Proceedings of the XVI ECSMGE
Geotechnical Engineering for Infrastructure and Development
ISBN 978-0-7277-6067-8

doi:10.1680/ecsmge.60678

Natural gas pipeline construction in sensitive peatland environment, Western Ireland

Construction d'un pipeline de gaz naturel dans l'environnement des tourbières sensibles, Ouest de l'Irlande

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ABSTRACT Part of a natural gas pipeline route constructed in Western Ireland passed through areas of ecologically sensitive peatland, with a history of peat failures. To ensure the pipeline works had minimal impact on the surrounding peatland the design included a variety of engineering and environmental mitigation measures. The peatland comprised essentially very soft blanket peat up to about 5m deep. The pipeline was buried within a stone road within the peat; the stone road comprised carefully sourced engineered fill which was placed to form a stable construction corridor up to 12m wide. Details of the engineering design for the works are included in the paper, which shows how the construction works satisfied the engineering requirements, such as stable construction platform, resistance to impact by potential peat slide and long-term integrity for the buried gas pipeline, with the environmental requirements for minimal impact on the surrounding sensitive peat land.

RÉSUMÉ Partie d'un réseau de pipelines de gaz naturel construit Ouest de l'Irlande a traversé des zones de tourbières écologiquement sensible, avec une histoire d'échecs de tourbe. Pour assurer les travaux de canalisation ont eu un impact minime sur la tourbière entourant la conception inclus une variété de mesures d'ingénierie et d'atténuation de l'environnement. La tourbière compose essentiellement très douce couverture tourbe jusqu'à environ 5 m de profondeur. Le pipeline a été enterré dans un chemin de pierre dans la tourbe; la route de pierre soigneusement composé provenant de remblais qui a été placé pour former un couloir de construction stable jusqu'à 12 m de large. Les détails de la conception technique des travaux sont inclus dans le document, qui montre comment les travaux de construction ont satisfait aux exigences techniques, comme plate-forme stable de la construction, la résistance à l'impact de lame de tourbe potentiel et l'intégrité à long terme pour le gazoduc enterré, avec les exigences environnementales pour un impact minimal sur la tourbe des terres sensibles environnant.

1 CORRIB PROJECT & ONSHORE PIPELINE

The Corrib Project comprises the development of a natural gas field located approximately 83km off the coast of County Mayo, in northwest Ireland in 350m of water. The project involves the use of subsea gas production wells with processing of gas and control of subsea wells carried out from a gas terminal located onshore at Bellanaboy Bridge.

The pipeline from the field to the gas terminal is about 91km in length with about 83km of subsea pipeline and 8.3km of onshore pipeline. The project is being developed by Shell E&P Ireland Limited (SEPIL) with two partners, namely, Statoil Exploration (Ireland) Ltd and Vermilion Energy Ireland Limited.

The onshore section of the pipeline passes through a variety of terrains. About 4.9km of the pipeline between the landfall at Glengad and Aughoose is within a tunnel that was constructed below Sruwaddacon Bay (Figure 1), which is an area of tidal mudflats that is a Special Protection Area. At Aughoose, the pipeline leaves the tunnel and the route passes through about 3km of sensitive peatland that comprises recovering eroded blanket peat, open peatland and peatland planted with commercial forestry.

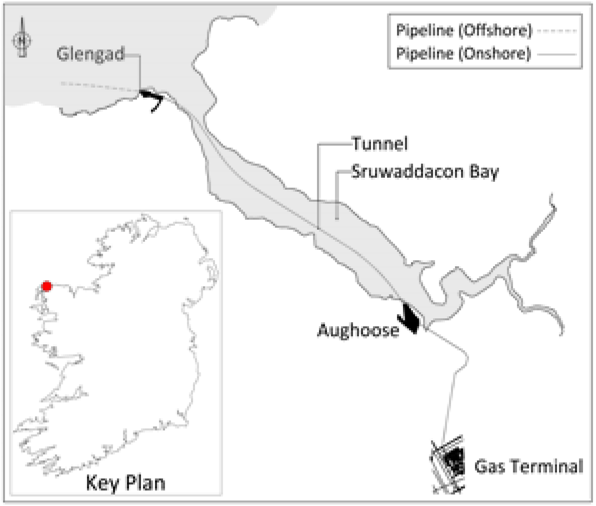

Figure 1. Location of onshore pipeline

Within the peatland the pipeline is buried within a permanent stone road that comprised the excavation and removal of peat over a 12m width along the pipeline route and replacement with suitable stone fill to form a stable roadway (Figure 2). The stone road provides stability for the pipeline in an area of northwest Mayo peatland that in the past has been affected by peat slides.

The use of a stone road within the peatland greatly reduces the risk of peat failure, protects the pipeline from possible adjacent peat movement, and essentially eliminates long-term settlement of the pipeline.

To justify construction of the stone road through sensitive peatland a number geotechnical assessments were carried out to demonstrate the stability of the road, which included mitigation measures to limit the environmental impact of the placed stone.

2 PEAT FAILURES

There are a number of recorded historical peat failures within County Mayo (GSI, 2006), some of which have occurred in recent times within the vicinity of the pipeline route.

The Dooncarton Mountain landslides in September 2003 comprised a cluster of 40 separate shallow landslides, including significant peat failures, which were triggered by an exceptional rainfall event (Dykes and Warburton 2008). The landslides occurred on steep topography (40 degrees) with thin peat cover about 1km south of Glengad (Figure 1).

A peat failure occurred on a local road (L-1202) road in proximity to the route in May 2008. The incident occurred during widening works for the road and comprised the movement of peat over a length of about 40m alongside the road and width of some 15 to 20m. The likely cause of the failure was bearing failure of the insitu peat due to excessive loading.

The above indicates the nature of the surrounding peatland and was a notable consideration in determining the use of a stone road, which provided a stable and robust platform in which to safely construct install the pipeline.

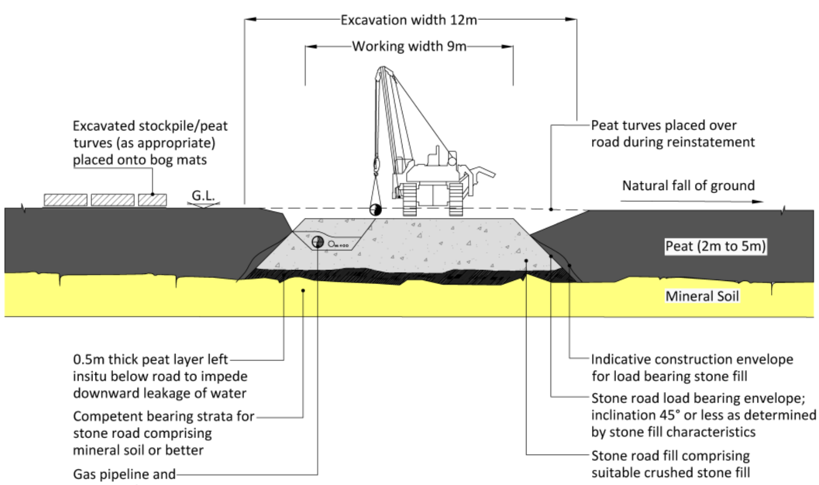

Figure 2. Typical stone road construction in peatland

3 ROUTE DESCRIPTION AND GROUND CONDITIONS

3.1 Route Description

The topography along the route rises gradually from Aughoose, on the shoreline of Sruwaddacon Bay, to a high point of about 36m OD at the gas terminal. The route is typically on gentle peat slopes with inclinations typically from 0.5 to 3 degrees increasing to about locally 4 to 8 degrees as the route crosses minor streams.

Within the peatland the pipeline is buried within a permanent stone road that comprised the excavation and removal of peat over a 12m width along the pipeline route and replacement with suitable stone fill to form a stable roadway with a minimum working width of 9m through the peat (Figure 2). The stone road provides stability for the pipeline in an area of northwest Mayo peatland that in the past has been affected by peat slides.

The route generally traverses the topography perpendicular to the prevailing slopes and where possible follows forest breaks that run through the commercial forestry plantation.

The 3km route is entirely within blanket bog. The peat surface condition along the route varies from surface hummocks with some water-logging to reclaimed peatland and peat cuttings.

3.2 Ground Conditions

The depth of peat along the 3km route ranges from 2m to locally up to 5m, with an average depth of about 3m. The peat is underlain by silty sandy glacial soil. The peat was described as very soft fibrous and decomposed peat with more fibrous peat within the upper metre. Peat strength along the route was determined using both in situ hand-held and mechanical vane (Figure 3).

Undrained peat strength varied from typically 4 to 15kPa, which would be comparable to results for low-lying blanket bog in the region.

The glacial soil below the peat was generally loose grey/brown slightly silty gravely sand with occasional cobbles which in part was cohesive. Locally the glacial soil was saturated and sensitive to disturbance resulting in liquefaction where exposed in excavations.

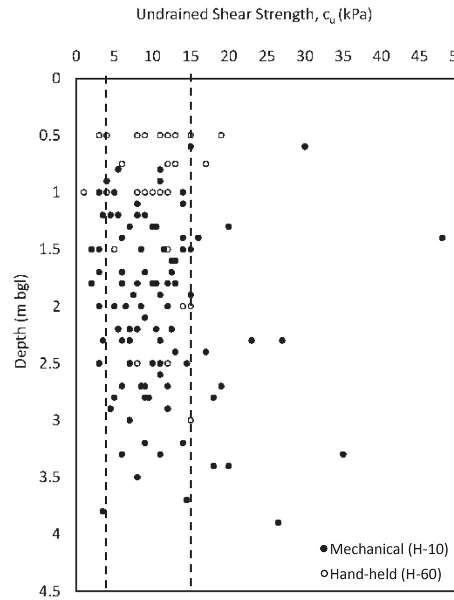

Figure 3. Undrained shear strength measurement of peat from insitu shear vane (Geonor H-10 mechanical and H-60 hand vanes)

Bedrock was encountered at depths of 6m or greater and comprised generally moderately weak to moderately strong psammite.

4 STONE ROAD

The stone road construction comprised the following key components:

- Upper about 0.5m of peat, or in selected areas intact peat turves, removed in advance and used for reinstatement.
- A layer 0.5m thick of insitu peat left in place below the stone road and above the glacial soil (Figure 1). This peat layer reduced downward transmission of groundwater. Peat layer penetrated by coarse stone fill (similar to HA class 6B) to form a stone-peat matrix.
- Stone road formed using granular fill (HA class 6F2 material). Stone compacted to provide a robust construction platform for plant and for installation of pipeline.
- Low permeability plugs, formed using a suitable low permeability reworked peat, constructed across the stone road at appropriate intervals to reduce longitudinal flow of water.

- Pipeline and associated services installed within the stone road. In areas where peat was shallow the base of the pipeline trench was within glacial soil and a suitable thickness of reworked peat was placed into and over the pipeline trench to reduce downward transmission of groundwater.

4.1 Alternatives and Geotechnical Assessment

To justify the construction of the stone road within the sensitive peatland it was necessary to review and compare alternative road construction methods in peat (Munro, 2004). Construction methods can be divided into:

- Type (1): Peat excavation (method used for stone road) is the preferred method in most cases as it greatly reduces the risk of peat failure and also eliminates subsequent settlement and maintenance.
- Type 2: Peat displacement requires peat to be displaced by placement of sufficient load. Most suited for deeper peat, but is difficult to control the peat displacement.
- Type (3): Peat left in situ and road constructed on the peat using reinforcing elements e.g. geosynthetic, piles, insitu mixing. Potential greater risk due to difficulties of extended construction period, installing pipeline and long-term settlement.

To demonstrate that a stone road provided the best option for constructing the pipeline through sensitive peatland a number of geotechnical assessments were carried out (Table 1). These formed part of a full environmental impact study.

Table 1. Geotechnical assessment of stone road

Assessment	Description of Assessment
Stability of stone road in peatland.	A geotechnical assessment on the stability and settlement of stone road under various loading conditions
Peat stability assessment	Assessment of the stability of natural peat slopes along the proposed pipeline route
Qualitative risk assessment of the relative potential for peat failure	A qualitative assessment of the relative potential for peat failure along the route in peatland
Assessment of landslide impact on stone road in peat	An assessment of landslide impact on the stone road

4.2 Stability of Stone Road

This involved a review of ground investigation and interpretation of ground conditions, stability and settlement analysis of stone road

Analyses were carried out to assess the stability of the stone road under various load cases in using partial factors in accordance with Eurocode 7 (EC7). Stability analysis comprised the slip circle method to determine bearing/sliding failure of the stone road using Talren software (Terrasol, 2005), and translational sliding (Skempton & DeLory, 1957).

Various applied loadings were considered with varying encountered ground conditions.

The applied loading included a number of scenarios ranging from general construction loading of 20kPa through to pipe-laying crane/side-boom load based on Caterpillar 583R with differential load distribution per track to represent eccentric lifting conditions.

The results of the stability analysis clearly showed that the stone road has a significant inherent stability both for circular and translational sliding failure, which would be expected with such a mass gravity fill structure. A check on the sensitivity of the factor of safety showed that an elevated water table in the stone road and edge failure were critical. As such, water monitoring within the stone road and working exclusion zones were recommended.

Whilst the stone road notably reduced the potential for long-term settlement, for primarily environmental reasons a 0.5m thick layer of peat was left in situ below the road. An assessment was carried out of the potential settlement of the pipeline and associated services constructed within the stone road due to differential consolidation of this peat layer.

The settlement analysis examined several hypothetical cases ranging from the base condition of no peat removed (case 1) to assuming varying thicknesses of peat left insitu below the stone road/gas pipe (cases 2 and 3). Analysis was based on consolidation theory and experience of peat settlement. A review of peat settlement by Long & Boylan (2013) showed that consolidation theory provides a reasonable prediction of settlement. The results of the analysis included a predicted settlement profile along the road, which showed hypothetical settlement ranged up to locally 570mm (Figure 4). The calculated settlements/strains were subsequently used to show the

induced stresses within the pipeline and services were within permissible safe limits.

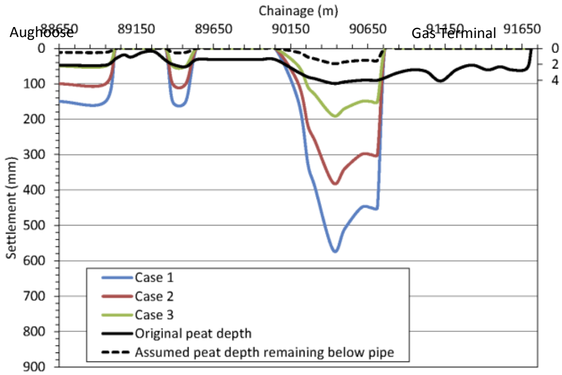

Figure 4. Hypothetical settlement profiles along section of road

4.3 Peat Stability Assessment

Whilst the route generally traverses the topography perpendicular to the prevailing slope there were a number of sections where the route was oblique to these peat covered slopes. The stability of the peat slopes was assessed with and without the stone road using an infinite slope analysis (Skempton & DeLory, 1957).

The stability of the natural peat slopes prior to construction was relatively high, though areas of weaker peat were present. The construction of the stone road in the peat slope provided a greater degree of stability against a peat slide. This is an inevitable result of the greater shear resistance to sliding provided by the stone fill within the 12m wide road footprint.

With respect to the stone road, the critical stability condition arises during construction, where possible over-excavation in front of the stone road prior to backfilling with stone could effectively unload the peat slope. This was avoided by adopting suitable construction practices. Following completion of the stone road, the risk of instability of the surrounding natural peat slopes affecting the stone road is considered to be extremely unlikely.

4.4 Qualitative Risk Assessment of Peat Stability

A qualitative risk assessment of the relative potential for peat failure was carried out along the pipeline route using a number of qualitative factors to determine the relative potential for peat failure.

This form of stability assessment provides additional insight into the effect of qualitative factors (land use, peat slide history, vegetation, etc.) which cannot be generally included in normal stability analysis. The qualitative assessment however is not considered a substitute for numerical stability analysis.

The qualitative assessment of the relative potential for peat failure has been applied to a number of developments on peatland in Ireland and Scotland (see MacCulloch, 2006). The qualitative assessment included the following:

- Compilation of 32 pertinent discriminatory factors.
- Factors rated from 1 to 3 with respect to stability.
- Zonation of the peatland route into sections with similar terrain characteristics.
- Rating of each factor from 1 to 3 for each section.
- Summation of ratings in percent for each section.

In general, the qualitative assessment provided an indication of where there are a number of factors that may result in an increased potential for peat failure. The qualitative assessment was used to inform confirmatory investigation and to indicate to supervising geotechnical engineers during construction possible stability issues along the route.

4.5 Landslide Impact

The effect of a peat slide originating upslope of the route of the pipeline route and impacting the stone road was assessed. The assessment included a range of impact loads and soil strength soil below the road and surrounding peat slopes. The analysis included for a hypothetical layer of weak sensitive clay with undrained shear strength varying down to 5kPa below the road. The maximum impact of a peat slide was estimated as an equivalent lateral static load of about 77kN.

The results (Figure 5) of the analysis showed that for the actual soil conditions the factor of safety varied from above 3 to about 1.50 for corresponding lateral impact load of 0 to 77kN. The results for an assumed weak soil layer under the road varied from 1.4 to 0.4 for corresponding impact load of 0 to 77kN.

The analysis shows that based on actual soil conditions the stone road would safely resist landslide impact. Ground investigation works (trial pits and boreholes) did not show the presence of a weak clay layer.

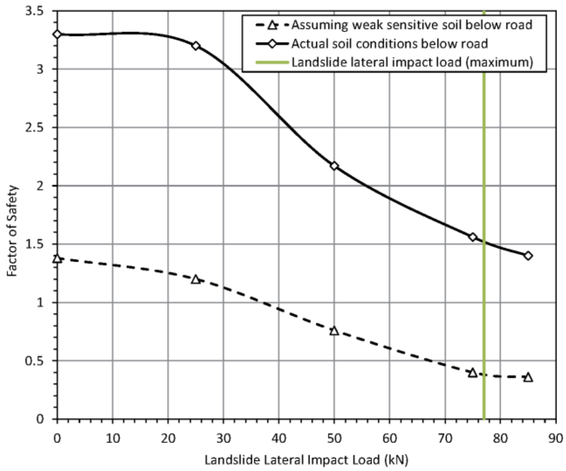

Figure 5. Stability (factor of safety) of stone road due to landslide impact with actual soil conditions and weak sensitive soil

4.6 Instrumentation and Monitoring

Recommendation from the above assessments included a number of movement monitoring installations along the stone road which included:

- Ground survey markers at regular intervals.
- Piezometers (typically drive-in type) installed in advance of stone road construction.
- Inclinometers installed adjacent to the line of the road and within areas of deeper peat (>3m).
- Visual sighting lines installed adjacent to the working areas beside stone road.
- Shape Accel Arrays (SAAs) installed below and parallel with pipeline axis.

Movement monitoring showed no evidence of adverse ground movement. SAAs installed below the pipe showed localised minor movement during construction, as a result of construction traffic, but a cessation of movement following completion of works.

Following reinstatement of the stone road the majority of the instrumentation monitoring was ceased. However, the automated readings from the SAAs were routed via buried fibre-optic cables to the gas terminal to provide permanent monitoring of ground movement within the stone road.

5 CONCLUSIONS

For the Corrib Project a section of the on-shore pipeline was constructed within a permanent stone road (Figure 2) within an area of sensitive peatland

To justify construction of the stone road within the sensitive peatland a number of geotechnical assessments were carried out to demonstrate the stability of the road.

The results of stability analysis clearly showed that the stone road has a significant inherent stability with a high factor of safety. Analysis also showed that the stone road would safely resist lateral landslide impact from a peat slide upslope (Figure 5).

Overall, the stone road provides a stable and robust platform in which to safely construct and install the pipeline. The stone road provides greater resistance to deformation, and offers greater security to the pipeline, than if the pipeline was buried within the peat itself.

ACKNOWLEDGEMENTS

The authors acknowledge the co-operation of SEPIL and partners on the Corrib Gas Project in producing this paper, and AGEC site staff. The opinions provided in the paper are those of the authors and do not necessarily represent those of SEPIL and its partners.

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