Soil at Rossport (Commonage)

4.6 Sruwaddacon Bay Upper Crossing

This section of proposed onshore pipeline crosses Sruwaddacon Bay between ch. 88,600 and ch. 89,500. There was one ground investigation carried out in this section of the bay.

The investigation included exploratory holes (cable percussion drilling and rotary core follow-on drilling) which were carried out from a jack-up rig at locations across the bay. A summary of the investigations is as follows;

- BHF005-08 to BHF0013-08, including BHF014b-08, (IDL, 2008).

The above investigation was carried out to indentify rockhead beneath this bay crossing and associated rock properties. The rock beneath the bay crossing consists of moderately strong to very strong semi-pelitic schist, and very strong psammite with elements of weathering.

This section is not considered further in this report.

4.7 South of Sruwaddacon Bay to L-1202

This section of proposed onshore pipeline is between South of Sruwaddacon Bay and the L-1202; between ch. 89,500 and ch. 91,000. The ground investigation carried out consisted of cable percussion boreholes, trial pitting and probing, a summary of the investigations is as follows;

- BH008-07, BH009C-07 (GES, 2007).
- PL-20 and TP-06 (AGEC, 2004).

AGEC carried out a walkover in December 2008 along this section of proposed onshore pipeline route. This walkover included identifying geomorphology features, logging exposures and probing peat to determine depths in the area of the proposed onshore pipeline route.

4.7.1 Ground Conditions and Material Properties

The overburden material between South of Sruwaddacon Bay and L-1202 was identified as grassland over peat between ch. 89,500 and about ch. 90,360 from AGEC walkover with the remainder identified as forestry. The exploratory holes described peat over cohesive soil over granular over bedrock.

The peat depths along this section of proposed onshore pipeline route ranged from 0.4m to 4.2m bgl in the southeast (RPS, 2008), with the granular and cohesive soils ranging between 5.8m and 7.2m bgl. Drilling of the bedrock was taken to depths between 8.8m and 25.4m bgl.

The peat was described as very soft fibrous and decomposed peat; the peat was more fibrous for approximately the upper metre.

The cohesive soil was described as locally very soft to soft sandy gravelly clay beneath the peat (BH009C-07) with cohesive soil recorded below the granular soil and above the bedrock described as stiff slightly sandy gravelly clay (BH008-07 and BH009C-07).

The bedrock was described as moderately weak to moderately strong psammite.

Standard Penetration Testing (SPT) was carried out in boreholes in mineral soil below the peat with SPT-N values ranging from 6 to 50 with a mean value of 24, see Figure 4.

Particle Size Distribution (PSD) testing was carried out on samples taken from boreholes giving fines values (% passing 63 micron sieve) between 10% and 41%. The majority of the results showed fines in the order of 15% passing the 63 micron sieve which classifies the material as generally granular with cohesive soil also present.

The natural moisture content was determined on samples with values ranging from 7% to 100%, the high natural moisture contents are attributed to the peat, with lower bound values being attributed to the cohesive and granular soils. The cohesive soils are classified as generally clay with low plasticity, with localised results indicating clay and silt of intermediate to high plasticity.

Peat

The strength descriptions of peat indicate undrained shear strengths less than 20kN/m^2.

Peat depth along this section of proposed onshore pipeline was determined by way of probing. The probes were carried out along the centre line of the proposed onshore pipeline, with probe depths varying from about 0 to 4m, with an average thickness of about 2m (Drawings 864_01_006 and 007).

The undrained strengths from the SL800 hand vane (RPS, 2008) ranged between 1 and 19kPa with a mean of 11kPa (Figure 5). The low strength values at shallow depth are not considered representative. Variation of shear strength along onshore pipeline route is shown in Figure 6.

For the purpose of peat stability assessment South of Sruwaddacon Bay and the L-1202 hand vane undrained strengths recorded along this section will be adopted. A summary of engineering properties of peat is given in Table 3.

Parameter	Typical Range of Values	Design Value	Comments
Bulk unit weight (kN/m^3)	10 to 11	10.5	Assumed based on experience of ground investigation of blanket peat.
Undrained shear strength, c_u (kN/m^2)	1 to 19	1 to 19	Based on strengths determined from insitu hand vane, see Figure 5.

Table 3 Geotechnical Properties of Peat from South of Sruwaddacon Bay to the L-1202

Mineral Soil (Cohesive Soil)

Mineral soil below the peat was generally recorded as cohesive from boreholes, though granular sols were also recorded. Examination of exposures in the cliff during the walkover confirmed the presence of generally cohesive mineral soil below the peat.

The material described as cohesive in exploratory holes indicate strengths locally between <20kN/m^2 to 40kN/m^2, and typically between 75kN/m^2 to 150kN/m^2. Strength estimated from SPT data, using a conservative f1 value of 5 gave strength of typically between about 90kN/m^2 and 250kN/m^2.

Mineral soil exposed in the cliffs on the foreshore was described as firm to locally soft dark to light brown slightly sandy to very sandy slightly gravelly to gravelly slightly organic silt. Locally the mineral soil was more granular.

Geotechnical properties of mineral soil are given in Table 4.

Parameter	Typical Range of Values	Design Value	Comments
Effective angle of friction, ϕ' (°)	28 to 40	30	Assumed based on description and experience
Effective cohesion, c' (kPa)	-	1	Assumed based on description and experience
Undrained shear strength, c_u (kPa)	Soft to firm	20kPa[(1)]	Immediately below the peat

Notes
(1) Tomlinson (2001)

Table 4 Geotechnical Properties of Mineral Soil from South of Sruwaddacon Bay to the L-1202

4.7.2 Groundwater

Groundwater was struck in exploratory holes between ground level and 2.3m bgl. No standpipe or piezometer records were available and the true groundwater level is not necessarily represented by the strikes recorded in the site investigation.

4.8 L-1202 to Terminal

This section of proposed onshore pipeline is between L-1202 and the Terminal Site, ch. 91,000 to ch. 92,560. The overburden material between the L-1202 and the Terminal Site is typically peat over mineral soil. The ground investigation along this section of onshore pipeline included probing, trial pitting, peat sampling and mechanical vane testing. The following is a summary of the ground investigations;

- TP-01 to TP-05, PL-01 to PL-19, PL01A to PL-11A and PL-14A to PL-18A (AGEC, July 2004).
- TP8 to TP10 (IDL, 2002)

Peat depth along the proposed onshore pipeline route, using peat probe depths typically along centre line, varied from about 2.1m to 4.6m, with an average thickness of 3.3m (see Drawing 864_01_006).

Undrained shear strength (c_u) of in situ peat was determined by IDL (Irish Drilling Ltd) using a Geonor H-10 mechanical vane (AGEC, July 2004). Results are not factored based on findings from previous investigations in blanket peat (see for example Hanrahan, 1967, Piggott et al., 1992 and AGEC, 2004); these previous investigations back-analysed failures and found that unfactored vane results provided a reasonable estimate of the operating undrained shear strength.

Shear strength recorded from vanes ranged between 2 and 35kPa with a mean of 10kPa. Plot showing the relationship between depth and peat c_u are shown in Figure 7. Variation of shear strength along pipeline route is shown in Figure 8.

No direct strength measurements were carried out in the IDL (2002) investigation. From trial pits, peat was described as very soft and soft. Based on BS 5930 (BSI, 1999), this would suggest peat strength of between 'less than 20' and up to 40 kPa.

A summary of engineering properties of peat is given in Table 5.

Parameter	Typical Range of Values	Design Value	Comments
Bulk unit weight (kN/m^3)	10 to 11	10.5	Assumed based on experience of ground investigation of blanket peat.
Undrained shear strength, c_u (kPa)	2 to 35	2 to 35	Undrained shear strength (c_u) of in situ peat from Geonor H-10 mechanical vane, see Figure 7.

Table 5 Geotechnical Properties of Peat from L-1202 to the Terminal Site

Geotechnical Properties of Mineral Soil

From AGEC (2004), trial pits TP-03 and 06 were taken into mineral soil below peat. From IDL (2002), trial pits TP8 to TP10 were taken into mineral soil.

In most trial pits mineral soil was not reached as sidewall collapse in peat prevented deeper excavation.

Mineral soil comprised the following and was described (from AGEC, July 2004) as:

(1) Grey/brown slightly silty gravely SAND with occasional cobbles (Upper Till) which overlies,

(2) Blue grey clayey gravely fine SAND with occasional cobbles (Lower Till).

In IDL (2002) mineral soil was described as gravelly sandy SILT.

Upper Till, which was not encountered in all trial pits and in IDL (2002) was only encountered in TP8. The Upper Till formed a relatively thin and discontinuous layer with thickness of about 0.3 to 1m, and is not considered further.

Lower Till was exposed in the bottom of trial pits over 0.35m to 1.1m thickness. The base of the Lower Till was not encountered.

Where mineral soil was encountered in IDL (2002) trial pits, an iron pan was recorded above mineral soil. The presence of an iron pan at this horizon is considered suspect as extensive investigations at the nearby terminal site found no iron pan and examination of soil exposures within excavations for the terminal showed no significant iron pan.

Strength descriptions were not included in trial pit logs. Based on trial pit descriptions and discussions with AGEC logging engineering geologist, the mineral soil was considered to be of relatively low strength when exposed and disturbed; and that the actual insitu strength was difficult to determine for this reason.

In some trial pits the Lower Till was described as 'running' (TP-03 and TP-06) or 'saturated silts unstable' (TP9 and TP10) and where encountered in trial pits was saturated and sensitive to disturbance. Where there is disturbance and/or removal of confining pressure (overburden) from the Lower Till liquefaction can occur. Liquefaction is a localised effect due to removal of confining pressure.

Based on the above descriptions the likely strength of these materials is given in Table 6.

Parameter	Typical Range of Values	Design Value	Comments
Effective angle of friction, ϕ' (°)	-	30	Assumed based on description and experience
Effective cohesion, c' (kPa)	-	1	Assumed to behave as cohesive soil
Undrained shear strength, c_u (kPa)	Soft to firm	40kPa(1)	Lower till where saturated is sensitive to disturbance and is liable to liquefy when exposed

Notes
(1) Tomlinson (2001)

Table 6 Geotechnical Properties of Mineral Soil (Lower Till) from L-1202 to the Terminal Site

4.9 Drained Strength Parameters for Peat

To determine a suitable drained strength values for peat a review of published information on peat was carried out. Appendix C (Peat Effective Strength Parameters) shows a summary of the published information on peat together with drained strength values.

From Appendix C the values for c' ranged from 1.1 to 10kPa and ϕ' ranged from 21 to 40°. The average c' and ϕ' values are about 4kPa and 30° respectively. Based on the above, it was considered to adopt a conservative approach and to use design values below the averages.

For stability assessment of peat the following general drained strength values have been used for all peat locations:

c' = 2kPa
ϕ' = 25 degrees

5 PEAT STABILITY ANALYSIS

5.1 General

A quantitative stability analysis was carried out to determine the Factor of Safety (FoS) of the existing natural peat slopes in three areas where blanket peat bog exists along the proposed onshore pipeline route, namely; Rossport (Commonage), South of Sruwaddacon Bay to L-1202, and L-1202 to Terminal.

The stability analysis method used to determine FoS against sliding failure of peat slopes along the proposed onshore pipeline route was an infinite slope analysis (Skempton and DeLory, 1957). This analysis is conservative and the calculated FoS is underestimated.

The stability analysis examined the following scenarios:

(1) Potential failure in the peat within the basal zone of the peat (total stress and effective stress condition), and

(2) Potential failure in the mineral soil just below the peat-mineral interface (total and effective stress condition).

Stability was analysed using two conditions, namely total stress and effective stress.

The total stress condition applies to short-term conditions occurring during construction and for a short time following construction until construction induced pore water pressures dissipate. Undrained shear strength values (c_u) for peat are used for total stress conditions.

The effective stress condition in the peat, which applies to long term conditions occurring after construction and at a time when construction induced pore water pressures have dissipated. A drained analysis requires effective cohesion (c') and effective friction angle (ϕ') values for the calculations. These values can be difficult to obtain because of disturbance experienced when sampling peat and weak soils. In particular, there are difficulties in accurately interpreting test results for peat due to the excessive strain induced within the peat. To determine suitable drained strength values a review of published information on peat was carried out see Appendix C.

The following assumptions were used in the analysis of stability of natural peat slopes.

(1) Peat strength and depth of base of peat determined from ground investigations.

(2) The shear strengths for the analysis were determined as follows;

   (a) For peat, undrained shear strength (c_u) was determined using the results from vane tests, see Figure 2, 5 and 7.

   (b) For peat the drained strength (ϕ' and c') was determined from published data, see above and Appendix C.

   (c) For mineral soil, undrained shear strength (c_u), and the drained strength (ϕ' and c') were determined from strength descriptions and experience. Design c_u varied from locally 20 to 40kPa immediately below the peat. For peat stability analysis only a generalised worst case of 15kPa was used for the whole of the route in peat.

(3) The failure (sliding) surface is assumed to occur at the base of the peat as determined from probe results. Where failure is within the mineral soil then it is assumed that the failure surface is 0.1m below the base of peat.

(4) Slope angle of failure (sliding) surface is assumed to be parallel to the ground surface.

For stability analysis, two load cases were considered representing the likely general range of loadings that may occur during construction, assuming that construction in peat will essentially be isolated from the peat by the use of 'stone road'. These load conditions are (1) no applied loading and (2) 10kN/m^2 applied loading.

The code of practice for earthworks BS 6031:1981 (BSI, 1981), provides advice on design of both temporary and permanent earthworks. It states that for a first time failure with a good standard of site investigation the design FoS should be greater than 1.3. This is similar to Eurocode EC7.

Where undrained parameters are used a FoS of 1.5 is preferable.

The FoS for natural peat slopes has been calculated at locations where shear vane test results are available. It is recognised that further peat strength testing is required to provide a more detailed coverage of the proposed pipeline route.

5.2 Glengad Headland

There was no blanket peat recorded in this area, therefore no peat stability analysis is required.

5.3 Rossport (West)

There was no blanket peat recorded in this area, therefore no peat stability analysis is required.

5.4 Rossport (Commonage)

5.4.1 Failure within the Basal Zone of the Peat

Undrained Analysis

An infinite slope analysis was carried out to determine the FoS against peat instability along the pipeline route at Rossport (Commonage) for the undrained condition. This analysis includes an assessment of peat stability assuming failure occurs just above the base of the peat. The undrained condition would correspond for example to the affect of sudden loading of the peat.

Results of analysis show that the FoS varies from 1.3 to greater than 10 (Table D1 in Appendix D). In general, the results show that the area has a low potential for peat instability.

A FoS less than 1.5 was recorded in the area of ch. 87,219 giving a FoS of 1.3 for load condition (2). This corresponds to a notably low value of undrained strength (1kPa) and is located close to a series of shallow pools. Given the increasing slope inclination to the east of this location, it is considered that this area represents an increased risk of peat instability. Particular construction controls should be exercised in this area, and particularly loading of the peat should be avoided.

Given the apparent low strength in this area further ground investigation should be carried out prior to construction to confirm the peat conditions. The strength used in the analysis (1kPa) is notably low and possibly not representative of the peat conditions.

<u>Drained Analysis</u>

An infinite slope analysis was carried out to determine the FoS against peat instability along the pipeline route at Rossport (Commonage) for the drained condition. This analysis includes an assessment of peat stability assuming failure occurs just above the base of the peat. The drained condition would correspond for example to concentrated water ingress into the base of the peat from an intense rainfall event.

The effective stress parameters used were ϕ' of 25^{o} and c' of 2 kPa, see Appendix C.

The analysis includes for a range of watertables corresponding to no water-table (0% water), watertable at mid-height of the peat layer (50% water) and a watertable at the ground surface (100% water).

Results of analysis show that all FoS's are greater than 1.5 (Table D2 in Appendix D). This assessment shows that the peat within the Rossport (Commonage) section of the onshore pipeline has an adequate FoS for the drained or long term condition which from experience would be considered the case as there are no signs of rainfall induced failures of the peat within the area.

5.4.2 Failure within the Mineral Soil below the Peat

<u>Undrained Analysis</u>

An infinite slope analysis was carried out to determine the FoS against sliding within the mineral soil below the peat along the pipeline route at Rossport (Commonage) for the undrained condition. This analysis includes an assessment of the stability 0.1m below the peat-mineral interface within the mineral soil. The undrained condition would correspond for example to the effect of sudden loading of the peat.

The total stress parameter used for the mineral soil was c_u of 15kPa which is assumed a worst case based on undrained shear strength of less than 20kPa.

Results of analysis show that all FoS's are greater than 1.5 (see Table D3 in Appendix D). This assessment shows that the mineral soil along the Rossport (Commonage) section of the pipeline has an adequate FoS for the undrained or short term condition.

Notwithstanding the above, further ground investigation is required to determine more accurately the condition of the underlying mineral soil. In certain cases where there are clay-dominant mineral soils below the peat, these can be sensitive and can be relatively brittle compared to peat. This can result in the clay-dominant mineral soils operating at shear strengths close to residual values (note this does not refer to liquefaction which is localised and affects silty sand and fine granular soils).

Drained Analysis

An infinite slope analysis was carried to determine the FoS against sliding within the mineral soil below the peat along the pipeline route at Rossport (Commonage) for the drained condition. This analysis includes an assessment of the stability 0.1m below the peat-mineral interface within the mineral soil. The drained condition would correspond for example to concentrated water ingress into the base of the peat from an intense rainfall event.

The effective stress parameters used for the mineral soil was assumed to be; ϕ' of 30^{o} and c' of 1 kPa.

Results of analysis show that all FoS's are greater than 1.5 (see Table D4 in Appendix D). This assessment shows that the mineral soil along the Rossport (Commonage) section of the proposed onshore pipeline has an adequate FoS for the drained or long term condition.

As the mineral soil in Rossport (Commonage) is not exposed at many locations it is recommended that further ground investigation is required to determine the condition of the underlying mineral soil, as discussed above.

5.5 South of Sruwaddacon Bay to L-1202

Ground investigation work (RPS, 2008) in this area included a number of probes together with hand vane testing in the peat. The following analysis uses data collated from the above investigation and AGEC walkover carried out in December 2008.

It is recommended that more confirmatory investigation work is carried out along this section of the proposed pipeline route prior to construction in order to confirm the ground conditions.

5.5.1 Failure within the Basal Zone of the Peat

Undrained Analysis

An infinite slope analysis was carried out to determine the FoS against peat instability along the pipeline route between South of Sruwaddacon Bay and L-1202 for the undrained condition. This analysis includes an assessment of peat stability assuming failure occurs just