S. 37

File With ____________

SECTION 131 FORM

Appeal NO:_PL 16.207212. **Defer Re O/H** ☐

TO:SEO

Having considered the contents of the submission ~~dated~~/ received 31/08/04. from Tom Phillips and Assoc I recommend that section 131 of the Planning and Development Act, 2000 be/not be invoked at this stage for the following reason(s):.

E.O.: Kieran Somers **Date:** 01/09/04

To EO:______________

Section 131 not to be invoked at this stage. ☐

Section 131 to be invoked – allow 2/4 weeks for reply ☐

S.E.O.:______________________________ **Date:**______________________

S.A.O:______________________________ **Date:**______________________

M ______________

Please prepare BP ________ **- Section 131 notice enclosing a copy of the attached submission**

to: ______________

Allow 2/4weeks – BP________

EO: ______________________________ **Date:** ______________________

AA: ______________________________ **Date:** ______________________

J:abp\forms\2000ActForms(s37)

CORRESPONDENCE FORM

Appeal No: PL 16.207212.

M r Fagan.

Please treat correspondence received on 31/08/04. **as follows:**

1. **Update database with new agent for Applicant/Appellant** ______	
2. **Acknowledge with BP** 23	1. **RETURN TO SENDER with BP** ______
3. Keep copy of Board's Letter ☐	2 Keep Envelope: ☐
Applicant's response to Section 132 notice.	3. Keep Copy of Board's letter ☐

Amendments/Comments

4. Attach to file

(a) R/S ☐
(b) Mapping ☐
(c) Processing ☐
(d) Screening ☐
(e) Inspectorate ☐

RETURN TO EO ☑

	Plans Date Stamped ☐ Date Stamped Filled in ☐
EO: Kieran Somers.	**AA:** James Fagan
Date: 01/09/04.	**Date:** 1/9/04

TPA
TOM PHILLIPS + ASSOCIATES
TOWN PLANNING CONSULTANTS

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Tel +353 1 478 6055 Fax +353 1 478 6054 info@tpa.ie www.tpa.ie

The Secretary
An Bord Pleanála
64 Marlborough Street
Dublin 1

Tuesday, 31st August 2004

By Hand

Dear Sir

RE: CONSTRUCT GAS TERMINAL FOR THE RECEPTION AND SEPARATION OF GAS FROM THE CORRIB GAS FIELD AND FOR A PEAT DEPOSITION SITE, BELLAGELLY SOUTH, SRAHMORE, ATTAVALLY, BANGOR ERRIS, CO. MAYO

Mayo County Council Register Reference: P03/3343

An Bord Pleanála Ref: PL 16.207212

1.0 INTRODUCTION

1.1 Status of the Appeal

This submission has been prepared by Tom Phillips + Associates, 8-11 Lower Baggot Street, Dublin 2 in association with Arup Consulting Engineers, Applied Ground Engineering Consultants (AGEC) Ltd, RSK ENSR, the Swedish Geotechnical Institute (SGI) and the applicant. It has been prepared on behalf of the applicant, Shell E & P Ireland Limited, Corrib House, 52 Lower Leeson Street, Dublin 2, in response to a letter from the Board, dated 11 August 2004, requesting the submission of further information on three items in accordance with Section 132 of the *Planning and Development Act, 2000*.

The three items requested by the Board relate to the following:

1. The Risk Assessment in Appendix 3A of Section 3 of Appendix 2 of Volume 1 of the EIS.
2. Peat Stabilisation.
3. Environmental Impact of Peat Stabilisation.

For ease of reference we have repeated the text of the Board's letter under each the above headings followed by the applicant's response in Section 2.0 below.

1.2 General Commentary on the Board's Request

The questions posed by the Board are of a detailed technical nature, and relate in the main to the technical appendices to Volume 1 of the EIS, detailing the various design aspects of the proposed earthworks, the site drainage, and the geology, hydrology and global stability of the site. Every effort has been made by the applicant and its advisors to provide detailed answers and explanations in response to the letter, however, without direct communication and interaction between the technical experts it is difficult to ensure that every aspect of these questions has been interpreted correctly, and the relevant explanation provided. We trust that this response satisfies the Board in respect of the detailed matters raised, however, should the Board require any further clarification, the applicant would be happy to provide it.

Before addressing the Board's request in detail, we wish to make a number of general comments regarding the proposed earthworks design, the global site stability considerations and more particularly the peat stabilisation.

A very experienced design team, consisting of leading engineering, geotechnical and hydrological consultants both national and international, including ARUP Consulting Engineers, AGEC Limited, the Swedish Geotechnical Institute and RSK ENSR, prepared the terminal earthworks design.

The earthworks design has been prepared following extensive site investigation (SI) over the past 4 years (as described in Volume 1 Technical Appendix 2 Section 2.3 of the EIS). The applicant gave the earthworks design team unrestricted scope to determine the nature and extent of this SI with a view to providing sufficient information to inform a robust and conservative design.

The members of the design team have specific and detailed knowledge of the geotechnical issues involved in construction on peat soils. In particular AGEC Limited have investigated the causes of both the Pollatomish and Derrybrien landslides, and have provided advice on recovery and preventative measures. ARUP investigated the causes of the Derrybrien landslide on behalf of a group of residents. The lessons learned from both of these events have been fully incorporated into the basis of the proposed terminal earthworks design in order to ensure that the design is safe.

The applicant and its advisors are confident that the design proposed is sufficiently robust (being both conservative and providing for a number of contingencies), to ensure that the risk of a geotechnical failure which might lead to a landslide is negligible.

An environmental assessment has been carried out on all aspects of the construction methodology. Environmental hazards have been identified and mitigation measures incorporated into the design where relevant. The assessment has concluded that there are no likely significant impacts on the environment arising from the development of the Bellanaboy Bridge Terminal.

2.0 Response to the Items Raised by The Board

2.1 Item 1: The Risk Assessment in Appendix 3A of Section 3 of Appendix 2 of Volume 1 of the EIS

The Board Requested the Following:

'1. The Risk Assessment in Appendix 3A of Section 3 of Volume 1, Technical Appendix 2 of the EIS appears to involve a very confident assessment of all design aspects of the proposed development and a very optimistic view of the risks associated with the project.

It appears that the values for P and I used in the Register may not be entirely consistent or based on objective evidence. For example, the hazard of "unexpected ground conditions" is given a P rating of 3, while the hazard of the "failure of an excavated slope" due to "encountering previously unknown weaker zone within the rock or mineral soils". (i.e. also unexpected ground conditions) is given a probability rating of 1. Another example is the hazard of flooding caused by "extended periods of wet weather" which is given a probability rating of 1 i.e. negligible. This appears very optimistic considering the location and nature of the site and the occurrence of the extreme rainfall event that caused bog slides at Pollatomish in September 2003.

You are asked to detail the basis on which probability (P) values of the hazards occurring have been selected. It is expected that these values should be consistent and, where possible should be based on objective scientific/statistical evidence.

Although a number of different causes have been given for the different hazards, the likelihood of each cause occurring is not evaluated separately. You are asked to submit such an evaluation.

The probability of several hazards occurring simultaneously or sequentially does not appear to have been adequately addressed (an example would be the hazard of flooding causing the hazard of the failure of ponds). You are asked to address this issue.

As a result of the above assessments and evaluations it is considered that revisions will be required to the Risk Assessment (with more of the hazards receiving an R rating above 5). This in turn may require revised design measures and contingency plans being prepared either to reduce the probability of occurrence or to deal with the hazard should it occur.'

2.1.1 Response to Item 1

A geotechnical risk register was provided to demonstrate that geotechnical risk was addressed in the earthworks design. For clarity, Appendix 3A of Section 3 of Volume 1, Technical Appendix 2 of the EIS should have been entitled Geotechnical Risk Register, and not Risk Assessment. The register identifies and lists the main credible geotechnical risks for both construction and operational phases, as well as health and safety, environmental, cost and programme risks. It provides a written record of the geotechnical risks and how they have been/are to be minimised or controlled through design and construction measures.

The risk assessment was completed as part of the earthworks design process. The primary means of minimising and controlling geotechnical risks is to undertake a comprehensive and detailed site investigation which is scoped to specifically address the geotechnical requirements of the proposed development. The site investigation undertaken on the Bellanaboy site has been extensive and provides a comprehensive dataset of information on the ground conditions on the site.

The main geotechnical risk associated with the proposed development is that posed by the presence of soft soil in the form of blanket bog across the gently sloping site. In order to minimise this risk the main terminal platform area is to be constructed within a site from which peat and underlying soft soils have been completely removed. Soil retaining measures in the form of sheet piles and gabions are then provided around the perimeter of the terminal platform. Site development works outside the platform comprise access roads, settlement ponds and drainage, administration area and temporary construction facility, flare stack and other minor ancillary works. In these areas the in-situ peat is to be strengthened by peat stabilisation in order to provide a stable working platform and access routes, particularly for the construction stage.

The geotechnical risk register shows the residual 'post-control' risks. Thus the probability and impact values in the register represent the assessment after taking into account all of the design and construction mitigation measures specifically adopted to ensure that the risks are at an acceptable level for the construction and permanent works. At the early stages of design the risks would have been greater in many cases. The purpose of the design, and specified construction controls, are to reduce these risks to an acceptable level.

In order to illustrate the effect of the proposed controls, the geotechnical risk register has been expanded to show the risk associated with carrying out the work in the absence of appropriate design and construction measures. In addition, the register includes evaluation of how the pre-control risks have been mitigated by appropriate design and construction measures. The expanded risk register is enclosed as Appendix 1 of this reponse.

The risk assessment was undertaken and the risk register prepared by the applicant's earthworks design consultants Arup Consulting Engineers and geotechnical advisors AGEC Limited. The design process involved numerous client/design team meetings at which earthworks designs were discussed and evaluated in terms of safety, efficiency, programme, constructability, etc. This design process also enabled relevant issues such as the events at Pollatomish and Derrybrien to be discussed in detail and taken fully into consideration. It should be noted that the Pollatomish and Derrybrien events occurred in the early design phase of the terminal earthworks design. The lessons learned from the two events informed the basis of the geotechnical design and construction with respect to local and global stability.

The risk register was produced following 'brainstorming' sessions involving senior engineers and geologists of the design team, and senior Shell project staff. The development of the risk register was a qualitative process rather than quantitative, in line with the guidelines provided by Clayton,(2001)[1] (copy of publication included as Appendix 2 of this response). The process included input from geotechnical specialists with international experience from Arup Geotechnics (UK). Where available, objective scientific data was considered. Conservative design assumptions and parameters were also applied (see Technical Appendix 2 of Volume 1 of the EIS).

These designs as presented in the EIS also include levels of redundancy such as the combined use of sheet piles and peat stabilisation for stabilising access roads and other paved areas.

The expanded register provides clarification by means of:

- Information on whether the hazard being assessed is a construction or operational stage hazard;
- information on whether the risks apply to cost, programme, safety and/or the environment; and
- an explanation of the basis for selection of the probabilities and impacts, to demonstrate a consistent approach to the overall geotechnical risk evaluation.

It is important to note however that the key benefit of preparing the risk register is the identification and consideration of potential geotechnical risks within the design. Once these risks have been reduced to an acceptable level by design, the actual numbers appearing in the table for the various probabilities, impacts and risks are considered indicative, rather than being scientifically or statistically proven. An acceptable level was considered to be one which was as low as reasonably practicable, i.e. a risk that could not be reduced further without additional resources which would be considered extraordinary and disproportionate to the credible consequences of a hazard.

In addition to the consideration of risks presented in the risk register and the proposed earthworks design, the applicant will in accordance with best engineering and construction practice implement pre-planned contingency measures to deal with potential risk items that become evident during construction. The proposed contract for the earthworks part of the construction is an IEI remeasurement contract which gives the Engineer on site the powers to direct the earthworks contractor to undertake alternative or additional works, if the Engineer deems this necessary in the interest of safety and risk control. In this way the 'potential' probability of a hazard occurring can be significantly reduced to a 'predicted' probability by design. To use the example quoted in the Board's letter, the probability of 'unexpected ground conditions' remains at 3 even with a comprehensive site investigation. However the probability of 'failure of an excavated slope' due to unexpected ground conditions can be brought down to a value of 1 by a conservative

[1] Clayton (2001). Managing Geotechnical Risk. Thomas Telford Publishing, London.

design. The design incorporates contingency measures to be implemented on site as required if ground conditions, such as softer than expected soils or higher than expected groundwater, are encountered. Similarly the probability of flooding is assigned a value of 1 because the surface water drainage system for the terminal platform is based on accommodating very low probability (1 in 700 years) storm events, including events such as that recorded at Pollatomish that resulted in the landslides at Dooncarton. The drainage design is presented in Technical Appendix 3 of Volume 1 of the EIS.

Paragraph 4 of the Board's letter requests that for the different hazards the likelihood of the occurrence of each cause be evaluated separately. This evaluation is an integral part of the risk evaluation. The probabilities and impacts quoted in the risk register relate to the risk of the hazard occurring. These take into account the hazard arising from any of the causes listed, or a combination of causes. The probability of each hazard, as presented in the expanded risk register, therefore represents the evaluation of the probability of any or all of the causes arising. This is consistent with the risk evaluation methodology recommended by Clayton (2001).

An assessment of the risk of several hazards occurring simultaneously or sequentially was undertaken as an integral part of the risk evaluation methodology.

The potential simultaneous or sequential risks fall into one of two categories as follows:

In some cases there is no inter-relation between the hazards. An example is the hazard of dust from soil strengthening (no. 13) and the hazard of access over soft ground (no. 1). In all other cases each hazard may be a contributor to the occurrence of other hazards, but there is no cumulative effect or increased hazard that has not already, although not explicitly, been addressed in the risk register. Some examples are discussed below:

- The risk assessment for hazard number 5 (failure of access road) is valid, regardless of whether the failure is due to unexpected ground conditions (hazard no.1), failure of dewatering (hazard no. 11), failure of soil strengthening (hazard no. 12) or flooding (hazard no. 15, and has been assessed accordingly.
- The risk associated with the occurrence of a bog slide (hazard no. 20) is the same regardless of the factors or other hazards that occurred to precipitate the bog slide. The overall impact of a bog slide is difficult to mitigate against, however the probability can be, and has been, greatly minimised and controlled by undertaking comprehensive analysis and assessment of global slope stability, and the implementation of robust and conservative design, construction control, monitoring and contingency plans.
- The risk of unexpected ground conditions could contribute to any of the other risks assessed in the register, but this does not increase the risk above that assessed.

To take the example quoted by An Bord Pleanála:

- Failure of the settlement ponds has been assessed in terms of structural failure of the sheet piled support system, and separately, in terms of the design of the ponds to adequately remove suspended solids from surface water runoff before discharge off site (Technical Appendix 2 and Technical Appendix 3 of Volume 1 of the EIS).

- The hazard of flooding is assessed in terms of the construction phase when temporary surface water drainage systems are in place (Technical Appendix 3 of the Volume 1 of the EIS).
- The impact of flooding in either construction or operational phases will not increase the risk of structural failure of the sheet piled settlement ponds which have been designed to accommodate all credible differential heads of water across the sheet piles (Technical Appendix 2 of Volume 1 of the EIS).
- Similarly, the impact of flooding on the ability of the settlement ponds to work effectively is considered within the design of the surface water drainage system, including the ponds, and addressed accordingly (Technical Appendix 3 of Volume 1 of the EIS).

The risk register therefore covers the risk of several hazards occurring sequentially or simultaneously.

To summarise the response to Item 1 of the Board's letter:

- The risk register is a qualitative presentation of the main geotechnical risks, after the implementation of control measures.
- These control measures include an earthworks design based on conservative assumptions and design parameters, with design controls and construction controls in place to address all anticipated scenarios, and with contingency measures in place should unlikely conditions arise.
- The earthworks design is based on data from a very comprehensive geotechnical site investigation.
- The risk register is provided to demonstrate that the main risks identified have been evaluated and reduced to acceptable levels.

Referring to the risk register, all key areas of geotechnical risk have been assessed and reduced to acceptable levels by design and/or construction measures, including:

- Failure of Excavated Cut Slope (item 3): Lower bound strength parameters are used in the design as well as conservative groundwater levels. The design achieves a Factor of Safety of 1.5 and is carried out to the recognised standard BS6031. Traditional methods of construction are employed and there is provision for drainage to be introduced where required.
- Failure of Access Road (Item 5): The Derrybrien methodology of 'floating' roads on peat has been avoided. Roads will be constructed on stabilised peat thereby avoiding the inherent risks of a) overloading weak peat with the road construction and any traffic, and b) excavating peat and possibly undermining a weak slope.
- Soil Strengthening Failure (Item 12): The design for all zones of strengthened/stabilised soil assumes a strength value which gives an adequate factor of safety in accordance with relevant codes and standards. This design value is less by a factor of 1.6 than the minimum strength which is specified to be achieved by the contractor undertaking the work. This specified strength will be subject to in situ confirmatory testing. Current testing demonstrates that the assumed design strength and the minimum specified strength can be achieved by mixing cement with peat.

- Flooding (Item 15): The permanent drainage system has been designed for a 1 in 700 year event and the construction phase drainage system for a 1 in 100 year event. These criteria are significantly more onerous than those typically used in civil projects. In addition the site is located at the crest of the catchment with no surrounding higher ground.
- Bog Slide (Item 20): The slope on the Bellanaboy Bridge terminal site is benign (2 degrees) compared with the failed slopes of Pollatomish (30-60 degrees); the peat at the terminal site is underlain by till, not directly by relatively impermeable bedrock as was the case at Pollatomish. Also, historically bog slides have often been caused by man - by loading crest of slope or excavating at toe; and for the terminal site these aspects have been addressed through design.

Having regard to the above and the attached expanded risk register ARUP Consulting Engineers and AGEC Limited are confident that all aspects of the proposed earthworks design and the geotechnical risks associated with the project have been dealt with appropriately.

2.2 Item 2: Peat Stabilisation

The Board Requested the Following:

'2. *It is noted that the use of dry cement to strengthen peat is a new technology in Ireland. It is further noted that the tests carried out by Farrell and Hebib, referred to in the EIS, were on two peats from raised bogs rather than on blanket bog as at Bellanaboy, and that the tests gave marked differences between the strengths of the stabilised mixture formed with the two peats. This may indicate that the risk of not achieving sufficient strength using cement stabilisation is greater than using sheet piles, which is proven technology. It is also noted that the use of sheet piles may have less potential for environmental impact than the use of cement stabilisation.*

No results of strength tests on stabilised peat appear to have been included in the documents provided to justify the values used in the stability analyses. You are asked to indicate what, if any, field tests have been carried out which would verify strengths obtained from laboratory tests and, if so, to submit results obtained from such field tests.

Please state if any of the contingency measures in the event of the required soil strengthening not being achieved would result in further excavation and removal of peat from the site. If so, please quantify the amount.'

2.2.1 Introduction to Response to Item 2

As detailed in Volume 1, Technical Appendix 2 of the EIS, peat stabilisation is being used within the earthworks construction phase primarily for access during construction. All the peat within the terminal footprint area will be removed and peat stabilisation is to be used to:

- Provide vehicle/plant access for construction (temporary works).
- Provide permanent support to the main access road and the main carrier drain.

As there are a number of facets to this question, it is proposed to respond under a number of principal headings as follows:

- Rationale for the use of peat stabilisation.
- Sheet Piles vs Peat Stabilisation.
- Peat Stabilisation Design Process.
- Peat Stabilisation History of Technology.
- Comparison of Farrell and Hebib Tests vs Bellanaboy Tests.
- Interpretation of Results of Laboratory Analyses of peat stabilisation.
- Contingency Measures.
- Environmental aspects of sheet piling and peat stabilisation.
- Factual Information from Site Investigation and Laboratory Analyses (Swedish Geotechnical Institute Report, enclosed as Appendix 3 of this reponse).

2.2.2 Rationale for the use of Peat Stabilisation

Peat stabilisation through strengthening of the existing peat by the mixing in of binders in situ (in peat), was chosen by the earthworks design team to deal with the issues which arise in gaining access to and undertaking both permanent and temporary works to the terminal site and ancillary features such as the settlement ponds. The main issue is to improve the strength of peat and other weak soils so that access roads can be constructed and used safely and without causing failures such as occurred at Derrybrien.

The reasons for choosing peat stabilisation are:

- It is a proven method of constructing temporary and permanent works over soft soils;
- the works can be undertaken progressively from previously stabilised ground;
- the factor of safety against failures during construction is often superior to alternative methods;
- the volumes of materials to be exported and imported from and to the site can be significantly reduced when compared with alternatives, such as excavate and replace methods; and
- the method is economic.

Peat stabilisation will establish defined and predictable engineering properties in the peat, which will remain in situ, under permanent and temporary access roads and hardstands. The properties of the stabilised peat will be proved by in-situ testing. This allows construction to proceed safely and avoids removing more peat from site which would generate additional construction traffic on public roads.

Other methods of temporary and permanent access over peat were explored and it was concluded by the earthworks design team that although these methods were feasible, there would be significant time and working methodology constraints. A number of these other methods have been retained as contingencies in the unlikely event that peat stabilisation is not entirely effective (see below).

2.2.3 Sheet Piles vs Peat Stabilisation

The principal function of the proposed peat stabilisation is to allow access to the areas where sheet piling is required. It has not been proposed that peat stabilisation can be used instead of sheet piles. Safe access cannot be guaranteed to locations for sheet piling in weak peat without stabilising or otherwise creating an access road. Peat stabilisation is proven technology for both temporary and permanent works, and is used on projects in England, Scandinavia, Japan, America, Canada and the Netherlands.

2.2.4 Peat Stabilisation Design Process

Over the past 20 years a design process for peat stabilisation has been developed. This is shown graphically below in Figure 1.

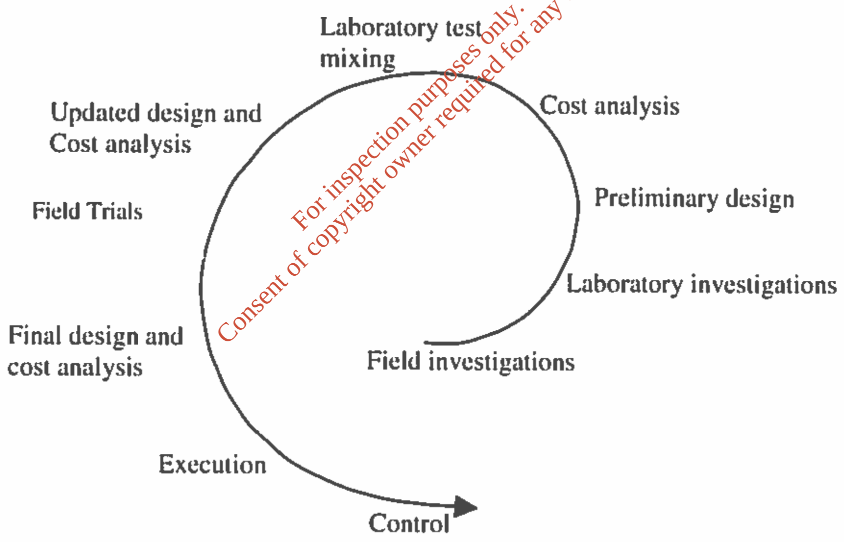

Figure 1: The Design Process for Peat Stabilisation[2]

With respect to the terminal site the following stages have been substantially completed: field investigations, laboratory investigations, preliminary design, cost analysis and laboratory test mixing, all of which confirm the feasibility of the proposal for peat stabilisation on the project. Updated design and cost analysis are presently in progress being undertaken by peat stabilisation specialists. Field trials have not yet been undertaken because it is considered that planning permission is required in advance of such work. Field trials are not required to establish the feasibility of the proposed works, but are used as

[2] Diagram taken from Hansson et al, 2001. Mixing of soft soil and cement near the Groene Hart Tunnel entrance, Stabilisatie van de diepere ondergrond, workshop, 15 February 2001, Rotterdam, Holland.

a tool to refine and select the most appropriate technically and commercially acceptable binder mix(es) and to prove construction methodologies on a site specific basis.

2.2.5 Peat Stabilisation History of Technology

Peat stabilisation is often referred to as "Deep Dry Mixing", the term deep dry mixing refers to dis-aggregation of the soil in-situ and its mixing with binders in dry form before a surcharge is applied. The soil once stabilised with binders containing cement will cure in a similar manner to concrete (i.e. it becomes in layman's terms "solid"). For additional information, please see the response to Item 11 of the request for further information Reg.Ref:P03/3343,

The method was introduced simultaneously in the Scandinavian countries and Japan during the 1970's. It was developed by the Swedish Geotechnical Institute (SGI) in Sweden and the Port and Harbour Research Institute in Japan and is used in different applications, such as:

- Reducing settlement.
- Increasing stability.
- Increasing bearing capacity.
- Liquefaction mitigation.
- Containment of contaminated ground.
- Improving manageability of excavated soil.

A number of examples of case studies of work undertaken on actual projects are given in the response to Item 11 of the request for further information Reg.Ref:P03/3343.

2.2.6 Comparison of Hebib and Farrell[3] Tests vs Bellanaboy Tests

Hebib and Farrell (2003) of Trinity College Dublin (TCD) carried out one of the first trials of peat stabilisation in Ireland. The work carried out by TCD was part of a Europe -wide investigation into stabilisation of soft organic soils and many of the test procedures applied in the Bellanaboy investigations were developed and standardised during the course of these studies. Hebib and Farrell (2003) stabilised peat from two different raised bogs in the Midlands. The properties of the peats from the TCD study are compared in Table 1 to peat from two locations, PS35 and PS21 on the blanket bog covering the terminal site.

Table 1

Properties	Raheenmore	Ballydermot	PS35	PS21
Natural water content (%)	1200	850	1019	1090
Organic content (%)	98-99	94-98	96-97	*
Von Post classification (*Hn*)	H2	H6-H9	H7-H8	H6-H7
pH	5.3	4.9	*	4.9

Note: * = results outstanding

[3] Hebib and Farrell (2003). 'Some experiences on the stabilisation of Irish peats', Can. Geotech. J. Vol. 40, pp 107-120

The organic content of the peats from the TCD study were broadly similar but the peats were in different stages of decomposition and, consequently, had different concentrations of humic acid. The concentration of humic acid has a significant effect on the strength achieved in soils stabilised with certain hydraulic binding agents. Hebib and Farrell showed that there was a significant difference in the strengths achieved in the Raheenmore peat stabilised with blast furnace slag and gypsum and the more humified Ballydermot peat. However, as shown in Figure 2, the differences in strength for peats stabilised using a binder consisting of 100% cement were less significant. The proposed peat stabilisation works for the terminal site will be restricted to cement or possibly a cement/sand mix.

The design of the peat stabilisation for the Bellanaboy site first involved coring and sampling the peat using specialist equipment at 34 locations across the site. The peat was classified using the Von Post classification system by both AGEC site geologists and the Swedish Geotechnical Institute (SGI). Samples of the underlying 'mineral' soils have also been taken and tested. The thickness of peat generally varies from 1.5 to 4m, with the deeper peat in the lower half of the site. The upper half of the peat profile tends to have a Von Post classification of H4-H6 with the fibrous nature of the peat still evident. Lower down and closer to the interface between the peat and the mineral soil the peat becomes increasingly decomposed and amorphous with little tensile strength. Samples of the fibrous and amorphous peats from various parts of the site were sent to SGI for detailed analysis. There, the different peat types were mixed separately using different binders in varying concentrations.

Some eighty unconfined compression tests have been completed. These were tested variously at 7, 14, 28 and 90 days after stabilisation – all samples were not tested at all four intervals. The samples were mixed in a dough mixer and placed into plastic tubes and allowed to cure under water. A surcharge of 18kPa was placed on top of the stabilised peat 45 minutes after mixing to replicate the placing of a 1m thick blanket of fill. There is a reasonable comparison between the strengths achieved for the cement-stabilised peats in the TCD study and those observed in the examination of stabilised peat samples from Bellanaboy (see Figure 2 and Figure 3).

Hebib and Farrell (2003) examined the cement-peat mixture under an electron microscope and showed that the cement particles filled the large void spaces in the peat and no interaction was observed between the hydrated cementation products and the organic matter. Based on the results observed to date from the SGI results and Hebib and Farrell (2003) the strength of well-mixed specimens 28 days and 90 days after curing appears to be proportional to the cement concentration.

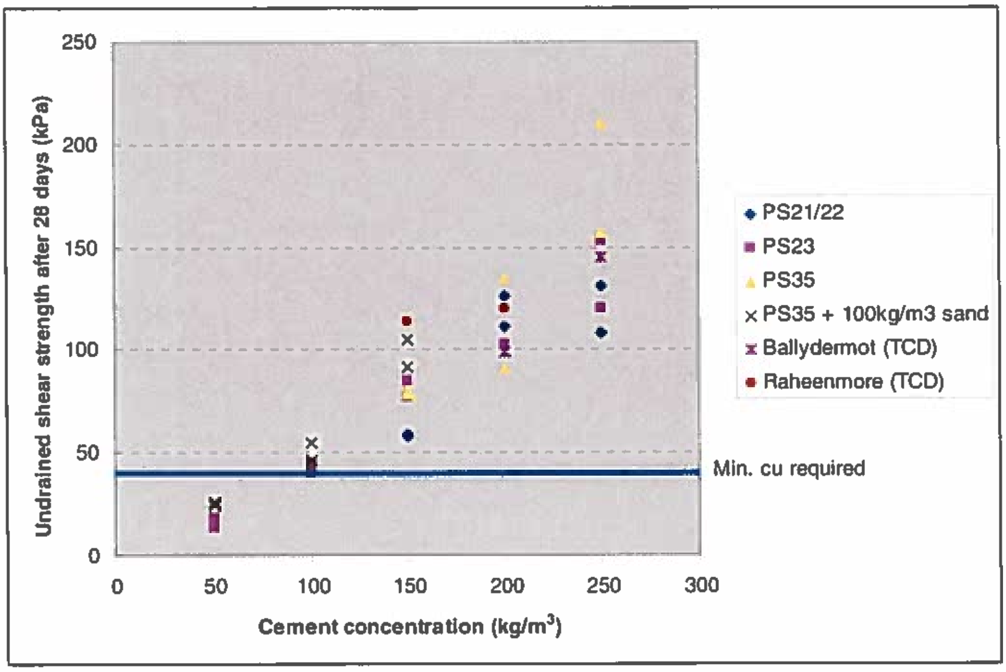

Figure 2. Comparison of undrained shear strengths observed from unconfined compression tests between TCD study and Bellanaboy Bridge terminal project for 28 days curing.

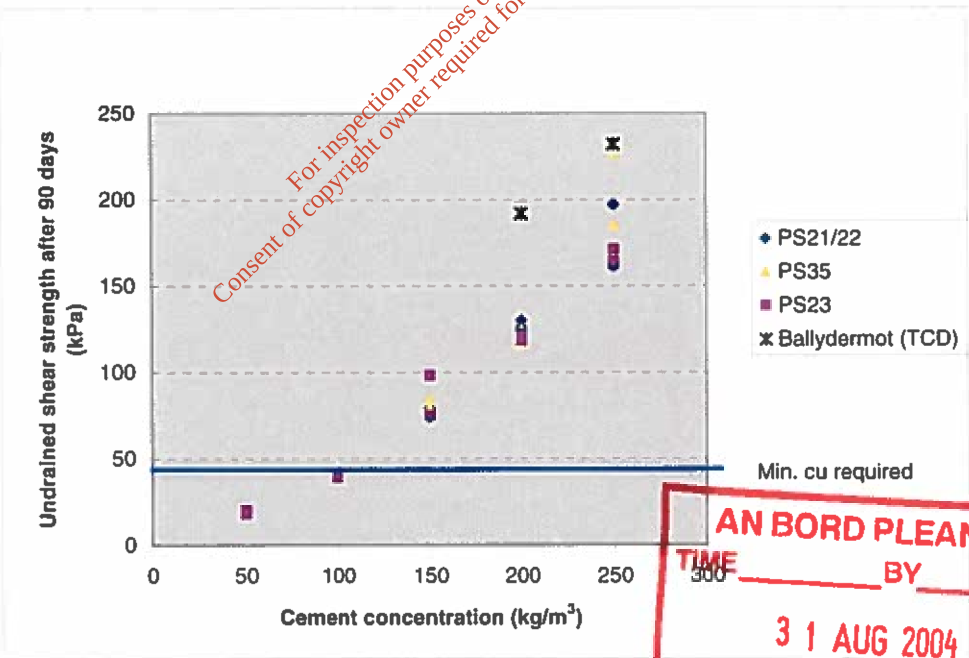

Figure 3. Comparison of undrained shear strengths observed from unconfined compression tests between TCD study and Corrib project for 90 days curing.

The results from the tests demonstrate that the design strength of 40kPa can be achieved with a minimum cement content of 150kg/m3.

2.2.7 Interpretation of Results of Laboratory Analyses of peat stabilisation

The strength requirements of the stabilised peat have been determined based on the design requirements, taking into account the actual field strengths likely to be achieved by the stabilisation process. A reduction factor has been applied to the laboratory results to determine the minimum field strength requirements 28 days after stabilisation. A minimum undrained shear strength of 40kPa has been specified for most of the temporary works. The stabilised soil under the main access road will form the foundation for the permanent road pavement and a higher undrained shear strength of 50kPa has been specified. The undrained shear strengths used for the design were 25 to 35kPa, providing an additional factor of safety against potential poor performance of the stabilised soil.

Frequent probing, coring and laboratory testing will check the effectiveness of the peat stabilisation at various time intervals after stabilisation. A large pad test using steel and/or concrete kentledge blocks will be carried out in one of the field trial areas to determine the ultimate strength of the stabilised peat.

2.2.8 Contingency Measures

As the site and peat to be stabilised and improved have been subject to a detailed site investigation and laboratory analyses there is good understanding of the soils on the site. This work has confirmed the feasibility of peat stabilisation and strength gain in the soft soils on the site. It is the professional opinion of ARUP Consulting Engineers, AGEC Limited and SGI that peat stabilisation will achieve the required design strength. Notwithstanding this, the methodology proposed will allow for a number of contingencies should unexpected conditions arise.

The execution of field trials will refine the binder design and mixing techniques. All works will be undertaken in a closely monitored and quality controlled manner. All peat stabilisation works will be subjected to a large range of regular and close centred strength tests to ensure that target strengths are being met. When/where any zones of underperformance are identified they will be quarantined and subject to rework. All equipment, work methods, binder designs and soils to be treated will be rechecked prior to further progressing works in untreated areas. The employment of these types of rigorous work methodologies will mean that the possibility of underperformance of soil strengthening techniques would be confined to small sections of the works and as such they will be then subjected to rework or the deployment of a suitable contingency measure (see below).

In the unlikely event of the required soil strengthening not being achieved there are a number of contingency measures available to the applicant as noted in response to Item 11 of the further information request Reg.Ref:P03/3343 and the EIS. In the case of enabling works, i.e. the strengthening of access to areas prior to installing sheet piles, the following contingency measures are available and will be considered:

- Re-stabilisation of the underperforming area.
- The use of bog mat roads (where temporary access is required).
- The application of geo-textile materials to spread loads over a greater area.
- Excavation and replacement of soft soils using acceptable materials sourced either on site or off site.

It is not considered likely that there will be a need to excavate and remove peat from site in order to gain temporary access as outlined above.

In the case of the stabilisation of the permanent site access road, the following contingency measures are available and will be considered:

- Re-stabilisation of the underperforming area.
- Piled embankments
- Piled rafts and bridges.
- Concrete columns.
- Floating roads.
- Embankments and roads constructed using preloading techniques.
- Preloading with vertical drains.
- Lightweight materials.
- Excavation and replacement of soft soils using acceptable materials sourced either on site or off site.

Only in the event that no other alternative is workable for the permanent access road, would there be need for any excavation and removal of peat off site. It is considered that this would be necessary in a localised area only , and that the quantities would not materially increase the peat volumes already stipulated in the EIS.

The unlikely event of not achieving the required strength improvement of the soil in main works areas, would generally be as a result of poor mixing, insufficient binder injection, incorrect binder type being used or localised variations in ground conditions not encountered during site investigation. These issues will be resolved by pre-works site trials to perfect the methodology, supervision of work and post construction quality control.

2.2.9 Environmental aspects of sheet piling and peat stabilisation

In respect of the comment made by the Board regarding the comparative impacts between sheet piling and cement stabilisation we respond as follows:

The potential and predicted environmental impacts arising from the use of sheet piles to stabilise the peat i.e. prevent it from moving horizontally, and the use of cement stabilisation to strengthen the peat i.e. increase the allowable bearing capacity of the peat to allow plant to work safely on it, are very different.

In the case of sheet piles the most significant impact arises from the generation of noise and vibration during installation with no measurable impact in respect of changes to soil or water chemistry as a result of leaching of iron form the steel piles. This technique is used daily worldwide and there are no proven negative impacts as a result of anaerobic or aerobic degradation of the steel in contact with ground water. Thus whilst in section 12 of Volume 1 of the Environmental Impact Statement for the proposed Bellanaboy Bridge Gas Terminal the predicted impact is ranked as moderate on the site itself, it is temporary and of short term in duration occurring only during the early part of the construction phase.

With cement stabilisation the audible and vibration impacts are much lower than for sheet piling and no different from the use of normal earth works machinery on a site. The potential for the cement and sand binder to be leached by the presence of groundwater is the main difference. Volume 1 of the Environmental Impact Statement for the proposed Bellanaboy Bridge Gas Terminal sections 6,7,8, and 11 as well as the Response to Request for Further Information by Mayo County Council dated 17/02/04 presents the impact assessment of the cement stabilisation process and concludes on the basis of experience in Scandinavia, Germany and the UK that the predicted impact i.e. residual impact arising from the leaching of the cement and sand binder is negligible. This aspect is discussed further below in the response to Item 3 of the Board's letter.

2.2.10 Factual Information from Site Investigation and Laboratory Analyses (Swedish Geotechnical Institute Report)

The results of the testing carried out to date at SGI are included in Appendix 3a and 3b. As shown in Figure 2 and Figure 3 above the results from the laboratory study confirm the feasibility of stabilising the peat on the terminal site and are broadly in line with the results from the TCD study and elsewhere.

SGI has also provided a response (enclosed as Appendix 4 of this response) to some of the questions raised by the Board. This confirms the feasibility of the peat stabilisation at the Terminal site from both a geotechnical and environmental perspective.

2.3 Environmental Impact of Peat Stabilisation

The Board Requested the Following:

> '3. *It is noted that the possible environmental impact of cement stabilisation and how it relates to the EC Water Framework Directive requirements are not considered by Farrell and Hebib and are not elaborated in the EuroSoilStab Design Guide for Soft Soil Stabilisation. You are asked to state if the chemical properties of the cement, and the potential short, medium and long-term runoff and/or leaching from stabilised soil have been examined, and to submit details of any such examination.'*

2.3.1 Introduction to Response to Item 3

The extent of the further information the Board is seeking in respect of this question is unclear as the issues are considered to have been comprehensively addressed in Volume 1 of the Environmental Impact Statement for the proposed Bellanaboy Bridge Gas Terminal 2003 and in the Response to Item 11 of the Request for Further Information by Mayo County Council. We have provided in this document a response addressing what we believe are the Board's requirements as requested under this item.

2.3.2 Response to Item 3

The Water Framework Directive (WFD) is a high level strategic planning directive, one of the purposes of which is to protect inland surface waters and groundwater bodies. One of the objectives of the WFD is to establish a framework that will prevent further deterioration and protect and enhance the status of aquatic ecosystems; ensure the progressive reduction of pollution of groundwater and prevent its further pollution. It will be the responsibility of EU Member States and their nominated Competent Authorities to implement the Directive. It places no responsibilities on an individual developer. Certain provisions of the WFD have been given effect in Ireland in various statutory instruments, in particular the European Communities (Water Policy) Regulations, 2003 (S.I. No 722 of 2003) ('the Regulations').

The objectives of the WFD have been addressed by the applicant in all aspects of the design including with regard to peat stabilisation, although not as part of the River Basin District Management Systems process required under the WFD, since these are not yet fully in place and such assessment will be the responsibility of the local authorities and the competent authority in each member state, in this case the EPA.

The main areas of concern (relevant to the WFD) that have been looked at by researchers and assessed as part of this development are the availability of alkaline compounds and heavy metals as leachable components in water that comes into contact with the cement during emplacement as it cures and finally when it has solidified.

An environmental risk assessment has been carried out in a similar manner to that in which the EPA and local authorities will be characterising and classifying River Basin Districts pursuant to the Regulations, to assess the potential for the cement and any sand binder used to firstly be a source of potential pollution, then secondly whether or not there is a pathway to the receptors. It is accepted that the receptors would be the local groundwater and surface water bodies in the vicinity of the terminal site which feed into the Bellanaboy River, which in turn flows into Carrowmore Lake.

The chemical properties of Irish cement and sand have been examined by the Swedish Geotechnical Institute (SGI), results attached (Appendix 3[illegible]). The potential for leachate products that will arise from a combination of cement, sand, peat and water (pore, ground and surface) created from the cement stabilisation process has been reported already in the Response to item 11 of the Request for Further Information by Mayo County Council dated 17/02/04 (Section 3). Further tests by SGI as part of the requirements of the EuroSoilStab guidance are in progress.

The European Cement Association, The German Cement Works Association Verein Deutscher Zementwerke (VDF) and the Institute for Construction Research (IBAC) in Germany have carried out extensive research into the environmental acceptability of cement products in the construction industry {www.vdz-online.de} all of which are referenced in the response to Item 11 of the further information request. The conclusions reached by the various research works as well as the applicant's advisers' work show that the cement is generally solid after 24 hours by which time the availability of leachable components is negligible.

During the reactive phase of cement (if a cement-sand mixture is used the sand will be inert in this context) and water, environmentally relevant substances contained in the cement constituents can theoretically be released into the environment if they are present in mobile form. Substances that might find their way into the surface water/groundwater include soluble alkalis and trace element compounds. However, trace elements in cement suspensions are predominantly insoluble and therefore unavailable for release. Hexavalent chromium is the only trace element that can theoretically be released from fresh cement at concentrations that might be environmentally relevant. However, if low concentrations of chromium are present in the cement then only a very small amount of hexavalent chromium can be released. In addition to trace elements being released, alkalinity is released as part of the cement hardening process resulting in an increase in pH. Increased pH values and chromate contents occur only in the immediate contact zone of the cement (less than 60mm) and only for a very limited period of time (less than 24 hours). As hydration progresses, the dissolved chromate reacts so that in hardened concrete virtually all the chromium is in an insoluble state. Furthermore, water will be drawn into the mixing process, as the cement will attract the peat 'pore' water during the hydration process. Increased concentrations in very thin boundary layers and for short periods are not environmentally relevant and do not cause any lasting or significant adverse impact on groundwater (Brameshuber et al[4]).

The peat stabilisation process is very similar in design terms to that used for concrete foundations and other concrete structures placed in the ground below the water table. The earthworks design team will use the Building Research Establishment guidance BRE SD1 for concrete design in the ground. This leads to classification of the concrete as ACEC class AC-2z for a natural site with mobile groundwater and pH < 5.5. This requires no special measures for protection of the concrete against the corrosive effect of the acidic environment (design class DC-1) where low structural performance is required and concrete sections are >450mm thick and surface damage is acceptable. This demonstrates that the cement or cement-sand mix once cured will not suffer significant deterioration in the ground.

A more detailed presentation of the leaching process and its potential to impact the environment is presented in Appendix 5 of this response.

In answer to the Board's question on the relationship of the cement stabilisation process to the WFD we respond as follows:

2.3.2.1 Implication on the Water Framework Directive

The introduction of cement in to the environment has been assessed in terms of its effects upon groundwater and surface water above. An appraisal of this in terms of the wider implications of the site setting, and the Water Framework Directive (WFD) are presented below. The proposed mitigation has been presented in Volume 1 of the Environmental Impact Statement for the proposed Bellanaboy Bridge Gas Terminal and in the response to Item 11 of the Request for Further Information by Mayo County Council dated 17/02/04.

The terminal footprint represents approximately 1.5% of the area of the Bellanaboy River catchment and within the site the area to be treated with cement stabilisation is much less than that. At any one time there will only be approximately 400 m^3 per 24-hour period of cement-stabilised ground that is curing. Furthermore in terms of catchment protection the site drainage is

[4] Brameshuber W, Hohberg I, Uebachs S, no date. Environmental Compatibility of Fresh Concrete in Contact with Soil and Ground Water

designed to capture all runoff that has the potential to become contaminated during construction and operation and this is discussed in detail in Sections 2, 3 and 9 of Volume 1 of the EIS.

It should be noted that the cement stabilisation method is used widely, particularly in the US, as a method of encapsulating contaminated soil in the ground.

2.3.2.2 Effects on Groundwater

Groundwater at the site is present in both the overlying peat, the mineral soil and the bedrock. Locally the ground water in the peat may be lower than the peat surface but is generally close to or at the peat surface. Therefore the cement may be emplaced into the peat both below the water table as well as above.

The geological and hydrogeological setting of the site show that the emplacement of the cement will be into relatively low permeability materials (1 to $6x10^{-9}$ m/s) predominantly composed of peat with some emplacement into mineral soils beneath, which have a slightly higher permeability of $1x10^{-6}$ m/s.

As stated in Section 8 and Technical Appendix 1 of Volume 1 of the EIS, groundwater gradients are very low and in combination with low permeability, this results in very low flow rates of groundwater. Therefore the effects of the introduction of high pH waters into groundwater will be very localised. The low flow rates will mean that reactions will have a long time to occur and therefore the neutralisation of high pH will be fully completed before the relatively small quantity of localised high alkalinity groundwater will impact any local watercourse. Research has further confirmed that increased pH values and chromate contents occur only in the immediate contact zone of the cement (less than 60mm) and only for a very limited period of time (less than 24 hours). SGI have previous experience of such issues which indicate that no harmful effects are expected from deep mixing stabilisation. Specific experience from Holma Bog in Sweden confirms that at about 1m from the stabilised soil it was not possible to detect any leaching.

With reference to the WFD, the effects of high pH porewaters are therefore expected to remain localised at the source and the potential for them to migrate away from the source is expected to be extremely low due to a combination of very low groundwater flow rates (approximately 0.3m per year in the deeper peat and 3m per year in the shallower peat and mineral soil) and the capacity for the surrounding materials to counteract the high pH. Therefore the introduction of cement into the below ground environment will not have any effect on the local drainage basin water quality.

2.3.2.3 Effects on Surface Water from Run-off

The potential effects of any surface water run-off from the cement stabilisation process are seen as being the more important in terms of affecting water quality and therefore the water quality of the local catchment area. The effects of surface water run-off and transport of highly alkaline waters is a potential short-term problem. Once the cement has become set, then the chemical reactions resulting in the production of lime will have ceased and the effect of the setting of the cement will be to hydraulically isolate the cement.

However, before the cement has set, any run-off generated will potentially be able to flow away relatively easily, depending on the topography and the presence of controls to manage this run-off. This would have a short term and relatively localised effect on surface water and could constitute a temporary degradation in water quality. If a sensitive receptor is located nearby then without the mitigation proposed (perimeter drainage system and silt ponds) there would be the potential for short term impact and in the case of surface water localised changes in water chemistry, notably a relatively high increase in pH. Although the potential effects will be localised and short lived, mitigation measures have been incorporated into the design as discussed in Volume 1 of the Environmental Impact Statement for the proposed Bellanaboy Bridge Gas Terminal and the Response to Request for Further Information by Mayo County Council dated 17/02/04, to ensure potential run off is minimised, intercepted and treated. Hence, as already stated in these two documents, the peat stabilisation works will have no residual effect on the quality of groundwater or surface waters or their associated ecosystems outside the Terminal site boundary.

3.0 Conclusion

We consider that this response has addressed the concerns raised by the Board in their letter. The earthworks design for the proposed development is both robust and conservative. This design has been developed by some of the leading national and international engineering, geotechnical and hydrological on the basis of extensive and exceptionally detailed site investigation. In this regard, we are confident that the Board will recognise this fact in considering the merits of this application and in particular the issues relating to the earthworks design.

Yours faithfully

Tom Phillips
Managing Director
Tom Phillips + Associates

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Changes to Appendix 3A have been marked in blue

APPENDIX 3A GEOTECHNICAL RISK REGISTER

Geotechnical Risk Register

A Geotechnical Risk Register has been compiled to show the degree of risk attached to various elements of the design. The purpose of the register is to provide an outline description of the hazard, identify the potential likely cause, describe the consequence or impact of the hazard and identify the design and construction controls to be implemented in order to reduce the probability to a tolerable level. The overall application of the risk register will allow the management of geotechnical risk.

Whilst probability of a hazard occurring can be reduced to a minimum by geotechnical design, the probability cannot be reduced below Negligible. The likelihood of a hazard occurring has been judged on a qualitative scale. The scale has been derived from Clayton (2001) see Table 3A.1 below.

Table 3A. 1 Qualitative Probability Scales

Scale	Probability (P)	Chance, per section of Works
1	Negligible	< 10 %
2	Unlikely	10 – 30 %
3	Likely	30 – 50 %
4	Probable	50 – 70 %
5	Very Likely	> 70 %

The severity of the risk (R) is also assessed qualitatively and depends on the risk tolerance. The risk results from the combination of the hazard and the impact/consequence. A similar qualitative scale has been derived for the impact of the hazard (Table 3A.2).

Table 3A.2 Qualitative Impact Scales

Scale	Impact (I)
5	Very High
4	High
3	Medium
2	Low
1	Very Low

The impact of a hazard manifesting itself can be either financial, health & safety or environmental or combinations of all three.

The degree of risk is determined by combining the probability and impact assessments, R = P x I. It has been judged against a third qualitative scale, the Risk Rating, which includes a descriptive response. The Risk Rating scale is given in Table 3.

Table 3A.3 Qualitative Risk Scales

Risk (R)	Risk Rating	Response
1 to 4	Trivial	Monitor
5 to 8	Tolerable	Regular Attention
9 to 12	Substantial	Early Attention
13 to 25	Intolerable	Unacceptable

The probability of a hazard manifesting itself can be reduced by adequate geotechnical design and sound construction techniques but the impact cannot be influenced*.

*This statement refers to the fact that an impact cannot be removed. However, the assessment of the impact of a hazard can result in the impact becoming more localized, or of less magnitude, if detailed knowledge of the site (e.g. through site investigation) can reduce the uncertainty associated with a particular hazard and enable a more accurate assessment to be made.

No.	Hazard	Cause	Potential Impact	Before Control P	Before Control I	Before Control R	Design Controls	Construction Controls	After Control P	After Control I	After Control R	Justification of Probabilities Chosen	Contingency Measures
1	Access over soft ground Hazard considered during the construction phase. Risk considered to be to the health and safety of the construction workers, to programme and cost.	Ground too soft; the upper strong vegetated layer has been broken; plant too heavy; existence of bogholes.	Not possible to carry out works; plant sinks into the soft ground; project delayed.	5	3	15	Specify the use of low ground pressure plant; use of bog mats; working platforms of stone laid on geotextiles; strengthening the ground work outwards from ground already strengthened; Avoidance or removal of 'extremely soft' material (such as bogholes) prior to starting construction. Installation of drainage to drain soft upper ground to improve strength.	Supervision staff on site fully briefed on ground conditions on site. Thorough induction of all personnel in the strength of the ground and issues associated with this ground. Employment of personnel familiar with the ground conditions existing on site, and working in soft ground. Site walkovers at start of each day to inspect ground conditions and to alert construction personnel to ' potential risk' areas.	1	3	3	Bord na Móna's experience in the area has shown that the soft ground can be accessed and harvested by adopting well proven techniques. There is a high probability of soft ground being a hazard if proven techniques are not used. By designing for soft ground – carrying out extensive site investigation (SI) using suitable plant, strengthening the ground, retaining all cut peat faces with gabions or sheet piles - the risks imposed by the soft ground can be reduced to tolerable and manageable levels. Knowledge gained from the SI, from current construction practices and from construction failures such as Derrybrien is used to properly manage the hazards of working in soft ground conditions. The site investigations carried out successfully on the Terminal Site have shown that safe access over soft ground can be achieved and the hazard of soft ground reduced to a low probability. With the deployment of suitable plant and suitably qualified personnel the soft ground encountered on site did not delay the works or give rise to health and safety issues as allowances were made for existing soft ground conditions. There will be designated specific access routes across the site during the construction phase of the project. These will be clearly sign posted. Construction personnel will be fully briefed on safe access routes.	Provision of bogmats; low ground pressure vehicles to be available on site at all times; schedule flexibility, where possible, to work around soft areas.
2	Unexpected ground conditions Hazard considered to be during the construction phase. Risk considered to be to the design, construction programme and costs of the project.	Ground conditions differing from those indicated in site investigation information.	Slows down construction progress; design changes required	4	3	12	Carry out extensive site investigation. Selection of conservative design parameters to allow for variable conditions on site. Monitoring and observation method proposed as part of construction controls.	Thorough monitoring of all works. Personnel involved in monitoring thoroughly familiar with the findings of the site investigation. Construction personnel briefed on expected ground conditions and to alert supervision / monitoring staff to any non-foreseen conditions. Work to stop and impact on design to be reviewed.	3	1	3	Given the Pollathomais and Derrybrien events it was decided that the design would be conservative to allow for variability in the ground and to ensure that the impact of unexpected ground conditions would not be significant. Also, given the extensive ground investigation and the frequency of exploratory locations in the area of the works, the likelihood of large areas of unexpected ground conditions is very small, however the likelihood of localised variability cannot be discounted. These factors gave the designers confidence that the design and contingencies could keep the impact of any unexpected ground conditions very low. By checking stability and designing for some very low probability scenarios – for example checking the possibility of the peat layer sliding into the terminal (on the basis of zero shear strength between the peat and the mineral soils) it has been demonstrated that the design can deal with 'unexpected' ground conditions.. What could cause problems is significantly greater thickness of peat and soft mineral soils – however given the extent of the SI within the areas of the works and also the understanding of the geological genesis of the site the team is confident, from experience, of there being a very low probability of any significant impact from unexpected ground conditions. The extent of site investigation work carried out on the site is greater than industry norms for such sites at such an early stage of the project. Literature and experience shows that the impact of unexpected ground conditions reduces significantly with the increase in the geotechnical knowledge of a site.	Works to be stopped and the ground conditions reviewed. Contingency rock bolting design to be prepared for the intact rock stratum, contingency soil nailing to be prepared for non-intact and mineral soils, contingency provisions for additional strengthening of peat.
3	Failure of excavated cut slope Hazard relates to the cut slopes in mineral soils (there will be no unsupported cut slopes in the peat so not considered here) and the failure of the rock slopes is considered later. The hazard is considered to be applicable during the construction phase – risk to health and safety of construction	Encountering previously unknown weaker zone within the rock or mineral soils, unexpected jointing of bedrock, permeability locally greater that expected. Unexpected variability in the ground conditions	Slowing down of construction work/ additional materials to be excavated.	4	2	8	Use of conservative soil strength parameters and groundwater levels in design; selection of shallow slopes in non-intact rock. Use of benches at changes in slope.	Provision and monitoring of instrumentation to record ground movement and groundwater pressures. Careful monitoring and logging of ground conditions as work progresses and thorough familiarisation of supervisory staff with expected ground conditions. Design team to be alerted to changes.	1	2	2	Failure of the cut slope (mineral soils) would only result in the slope material accumulating in the excavation. Note that the cut slopes all have well in excess of 100m of flat ground at the toe so for any failed material to travel over this surface to push peat at the other side of the terminal down hill is a not a -credible scenario. To summarise a local failure would not lead to progressive failure. Even if it regresses up the hill behind the terminal – it will still stop on the terminal platform - Extensive site investigation work has been carried out in the area of the cut slopes. Extensive monitoring of the ground water has also been undertaken so there is a reliable and significant amount of information available on the critical design parameters for slope stability. Based on robust design, extensive knowledge of the site conditions and good construction practices the probability and impact of the failure of excavated slopes are low. - The design of the cut slopes is based on conservative strength parameters (lower bound parameters have been used) and the design has been carried out in accordance with British and European standards – BS8002, BS6031, BS8004 and EC7. A minimum factor of safety of 1.5, was achieved in the design using the conservative strength parameters.	Work to be stopped locally, ground conditions to be reviewed, slope to be cut at shallower angle or strengthened with soil nailing in mineral soils and non-intact rock. Rock bolting to be considered in intact rock. Strengthening to be carried out in the peat stratum.

No.	Hazard	Cause	Potential Impact	Before Control			Design Controls	Construction Controls	After Control			Justification of Probabilities Chosen	Contingency Measures
				P	I	R			P	I	R		
	workers, design, programme and costs of project											- In the areas of the cut faces in the mineral soil the water table is generally perched within the peat and at depth with the bedrock or mineral soils. The design conservatively assumes the groundwater level at 0.3-0.5m below the ground surface and continuous through out the slope. This is a conservative assumption as it reduces the effective stress in the ground and the capacity of the slope to resist failure. - There are no unsupported cut slopes in the peat and this is not considered in this hazard. - Due to the progressive excavation of the slopes, coupled with monitoring and supervision it will be possible to compare expected ground conditions with those encountered on site. Thus if there are any concerns the gradient of the a slope can be locally reduced. The small additional quantities of material excavated will be negligible compared to the overall amount. - There will be strict control of the loading at the top of cut slopes, and excavation at the toe of slopes, to ensure compliance with the design conditions.	
4	Failure of sheet piled peat face Hazard occurs only during the construction phase as there are no exposed sheet piled peat faces in the permanent condition. Health and safety hazard, programme and commercial risk also.	Sheet piling embedment not sufficient, propping of sheet piling not sufficient. Peat depths in excess of those expected from site investigation findings. Over excavation.	Delay of construction work. Collapse and failure of retained peat.	4	2	8	Use of conservative soil strength and deformation parameters for design. Conservative design of propping system. Design check of implications of over excavation. Minimum embedment depths and maximum excavation levels to be clearly specified on the construction drawings.	Provision and monitoring of instrumentation to record ground movement and groundwater pressures. Thorough monitoring and recording of depths of embedment achieved. Where embedment depths are less than specified design team to be advised. Provision of additional temporary propping systems to be available on site during excavation phase. Monitoring of sheet pile movements during construction.	1	2	2	- Main concern for stability is the embedment of the sheet pile and the extent of excavation in front of the wall. Allowance for construction loads on the retained peat has also been taken into account in the design. In the event of any movement of the wall, which will be immediately apparent in the monitoring and supervision, the situation can be controlled by providing temporary propping, backfilling or removing any load on the retained side of the wall. Also the installation records can be compared to the expected ground conditions to see, well in advance of any excavation, if any unexpected (as in not covered by the design) ground conditions are present. Because of all these controls the probability of failure is greatly reduced. - There is extensive geotechnical information available along the line of the sheet piling systems. This information identifies the most onerous design conditions and the closeness of the data points of the SI fieldwork ensures that, if there are ground changes these can only be very localised. - The use of conservative parameters for the strengthened peat in the design of the sheet piles also ensure that the probability of the hazard of failure is reduced. See item 12 below. - As sheet piled faces are generally on the down hill side of the terminal the failure of these sheet piles cannot lead to a bog slide. Sheet piles are installed on the uphill and downhill side of the main drainage route to the settlement ponds and in the settlement ponds double rows of sheet piles, internally tied, are used.	Work to be stopped locally, construction method and ground conditions to be reviewed. Additional strengthening of peat stratum to be undertaken. Additional propping of the wall to be installed.
5	Failure of access road Hazard considered to be mainly during the construction phase as the loads and frequency of loading imposed during the construction programme are significantly greater than during the operation of the terminal. – failure can be the complete failure of the road or a service failure whereby construction traffic has to slow down to negotiate an uneven surface – programme	Failure of strengthening of peat system, failure of sheet pile retaining system	Loss of access to works area, delay to construction works	4	3	12	Use of conservative soil strength parameters for strengthened soil for design. Use of conservative sheet pile sections and design of tie where appropriate.	Regular monitoring of the surface of the road for signs of failure, monitoring of sheet piles for movement and regular reporting of construction conditions to the on site design monitoring team.	1	1	1	- Proven soil stabilisation techniques will be used for strengthening the peat layer under the roads. See Item 12 below - A surcharge load of 30kPa has been used in design. - The stabilised peat, on all main access roads, is confined between lines of sheet piling which can be tied together in the event that excessive lateral movement is observed. - The extensive monitoring and supervision requirements will ensure that all movements will be monitored and action will be taken to reduce the probability of any failure to very low levels. For example if greater settlement than anticipated is observed (but no structural failure of the road has occurred) then action can be taken to locally re-strengthen the road. - The Derrybrien failure started just below the access road. The assessment of the failure indicated that it was caused, amongst other things by an excavator on the access road digging a wind turbine pad. The excavator was digging up hill and dumping downhill of the road. Also the water in the excavation was being pumped and discharge to the down hill side. No such excavations will be carried out in the proposed development. A minimum strength of 50kPa has been specified for the stabilised peat under the main access road. However the design uses a lower-value – thus incorporating a greater factor of safety into the design and reducing even further the probability of failure of the access roads.	Work to be stopped locally. Traffic restrictions. Additional strengthening beneath and adjacent to the road to be undertaken.

No.	Hazard	Cause	Potential Impact	Before Control P	Before Control I	Before Control R	Design Controls	Construction Controls	After Control P	After Control I	After Control R	Justification of Probabilities Chosen	Contingency Measures
	and commercial risk												
6	Not used (typo in original document)												
7	Failure of excavated surface in the Terminal platform area The terminal surface will be mineral soil. This hazard is considered to be a construction hazard and is a risk to programme and construction costs. There are no long-term risks to the operation of the terminal and there are no environmental hazard as all water from the terminal excavation surfaces are directed through the settlement ponds which are designed to reduce the sediment load of the drainage water.	Material too soft and too wet to be trafficked. Strength parameters of trafficking surface underestimated. Over trafficking of some areas.	Loss of access to areas of work, slowing down of progress in excavation, restricted access to areas within terminal footprint leading to congestion in some areas and an increased risk of danger to operatives	4	1	4	Design capping layer and geotextile to deal with very low CBR values. Use lime or cement stabilisation to improve strength of formation level.	Monitor condition of formation level, place temporary haul roads in areas of better ground. Ensure use of proper tracked plant with minimal use of 'wheeled' vehicles within the Terminal footprint. Ensure loading of vehicles is at or below the design maximum. Maintain effective surface drainage.	1	1	1	Failure of the terminal surface would only impact on the works being carried out within the terminal. - A very detailed SI has been carried out within the area of the terminal resulting in very close spacing of the exploratory holes. As a result the locations where soft ground exists under the peat and also the extent of this soft ground are considered to be well understood. This soft ground will be removed. Mineral soil stabilisation will be implemented for the 'marginal' ground – that is ground likely to deteriorate when trafficked. - Given the proposed method of peat extraction the exposed surface at any one time will be far greater than what is required for trafficking. A supervision/ monitoring programme will be implemented. If any area is seen to be deteriorating, new access routes can be prepared and used. Remedial action can be taken prior to the deterioration of surfaces causing a delay. - Given the extensive SI it is possible to avoid the known soft areas. Availability of space is not an issue on this site. - Access to 'soft' areas can be limited to only low ground pressure plant. Observation of the performance of this plant can be used to determine if access for heavier plant is advisable. - Road going vehicles, with axles and wheels place relatively high pressures on the ground. Some tracked vehicles place less pressure on the ground than the human foot. The HGVs used on site can be restricted to routes specifically designed to carry their heavier loads.	Carry out strengthening of surface either by lime/cement stabilisation or by placing an increased thickness of capping layer. Stop access to 'wheeled' plant. Improve and/or install additional drainage.
8	Failure of gabion walls This is both a construction and long-term risk. It is a hazard to the health and safety for the construction workers and the terminal personnel. It is a hazard for the programme and for costs. It poses no environmental hazard as all drainage from the terminal is directed through the settlement ponds.	Sliding along the base of the gabion, underestimation of imposed loads on gravity structure, underestimation of ground bearing pressures.	Movement of gabions on the upper slopes, danger to operatives working within the terminal platform below.	3	3	9	Use of conservative strength parameters in design, assumption of conservative groundwater levels and choice of conservative factors of safety. Clear specification of required formation level conditions for the gabion walls. Production of table of gabion wall configurations for variety of conditions likely to be encountered on site.	Detailed knowledge amongst the supervising personnel of the design requirements and sensitivity of design to the variable conditions likely to be encountered on site. Properly installed and propped temporary works that will allow proper excavation to formation level and allow for preparation of formation level to match design requirements. Monitor movements. Maintain effective drainage.	1	3	3	- Conservative design parameters have been used in the geotechnical design of the gabions and this is demonstrated below. - Zero shear strength parameters have been used for the retained peat which effectively treats the peat as a liquid. - Conservative friction values have been taken for the mineral soils under the gabion wall to resist sliding. Similar design approach adopted for overturning and bearing capacity checks. The design was carried out in accordance with BS 8002. - A stability analysis has been undertaken which examines the very unlikely event of the complete failure of the peat mineral soil interface to the north of the terminal. This models a bog slide to the north of the terminal and the gabion wall has been designed to resist these forces. See Section 4.6 of Appendix 2 of the Volume 1 of the EIS. - The extensive routine supervision and monitoring during construction, as detailed in the EIS, ensures that the construction works will comply with the design. See Section 3.9 of Appendix 2 of Volume 1 of the EIS.	Provision of 'bench' on down slope side of gabions to prevent sudden failure conditions. Carry out additional strengthening of ground behind the gabion wall. Increase width of gabion wall
9	Difficulties in excavation of rock Hazard is a construction hazard with risk to programme and costs. There is no environmental risk. Note these difficulties only relate to the extraction of the rock	Frequency of rock jointing overestimated and rock strength underestimated.	Delays to works, increased noise levels due to additional rock breaking requirements. Rock splitting techniques, required. (Blasting will not be used.)	4	1	4	Carry out extensive site investigation into the in-situ condition of the bedrock and determine the frequency and orientation of joints and rock strength. Design for conservative slopes within bedrock. Provide provisional design for the use of pre-splitting techniques.	Supervision staff to have detailed knowledge of design proposals and findings of site investigation work. Detailed monitoring to be carried out during construction works. Site staff to have appropriate skills in the proposed pre-splitting techniques proposed.	1	1	1	- The extensive SI, in particular rotary cored holes in the rock, has produced a large amount of high quality, reliable information on the structure, strength and weathering condition of the bedrock. - Borehole imaging, both optical and acoustic, has been undertaken in the north east of the terminal where the maximum depth of rock excavation will occur. - These images show that the rock is generally fractured in a manner that will facilitate its excavation. Excavation is expected to be a mixture of hard digging and hard ripping.	Carry out non-explosive pre-splitting of rock body using expansive grouts or similar.

No.	Hazard	Cause	Potential Impact	Before Control P	Before Control I	Before Control R	Design Controls	Construction Controls	After Control P	After Control I	After Control R	Justification of Probabilities Chosen	Contingency Measures
	– so difficulties mean the rock is better than expected.												
10	Failure of slopes excavated in rock Hazard is both a construction and long-term operational one with risk to the health and safety of the construction workers and terminal personnel. There is also a risk to the programme and costs. There is no environmental risk.	Frequency and orientation of joints underestimated and strength of rock overestimated	Delays to work, reduced slopes in rock surfaces.	3	3	9	Carry out extensive site investigation into the in-situ condition of the bedrock and determine the frequency and orientation of joints and rock strength. Design for conservative slopes within bedrock.	Supervision staff to have detailed knowledge of design proposals and findings of site investigation work. Detailed monitoring to be carried out during construction works. Removal of unstable blocks.	1	1	1	- The direction of the joints and fractures is generally favourable to the cut faces so the probability and impact of block failure is low. When the excavation works are underway the monitoring and supervision will detect any potential block slippages. Allowance has been made for rock bolting or removing any marginal areas. - 1 vertical to 1 horizontal cut slope face in the rock excavations is conservative, especially when the SI has shown that the orientation of the joints and fractures lies at a favourable angle to the cut faces. - Extensive site investigation work has given the designers a very comprehensive picture of the nature, strength and variability of the rock on site. As a result unanticipated variability will be local. - Excavation will be a gradual process and any locally variable rock will be quickly recognised. - Locally the slope can be made shallower if required. - There is a low probability of significant propagation of the failure back up the slope given the 1in 1 rock slopes and the 1 in 3 mineral soil slopes and the shoulders at the interface of the strata. See drawing C026.	Stop work locally and review rock face conditions. Carry out bolting of rock blocks to rock body. Netting to contain local spalling.
11	Failure of Dewatering Process This is only a construction hazard with risks to the programme and costs. Failure of the terminal surface would only impact on the works being carried out within the terminal. A local soft area can easily be dug out and replaced with rockfill and geotextile	Dewatering wells too widely spaced, pumps not adequately sized for conditions encountered	Delays to works, reduced access to the lower end of the site. Poorer ground conditions that allowed for in design.	3	3	9	Carry out detailed site investigation to measure permeabilities of the varying strata. Carry out dewatering trial to determine design of dewatering system.	Supervising staff fully briefed on the details of the dewatering system and the drawdown expected. Full monitoring of wells and observation points by experienced personnel.	1	1	1	- Dewatering pumping tests, constant rate tests and step down tests were carried out. The design of the dewatering system can be based on actual measured parameters. The use of measured design parameters ensures that the probability of failure of the dewatering system will be very low., - Design will be carried out in accordance with the appropriate standards. - In addition to the pumping tests there is a very comprehensive data set on the groundwater levels on site leading to a good understanding of the hydrogeological conditions of site. - Monitoring and supervision will ensure that the system is properly run and all appropriate actions are taken. - In the event that the drawdown of ground water levels is insufficient it will be possible to install additional pumping wells or to increase the capacity of the pumps serving the wells. - The impact of the failure of the dewatering system could lead to softening of the formation level. This can be compensated by the placement of stone and geotextile on the formation level. If the dewatering system does not function to the design level in advance of the installation of the southern perimeter drain it will be necessary for additional sump pumping to be installed to avoid ponding. The quantities of groundwater infiltration are expected to be quite small and manageable. Also a series of grips and stone fill dykes could be installed to direct the ground water to a sump for pumping.	Install additional wells at closer spacings and use additional pumping power.
12	Soil Strengthening – strength not achieved or deformation failure This hazard is mainly a construction hazard in that the majority of the stabilised peat functions as an access route for the construction plant. Roads are also formed by the stabilisation of the peat layer but the loads imposed on the roads during the construction process are far greater than the loads that will be	Overestimation of strength and deformation parameter during design. Installation procedures not adequate.	Delays to works.	3	3	9	Use of conservative design parameters for strength and deformation – to be determined from on site trials and also from experience worldwide within the industry. Restrict access to heavy traffic to allow conservative gains in strength.	Supervising staff to be fully briefed on strengthening method and rate of strength gain. Detailed monitoring to be carried out to check strength gain is in line with design requirements. Use reputable specialist contractor with proven track record	1	2	2	- As detailed in the response to Item 2 of the Board's letter extensive tests have been undertaken by the Swedish Geotechnical Institute (SGI) (lead institute worldwide on the stabilisation of soils) to confirm a) that the peat from the terminal site can be strengthened using binders and b)to determine the optimum mix for the binder. The mean strength values obtained in these tests are far greater than the values used in design. Strength values used in design are taken conservatively low. - Conservative values of 25kPa are used for the strength of the stabilised peat in the design (see Response to Item 2 of the Board's letter) - A further conservatism is added to the design and construction process in that the minimum (NOT mean) strength to be achieved on site is 40kPa whilst only 25kPa is used in design.	Re-do strengthening process. Increase binder content. Also consider the use of structural piles and surface load transfer platform to carry loads.

No.	Hazard	Cause	Potential Impact	Before Control P	Before Control I	Before Control R	Design Controls	Construction Controls	After Control P	After Control I	After Control R	Justification of Probabilities Chosen	Contingency Measures
	experienced during the operation of the terminal. The main risk is to programme and costs. There is also some small environmental hazard through the use of cement.												
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14	Ground strengthening - leaching of cement This is assessed as an environmental hazard during construction and also during the lifetime of the terminal.	Groundwater contamination	Contaminated groundwater entering local water courses	1	3	3	Pre construction laboratory and site trials to assess quality of groundwater leachate from strengthened peat	Sampling and testing of groundwater runoff.	1	3	3	- Industry norms and laboratory work show that cement leaching is a non-issue. The impact rating given is conservative. - Refer also to the response to Item 3 of the Board's letter.	Water quality monitoring in 'reference' wells and settlement ponds allows for possible containment and treatment of water before discharge to watercourses
15	Flooding This is the hazard of flooding occurring within the terminal site. It is a health and safety issue, an environmental risk, and a programme and cost risk too.	Extended periods of wet weather and under-design of drainage for the temporarily prevailing conditions	Cessation of work, deterioration of working surfaces.	3	3	9	Review rainfall historic patterns in the locality from Met Eireann. Use conservative design parameters for the design storm event. Show that the extreme rainfall event such as on September 19th 2003 in Pollatomish can be catered for.	All drains to be correctly installed on site and maintained in good working order. Supervising staff to be fully conversant with weather forecasts and appropriate pumping facilities to be put in place during the construction phase.	1	1	1	- The extreme rainfall event that gave rise to the Pollatomish landslide has been catered for in the design of the permanent drainage system. The relevant meteorological data was provided by Met Eireann. This was considered to represent a 1:700 year event. The drainage for the construction phase has been designed for a 1:100 year rainfall event. These are both very conservative designs and it is more typical to design the construction phase for a 1 in 5 year rainfall event. See also Item no. 18 below and Volume 3 of the Technical Appendices to the EIS. - Given the shape of the site water cannot pond on the site unless surrounding water levels are at or above the level of the terminal platform. All surrounding ground to the west and south slopes away from the platform so no mechanism exists by which the site can flood even if the drains fail. - Given the gently sloping convex nature of the site and the smooth,	Provision of additional pumping capacity on-site.

No.	Hazard	Cause	Potential Impact	Before Control P	Before Control I	Before Control R	Design Controls	Construction Controls	After Control P	After Control I	After Control R	Justification of Probabilities Chosen	Contingency Measures
												undulating surface, no mechanisms exist to concentrate water in the area of the development works. The D22 drain is the only area with a concave surface but this area and the catchment area for the D22 drain are not impacted by the proposed works. - Only the rain falling on the site can 'flood' the site as the site is located at the crest of three catchment areas and there is no surrounding land higher that the site. - Geotechnical design has been carried out assuming the ground water levels are at or very near the surface of the ground. So flooding will not introduce any significantly larger destabilising loads on slopes, sheet piles or gabions. - Currently the only known (anecdotally) area of the site subject to ponding is the southwest corner nearest to Bellanaboy bridge. This area would overflow to the Aghoos river before flooding would extend to the terminal area. .	
16	Ground failure around drainage pipe to the settlement ponds This is a construction hazard with risks to the health and safety of the construction personnel, to programme and to project costs.	Low strength within the ground local to the pipe. Support of trench inadequate during excavation.	Delay to works	4	2	8	Carry out detailed site investigation around the site investigation along pipe route. Use conservative design parameters for ground strength and deformation characteristics. Design robust temporary works structures. Require contractor to provide detailed construction method statement.	Supervision staff to be fully briefed on the ground conditions, design requirements and construction methodology. Strict supervision to ensure construction carried out as detailed in the method statement.	1	2	2	- Stabilisation of the ground is to be carried out along the route of the pipe to the settlement ponds for access. Sheet piles will be installed to retain the excavation sides. Excavated material will not be stored on the sides of the excavation and so cannot lead to over loading. Conservative strength parameters have been used in the design of the sheet piles and the design has been carried out in accordance with recognised codes of practice (Refer to Technical Appendix 2 of the Volume 1 of the EIS). - An extensive site investigation has been carried out along the line of the pipe route to the settlement ponds. There is comprehensive information on the ground conditions and their variability, the strength and deformation parameters of the various strata and their variability and finally on the ground water conditions along the route. Proper design , which has been undertaken by experienced geotechnical engineers based on this information ensures that the risk of failure due to incorrect design is very low. - Experienced construction personnel will be fully briefed on the design criteria and will ensure that excavated material is not stored adjacent to the excavation. They will ensure that the minimum penetration depths are achieved by the sheet piling and that over excavation does not occur. The works will be monitored to ensure that movements remain within predicted levels. If there are any concerns propping of the sheet piles can be used as a temporary measure.	Carry out additional strengthening of the peat. Install king posts if necessary to minimise embedment requirements of sheet piling.
17	Failure of settlement ponds – structurally Considered to be a construction and long-term hazard with risks to costs and programme. There are some risks to the health and safety of the construction workers.	Low strength in the ground local to the ponds. Support of sides inadequate during excavation.	Delay.	3	2	6	Carry out detailed site investigation around the area of the settlement ponds. Use conservative design parameters for ground strength and deformation characteristics. Design robust structures. Require contractor to provide detailed construction method statement.	Supervision staff to be fully briefed on the ground conditions, design requirements and construction methodology. Strict supervision to ensure construction carried out as detailed in the method statement. Monitoring of sheet pile movements during construction.	1	2	2	- Stabilisation of the ground is to be carried out around the settlement ponds. Sheet piles will be installed to retain the excavation sides. Excavated material will not be stored on the sides of the excavation and so cannot lead to over loading. Appropriate plant will be used to install the sheet piles and carryout the excavation of the ponds. Monitoring and supervision will detect any movement of sheet piles that is greater than predicted and immediate steps can be taken to determine why and what remedial action needs to be taken. Monitoring and supervision will also ensure that the design criteria are met and that over excavation or overloading of the retained ground does not occur. All construction personnel will be fully briefed on the design criteria, including minimum penetration depth for the sheet piles. - The design of the sheet piles has been conservative and in accordance with recognised codes of practice (BS 8002 and BS 5950). - An extensive site investigation has been carried out in the area of the settlement ponds so there is comprehensive information on the ground conditions and their variability, the strength and deformation parameters of the various strata and their variability and finally on the ground water conditions around the ponds. - The settlement ponds have been designed for all credible variations in the water levels from full to empty. Flooding will not lead to structural failure as it does not lead to structural loads in excess of design. - The impact of failure is not significant as the ponds would continue to exist, albeit with a reduced capacity, given the impermeability of the peat.	Extend strengthened zone around sheet piles. Use king posts to reduce the embedment requirement for the sheet piles.

No.	Hazard	Cause	Potential Impact	Before Control P	Before Control I	Before Control R	Design Controls	Construction Controls	After Control P	After Control I	After Control R	Justification of Probabilities Chosen	Contingency Measures
18	Failure of ponds – inadequate settlement in pond This is an environmental hazard, particularly during the earthworks phase of the construction project. Once earthmoving has been completed, it is expected that the sediment loading on the ponds will be much lower that what they are designed for.	Excess velocity of water flowing through the pond. Excess levels of sediment in the water discharged from the pond.	Excessive sediment in streams down hill of site and in Carrowmore Lake	4	3	12	Design ponds to proven Bord na Moná standards. Use conservative rainfall figures for the design storm event. Use conservative values for ground permeabilities within the terminal site.	Monitor pond to determine quality of water discharging to the D16. Clean out drains and add intermediate mini settling/stilling ponds.	1	3	3	The drainage system has been designed to deal with an extreme event similar to the Pollatomish event. If failure occurs, caused by a more extreme rainfall event, then the contribution of increased sediment load from the ponds to local watercourses is expected to be negligible as the whole area would be suffering from the same event, and high sediment loadings will arise from all the surrounding areas (forestry, fields, riverbanks etc), none of which have any sediment control measures installed See also Item 15 above. The settlement pond design is based on Bord Na Mona's Guidelines for settlement ponds. According to their guidelines, Bord na Mona designs their ponds to limit the suspended solids over the discharge weir to <30mg/l for the 1 in 5 year storm and to <100mg/l for the 1:100 year storm. The terminal site ponds have been designed to limit the suspended solids in the 1:100 year storm to 45mg/l which is much more onerous. If a 1in 100 year storm rainfall event is exceeded then the level of the suspended solids over the weir may exceed 45mg/l but will still not be close to the Bord na Mona suggested guideline of 100mg/l. In the 1 in 100 year storm event the water depth over the weir is 62mm. The ponds have a freeboard of 300mm and in a 1:700 year storm the water depth over the weir is approximately 1.5 times the 1:100 year storm – say 93mm. The likelihood of the ponds being overtopped is very low although they will be less efficient in settling out suspended solids. In the medium to long term there will be no exposed faces of peat , and sediment loading is not expected to be high beyond the construction phase of the project. The construction of the terminal enabling works is of limited duration – approximately 12 months. Therefore the likelihood of an extreme event exceeding the Pollatomish event is extremely low. There will be no impact to the site from the failure of the settlement ponds to settle the silt.	Add flocculation agent.
19	Material quantities This is considered to be a construction risk with impact on the programme and costs	Insufficient material for fill, large quantities of unsuitable materials.	Additional materials to be imported to and exported from site. Delay to schedule.	5	2	10	Carry out detailed site investigation. Obtain good understanding of strata make up and distribution on site. Allow for stabilising mineral soils.	Carefully excavate and store all materials on site. All excavation surfaces to be cut to slopes to facilitate run off of surface water. Works to be sequenced to minimise double handling of materials sensitive to moisture.	1	2	2	Extensive site investigation work has been undertaken to determine the ground conditions. 3 dimensional computer ground model has been build up using the 'In-Roads' programmeme to determine quantities of materials excavated and required for filling. 3D model has been subject to repeated QA checks on data entered. Hand calculations have also been carried out to verify 3D computer model. There is a surplus of U1 material on site that can be treated and used for general filling. Allowance has been made for the removal of the soft cohesive material that is unsuitable for treatment and use as a fill material. Laboratory trial show that with a cement binder the majority of the cohesive mineral soil can be successfully treated for use as fill material. In the event of extreme weather conditions steps can be taken, such as covering of stockpiled materials, to protect the soils from gaining excessive moisture contents.	Remove unsuitable material off-site and import additional suitable material.
20	Bog Slide This is considered to be a construction and long-term hazard with potential significant impacts on the safety of construction workers and the public.	Insufficient understanding of the mechanisms of failure, inadequate site investigation information from the site and inadequate design. Improper construction method, controls or sequence of construction. Inadequate drainage systems installed for the control of ground and surface water.	Movement of peat down slope, stoppage of works, loss of plant, danger to operatives and to the public.	3	5	15	Carry out detailed site investigation. Obtain good understanding of stability of site and possible mechanism that might trigger ground movement. Design conservatively to eliminate all mechanisms likely to trigger movement.	Provision and monitoring of instrumentation to record ground movement and groundwater pressures. Ensure strict control of all construction practices so that all works on site are within design conditions. Daily site inspection looking for evidence of movements.	1	5	5	Significant studies have been done on all available information on bog slides in Ireland and worldwide. The Derrybrien bog slide occurred as a result of failure associated with construction works. The lessons learned from Derrybrien has informed the proposed earthworks design. - Slope of the site is less than those historically subject to bog bursts (>6°) or bog slides (>3°). - Generally slides or bursts are initiated by accumulation of water. Terminal site is located at the crest of the catchment for both the Aghoos and Glenamoy rivers. No collecting or ponding of water can occur on the site except in the extreme south west where no works are proposed. This ponding has occurred to date in this area and has not resulted in any ground movement. - Considering the Pollatomish event it will be noted that the side slopes of the hills are of the order of 30° to 40°. The peat cover varied from 0.2m to 1.2m and in most failure zones lay directly on the weathered bedrock. The highly permeable root zone of the upper peat would be expected to be up to 0.5m-0.75m thick. It would be expected to readily dry out by a combination of simple evaporation and also by take up of water by plants. Flowering	Cease operations, remove material, provide additional drainage, provide toe weighting.

No.	Hazard	Cause	Potential Impact	Before Control			Design Controls	Construction Controls	After Control			Justification of Probabilities Chosen	Contingency Measures
				P	I	R			P	I	R		
												time – summer time- is the most demanding time for water in a plant's annual cycle. Given the dry summer of 2003 it is very plausible that drying cracks would have formed in the thin peat through to bedrock. Glacial till or other mineral soils were not present in any of the failure zones. On the Terminal site the peat is generally 2m (only less in very localised areas) and the greater thickness would ensure against drying cracks to underside of peat. Also the peat is everywhere underlain by glacial till on the Terminal site. Slope of site is 1-2°. - The slopes are uniform on the site with no sudden changes that would favour the creation of a weak zone where a slide of burst could initiate. - Examination of aerial photographs of the site show no sign of previous history of slides or bursts on the site. - Global stability calculations have been carried out to show that the site presently has a high degree of stability. - Global stability analyses have also been carried out on the valley itself to determine if any areas are prone to sliding. These analyses have shown general stability of the valley.	

Appendix 2

Managing Geotechnical Risk (Clayton)

MANAGING GEOTECHNICAL RISK

IMPROVING PRODUCTIVITY IN UK BUILDING AND CONSTRUCTION

Prepared under the DETR Partners in Technology programme

for The Institution of Civil Engineers, London

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CONTENTS

CD rom

The CD included in the back of this book contains a short video which is intended to set the scene. It is a tool for the professional to use to educate promoters, clients and principal policy makers by raising awareness of the major issues and assisting in the promotion and promulgation of the recommended best practice for managing geotechnical risk, to deliver building and construction work with maximum certainty and least cost resulting from ground related events.

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GLOSSARY

analysis	The process of breaking down a design into its constituent parts and of calculating the behaviour of each of those parts.
client	An organisation or individual using the services of construction professionals in order to invest in new building or construction work.
conceptual design	The identification of an appropriate design solution by qualitatively assessing the strengths and weaknesses of a range of possible design variants, without recourse to detailed analyses.
consequence (effect)	The result of an event occurring.
defence in depth	A 'belt and braces' approach to ensure that critical failure mechanisms cannot occur.
degree of risk	The combination of the likelihood or chance of an event and its consequences (normally numerically taken as likelihood x consequence).
desk study	An examination of all existing information concerning a site, such as geological maps, previous borehole records and air photographs, to determine ground conditions and previous land use.
effect (consequence)	The result of an event occurring.
engineering design	The use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform prespecified functions with the maximum economy and efficiency.
engineering judgement	A feel for the appropriateness of a solution, from the narrowest technical details to the broadest concepts of planning.
geotechnical adviser	A qualified and experienced geotechnical engineer or engineering geologist.
geotechnical risk	The risk posed to construction by the ground or groundwater conditions at a site.
ground investigation	The process by which geological, geotechnical and other relevant information is obtained for a building or construction site.
ground model	A conceptual model based on the geology and morphology of the site, and used to speculate on likely ground and groundwater conditions and their variability.
hazard	A thing or activity with a potential for consequences.
likelihood	The probability that an event will occur.
mitigation	The limitation of the undesirable effects of a particular event.

partnering	Two or more organisations working together to improve performance through agreed mutual objectives.
precedent practice	The use of successful existing design solutions as a basis for future designs.
project manager	The individual or organisation responsible for managing a project.
residual risk	The risk remaining after risk treatment.
risk analysis	The systematic use of information to identify sources of risk and to estimate the magnitude of each risk.
risk management	The overall application of policies, processes and practices dealing with risk.
risk modelling	Computation to estimate the effects of uncertainty.
risk rating	A classification of the degree of risk presented by a particular event.
risk register	The file where risk information is stored. The register usually contains a description of the risk, an assessment of its likelihood and consequence, response actions and owners.
site investigation	The process by which geological, geotechnical and other relevant information is obtained for a building or construction site.
source of risk (hazard)	A thing or activity with a potential for consequences.
systematic engineering design	A predefined staged approach to design, to ensure that The client's need is correctly identified, optimal solutions are found and creativity is maximised.
walkover survey	A visual survey of a construction site, carried out after the desk study, aimed at collecting further information on ground conditions and land use.

CHAPTER 1

INTRODUCTION

WHY READ THIS BOOK?

Building and construction case records show that ground conditions are often the cause of very large cost and time overruns. Geotechnical risk can affect all those involved in construction, including the client, the designers and the constructors. This book explains why such risks occur. It provides best practice guidance on how geotechnical risks can be managed to deliver building and construction work with maximum certainty.

The government's Construction Task Force[1] has identified the five key drivers of change that it believes are needed to set the agenda for construction in general:

> '...the task force wishes to emphasise that we are not inviting UK construction to look at what it does already and do it better: we are asking the industry and government to join with major clients to do it entirely differently ...'
>
> 'We have identified five key drivers of change which need to set the agenda for the construction industry at large: committed leadership, a focus on the customer, integrated processes and teams, a quality driven agenda and commitment to people'.
>
> (*Rethinking Construction*, 1999[1])

These key drivers are as relevant to geotechnical risk management as to other parts of the construction process.

WHAT IS GEOTECHNICAL RISK?

Geotechnical risk is the risk to building and construction work created by the site ground conditions. Ground-related problems can adversely affect project cost, completion times, profitability, health and safety, quality and fitness for purpose, and can also lead to environmental damage.

Risk, in common parlance, can be taken to mean either

- the chance or possibility of danger, loss, injury or other adverse consequences,

or

- a person or thing causing a risk.

There are many definitions of construction risk. One of the simplest is as follows. Risk is an adverse event having a probability of occurrence and an impact that will affect the achievement of the project's objectives. Other technical definitions, taken from the ISO

Source of risk (hazard)	A thing or activity with a potential for consequences.
Risk	The combination of the chance of an event and its consequences.
Consequence	The result of an event.
Risk analysis	The systematic use of information to identify sources of risk and to estimate the risk.
Risk register	The file where risk information is stored. The register usually contains a description of the risk, an assessment of its likelihood and consequence, response actions and owners.
Risk management	The overall application of policies, processes and practices dealing with risk.
Mitigation	The limitation of the undesirable effects of a particular event.
Residual risk	The risk remaining after risk treatment.

(Based on the definitions of the ISO/TMB Working Group on Risk Management Terminology[2])

Box 1 Risk terminology

(International Organisation for Standardisation) Technical Management Board Working Group on Risk Management Terminology,[2] are shown in Box 1.

Risk results from the combination of:

- *hazard* – something with the potential to do harm, such as a substance (e.g. soft ground, arsenic in contaminated land), a geometry (e.g. a slope, a cavity) or a person (e.g. an incompetent engineer);

and

- *vulnerability* – those factors which determine the likelihood that a hazard will have unfavourable consequences (e.g. for workers, a programme of work, the quality of particular parts of what is to be built).

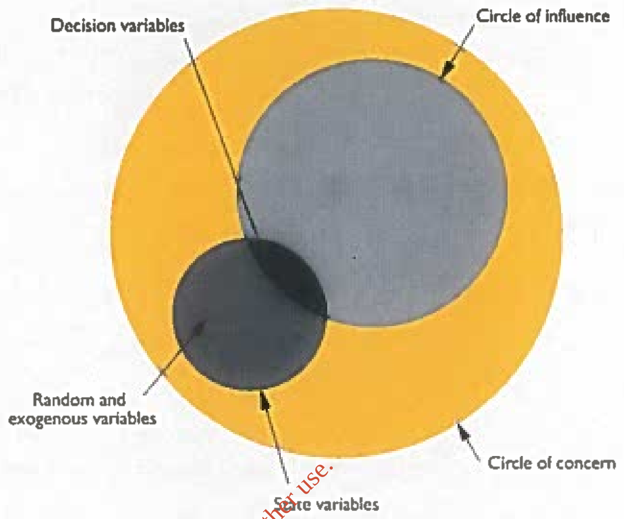
For example, common ground-related risks include:

- the possibility that building foundations may fail due to the unexpected presence of soft spots in the ground
- the possibility that concrete placed in the ground may be attacked by acid or sulphates in the groundwater
- the possibility that a highway cutting slope may fail when the road is in use, due to an unexpectedly high water table
- the possibility that a dewatering scheme for a deep building excavation may be ineffective, for example due to unexpected sand or gravel layers in the soil
- the possibility that the time taken to complete a contract may be increased due to unexpected difficulties in completing the groundwork.

There are many different types of hazard in the ground, and the consequences of failing to manage the risks they produce are often severe. In financial terms, minor design decisions can easily add 5% to the cost of construction, and figures as high as 30–50% are not unheard of.[3] If unforeseen ground conditions are encountered during construction, then additional costs as high as 100% of the entire project price may be incurred.[4] Given the normal level of profit margins in UK business, it is imperative both for clients and constructors that such cost overruns are avoided. Health and safety consequences can also be very large, in terms of both human and financial cost.

So why are ground-related risks to construction so large, and why do things go wrong? Primarily it is because of the special nature of the ground:

- **The properties and distribution of the ground and groundwater beneath a building or construction site are predetermined, and therefore (unlike other materials in construction, such as concrete and steel) are largely outside of our control (Box 2).**



In the drawing the circle of concern represents all those ground-related matters that might affect construction. State variables are the things that control what happens within the circle of concern. Only those factors within the circle of influence can be controlled. When dealing with the ground, many state variables (e.g. the geometry and properties of the ground) are outside our control, and are fixed. The only scope for control is through the remaining decision variables.

Box 2 State variables and decision variables

- Ground and groundwater conditions can be highly variable, from place to place, and with depth (for an example see Figure 1). This is in sharp contrast with other construction materials, such as steel and concrete, which are man-made, to predetermined specifications. Unexpected ground conditions are common.

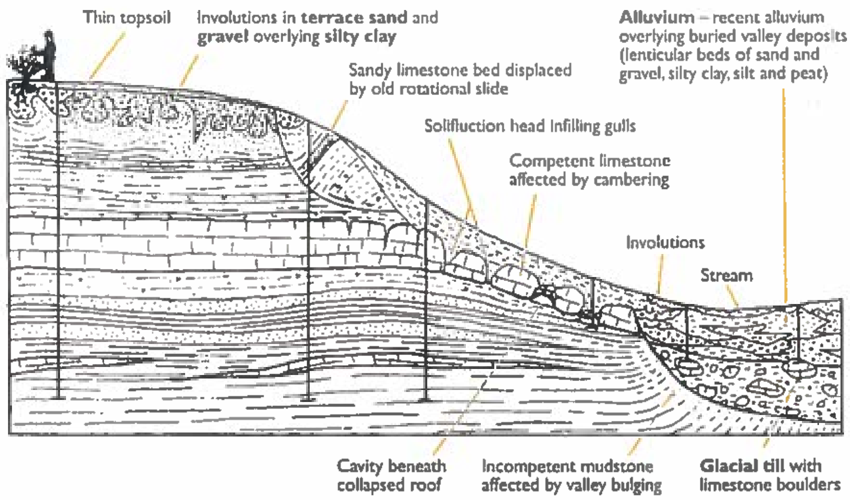


Figure 1 An example of ground variability (from Fookes, 1997[5])

- Although the underpinning engineering sciences (soil and rock mechanics) are now well developed, the accuracy of many ground-related design calculations remains very poor. Two examples of the poor accuracy of geotechnical calculations are shown in Figure 2.

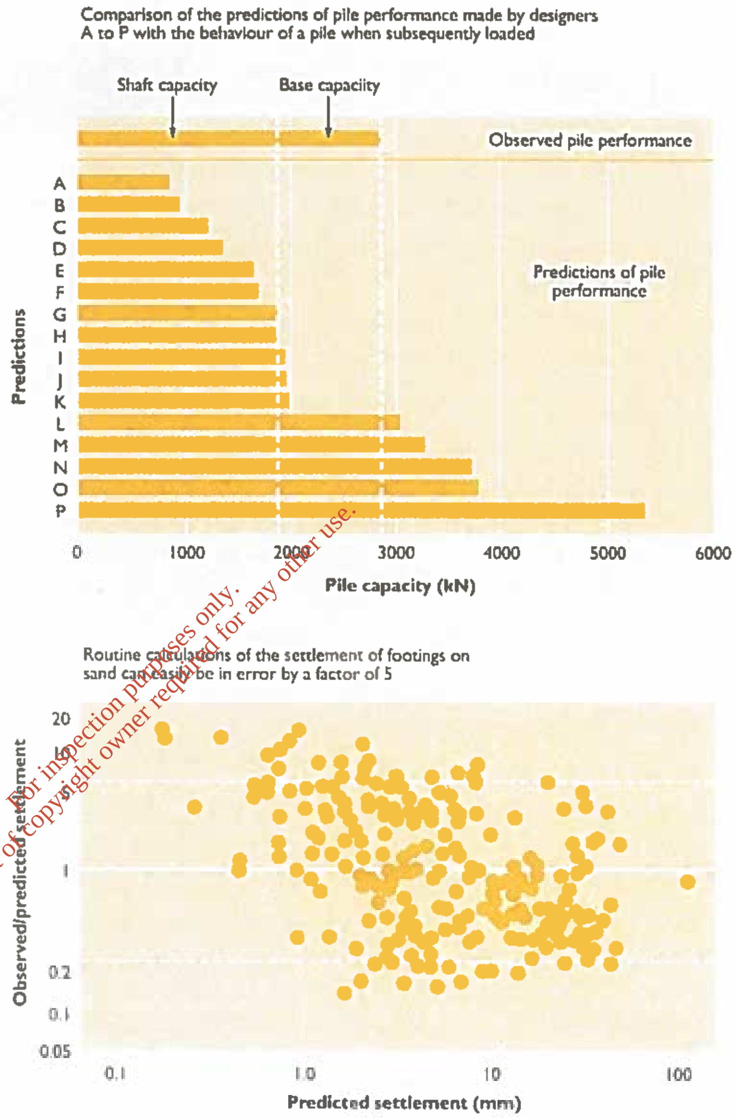


Figure 2 Examples of the inaccuracy of geotechnical engineering calculations (Wheeler, 1999;[4] Clayton et al., 1988[7])

- There are numerous ways in which the ground can cause problems for construction; for example, due to chemical attack on concrete, groundwater flow into excavations, slope failure, and excessive foundation settlement. The results of a recent survey illustrate the broad range of geotechnical problems to be managed (Figure 3).
- Ground behaviour will affect different methods of construction in different ways.
- Construction in the ground is normally carried out early in a project. Problems at this stage will delay and affect the later stages of construction.

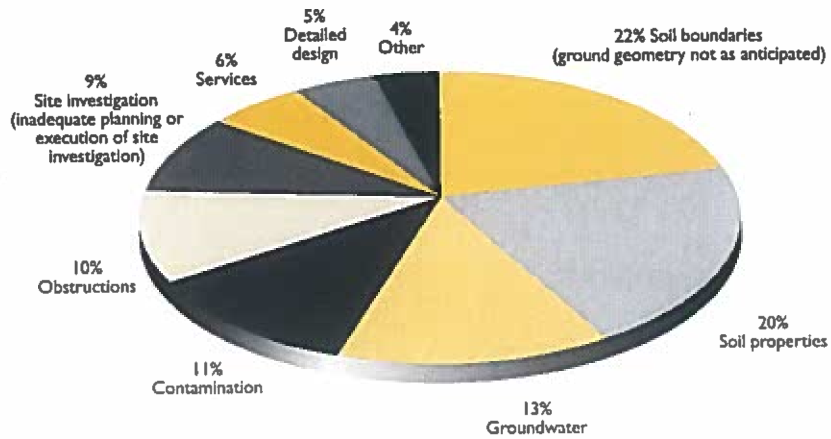


Figure 3 Types of ground-related problems encountered during construction

Geotechnical risks have three components or impacts: technical, contractual and project management. Technical risks arise from the particular problems on the site, such as soft ground or contaminated land. The type of contract that the employer adopts determines the contract risks. Project management risks are determined by the way the manager or his advisers elect to manage the project.

There are many forms of construction risks besides 'geotechnical risk'. Construction management should attempt to integrate its approach to risk so that all construction risks are brought together under a total risk management system.

WHAT ARE THE IMPLICATIONS?

The implications of these factors are as follows:

There will normally be some uncertainty during design and construction

- Since the ground conditions beneath a site cannot normally be changed, either
  - problem areas within the site must be avoided, or
  - appropriate forms and methods of construction must be identified during design that can provide safe, economical and environmentally sound construction.
- It is rarely possible, however much expertise, time and money is used, to obtain either
  - a complete picture of the ground conditions beneath a site, or
  - the precise properties of the ground from place to place, and therefore there will normally be some uncertainty during design and construction.
- Predictions of behaviour made during design can be expected to be approximate, at best.
- It is relatively easy for an inexperienced designer, perhaps using routine procedures, to fail to recognise a critical mechanism of damage or failure which may threaten either the financial viability or the health and safety aspects of a project. Ground–structure interaction is an example of a technically difficult area which can easily be overlooked.
- Ground-related problems may (and often do) have a disproportionate effect on the cost and progress of a project, since problems occurring at an early stage of construction will often lead not only to the additional costs of putting things right, but also to irrecoverable delays, which are themselves costly.

- Potentially, there are great benefits to be obtained from the effective management of geotechnical risk. A risk management system is needed to ensure that all geotechnical risks are
  - identified,
  - analysed and
  - controlled.

HOW TO READ THIS BOOK

The book is divided into five parts. Chapters 1 and 3 are intended for the general reader. The key processes involved in managing geotechnical risk are described in this book and are shown schematically in Chapter 2, immediately after this Introduction. The reader should note that, although the various components of risk management are assigned to 'client or project manager', 'designer', 'geotechnical adviser' and 'constructors', no specific procurement approach is implied. For example, the designers for a project might be employed by a client, by a general civil engineering consultant, by a constructor or the constructor's subcontractors, or more probably by a number of these organisations.

Chapter 4 explains how the client can help control and eliminate geotechnical risk. Chapter 5 examines the designer's role, and Chapter 6 demonstrates the constructor's role. Each part starts with a key point summary.

It is assumed that the reader has some experience and knowledge of engineering, of building and construction and of risk management. Further information and advice on general construction risk management can be obtained from the recently published Construction Industry Research and Information Association (CIRIA) guide,[8] and the RAMP[9] and PRAM[10] reports. Software to support the production of construction risk registers should shortly become available.[11,12]

BASIS OF GUIDANCE

This document provides best practice guidance based on the experience of some of the UK's leading building and construction client, designer and contractor organisations. As part of this research project, carried out by The Institution of Civil Engineers under the Department of Transport, Environment and the Regions (DETR) Partners in Technology programme, a number of studies were carried out:

- Case studies of geotechnical aspects of building and construction were collected, a selection of extracts from which are included in summary form, and an interim report produced.
- A review of available risk software was carried out, and an interim report produced (see Appendix B).
- A series of seminars were held across the UK, at the Institution's local associations or geotechnical groups, and also in conjunction with English Partnerships, the Association of British Insurers and the Chartered Institute of Building.

A Steering Group representing some of the UK's major client, design and construction organisations guided the project.

We expect that the advice given can be improved upon and enhanced by application and the use of feedback to ensure continuous improvement. Although the report does not specifically cover the operation and decommissioning of buildings and construction, the Steering Group recognised that for many owners these are key issues. It is believed that, with some modification, the principles proposed can also be applied to these phases of project life.

CHAPTER 2

THE KEY PROCESSES

The key processes involved in managing geotechnical risk, which are described in this book, are shown schematically in Figure 4. The numbers in parentheses in the subheadings in Chapters 4 to 6 refer to the numbers in the figure

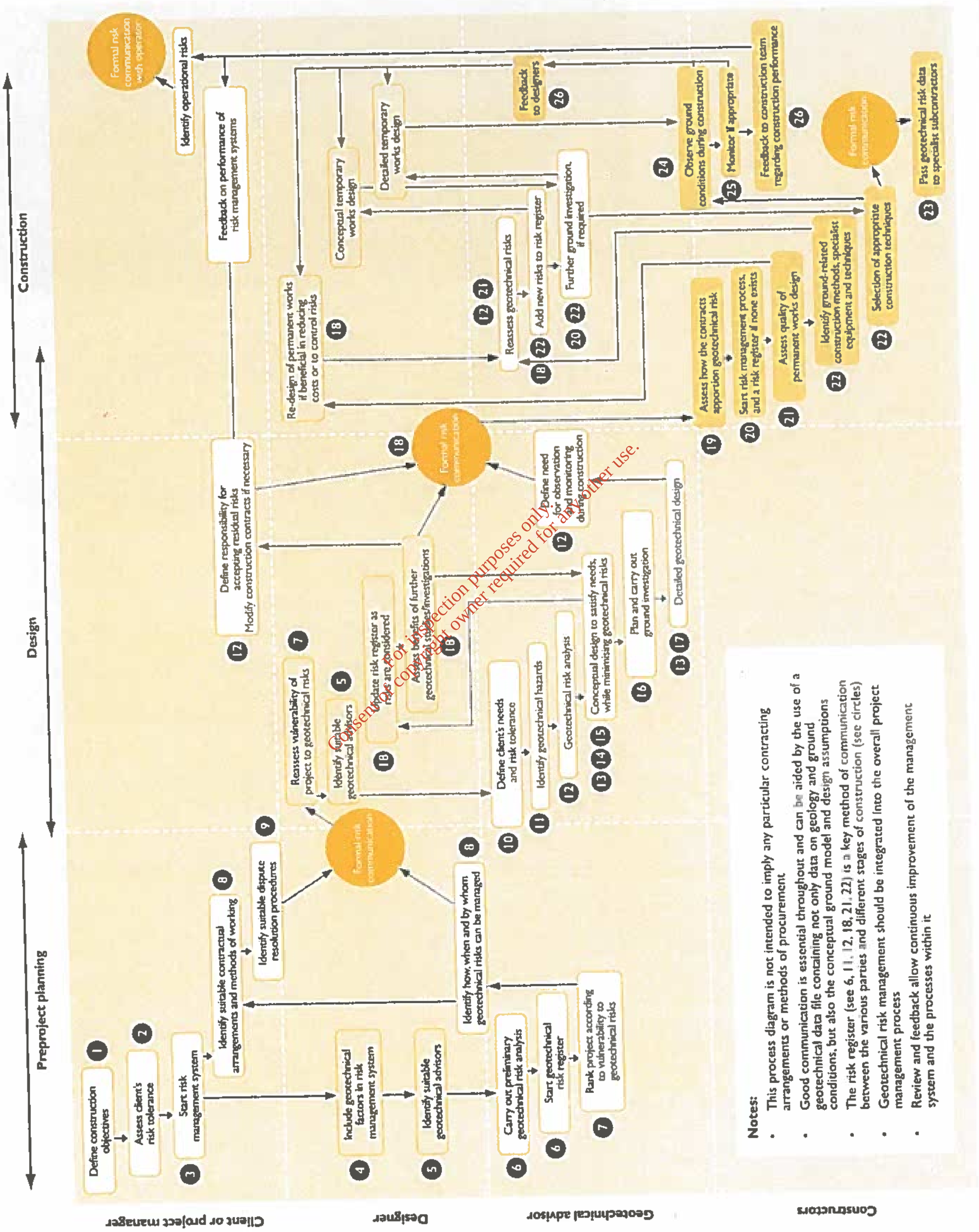
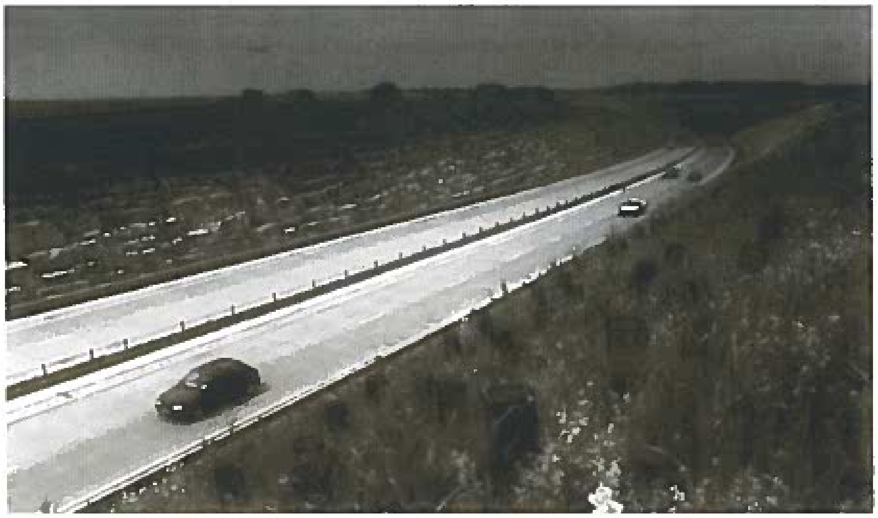


Figure 4 The key processes in managing geotechnical risk



CHAPTER 3

THE ESSENTIAL PRINCIPLES

KEY SUMMARY POINTS

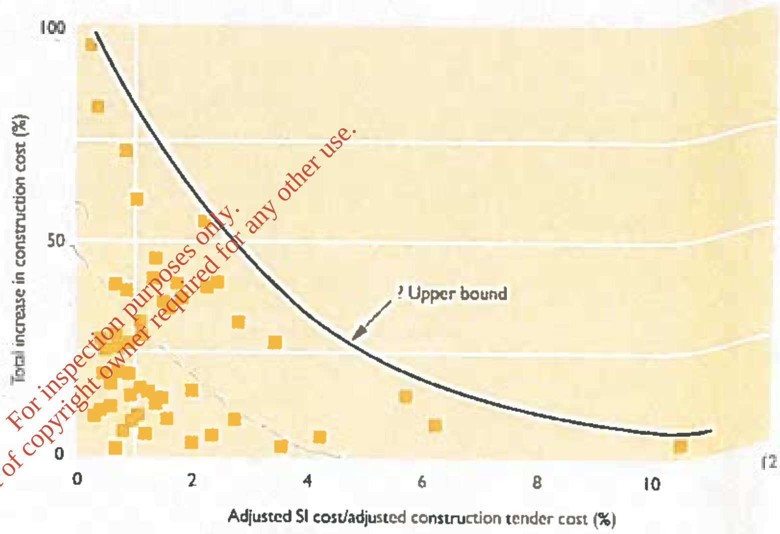
- Ground-related factors are already a common cause of delay and cost increase in building and construction.
- Changing methods of procurement in the industry mean that ground-related risks are likely to become even more significant in the future, unless effective geotechnical risk management is used.
- Systematic risk management techniques, already available and in use for controlling health and safety, financial and environmental risk, can also be used as a basis for controlling geotechnical risk.
- Geotechnical risk management is most effective when started as early as possible in a project.
- Early structured expert identification and analysis of geotechnical hazards and risks provides a fast and cost-effective start to geotechnical risk management.
- Effective design offers one of the best ways of minimising geotechnical risk.
- Conditions of contract and longer term relationships between those carrying out construction (such as partnering and term contracts) have important implications for the way in which geotechnical risks are shared and the effects of unforeseen ground conditions dealt with.

INTRODUCTION

It is essential to put in place a risk management system to reduce or avoid problems and to exploit any opportunities for improvement that may arise

Ground-related factors are a common cause of lengthy delays and large increases in building and construction costs. It is essential to put in place a risk management system to reduce and, if possible, avoid these problems and to exploit any opportunities for improvement that may arise.

In the past, it was assumed that, with enough skill, care and resource devoted to the ground investigation and geotechnical design, ground conditions could be completely discovered and designed for, and unforeseen delays and cost overruns eliminated. Unfortunately, the work was often poorly managed, leading to major geotechnical difficulties. Even when well managed, using the best skills and techniques available, past events have amply demonstrated that for many types of project (such as highway construction and tunnelling) the ground still represented a significant risk[4] (Box 3).



Less than 1% of the total construction tender price is typically spent on site investigation, and the data show that cost overruns of up to 100% are then possible, even when high levels of skill are used, such as on the highway projects which provided the data for this study.

Evidence from the past shows that construction cost overruns are significantly reduced as expenditure on site investigation is increased. But expenditure would have to reach an unrealistic 7% or 8% of total construction costs to bring additional costs down to less than 10% of tender price.

Box 3 Cost overruns as a function of expenditure on site investigation for UK highway projects (Mott MacDonald and Soil Mechanics Ltd, 1994[4])

CHANGING WORK PRACTICES

Methods of procurement are changing in the industry. Traditional arrangements involving a single consultant, who designed and supervised all aspects of the work, including geotechnical design and the associated site investigation, are being used less frequently (Figure 5). Current, more competitive and time-restricted conditions have led to the use of a whole range of new types of contract, creating new challenges for construction managers, designers and constructors.

To provide more certainty of outcome in an increasingly fast-track and fragmented construction environment, the following are required:

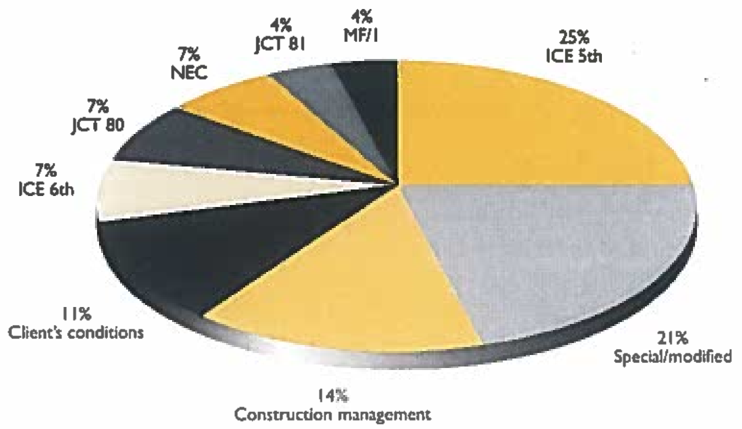


Figure 5 Conditions of contract in use in UK construction

- good communication
- a team approach to problem-solving
- an integrated total project process
- a risk-based approach to construction management and design.

Ground-related risks must be managed systematically if significant problems are to be avoided. Fortunately, there is now a growing body of experience of risk management in construction generally,[11–13] and in dealing, for example, with health and safety,[14–18] finance[19–23] and environmental risk,[24,25] on which to base systematic geotechnical risk management.

SYSTEMATIC RISK MANAGEMENT

Systematic risk management recognises that building and construction work always involves uncertainties

Systematic risk management recognises that building and construction work will always involve uncertainties. It introduces procedures to ensure that the risks to the successful completion of the project are systematically reduced to acceptable levels. As already noted, ground-related risks are substantial, and can affect many facets of construction (Figure 6). Therefore any risk management system for building and construction should certainly contain elements aimed at managing geotechnical risk. An example of a risk management system (from the Health and Safety Executive) is shown schematically in Figure 7.

Figure 6 Ground-related risks can affect many other facets of construction

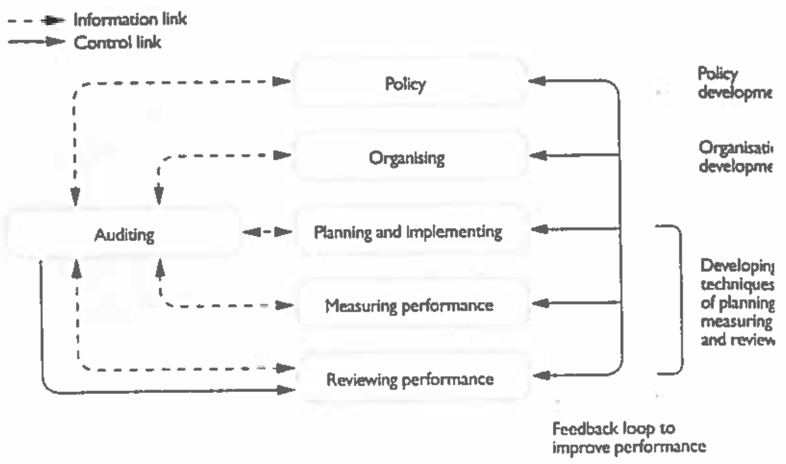


Figure 7 The key elements of a successful risk management system (HSE, 1997,[24] 1998

The decision to establish a risk management system must be taken at a high level, the directors and managers of the organisations concerned. The key steps are to:

- formulate policy and provide a written statement to inform staff
- organise and motivate colleagues and provide them with the necessary skills carry out the work competently
- ensure that planning, procedures and measurable targets are set for risk redu
- require measurement of the performance of the risk management procedure investigation when things go wrong
- introduce audit and review, in order to learn from experience.

GEOTECHNICAL RISK MANAGEMENT

When to start

Geotechnical risk management is most effective when it is started during pre-project planning

Geotechnical risk management is most effective, in terms both of reducing risks ar identifying opportunities, when it is started during pre-project planning. For buildir projects this means before the purchase of land for development. The pre-project planning phase extends from the point at which a business opportunity (involving construction) is first identified, through the planning phase to the end of conceptu design. It is the phase of construction where the client is typically most involved, a where the project objectives are defined, financial planning carried out and necess resources identified.

Management of other risks (financial, health and safety, and environmental) is typic started at this stage, and geotechnical risk management should be woven into exis systems where possible. Important parts of the risk management process are best carried out during pre-project planning:

- the risk management process is started
- the client's risk tolerance is assessed
- a first assessment of geotechnical hazards and their possible associated risks made

- the stages at which risks can be controlled, and will be re-evaluated, are identified
- the techniques to be used for risk management are defined
- the responsibility for risk management during the various phases of the project is defined.

Geotechnical risk management is good business practice; it offers the chance to reduce uncertainties, and in some cases to reduce costs and construction time.

The first steps in risk management require the client to invest up front

The first steps in managing geotechnical risk are to:

- identify the geotechnical hazards that might be present on the proposed construction site, and
- assess the vulnerability of possible types of construction to the geotechnical risks arising from those hazards.

This requires clients to invest up front, taking action very early during pre-project planning.

Hazard and risk identification

Geotechnical hazard identification is a fast and cost-effective process that uses a combination of existing information, experience and expert opinion to identify the unfavourable conditions that might be possible on site. The stages are (Figure 8 and Box 4) to:

- identify a geotechnical adviser (or, in the case of large projects, a team of specialists) to supervise the work and make recommendations based on the results
- carry out a thorough search for existing information on the site (related, for example, to its location and surroundings, history, geology, current use, groundwater conditions)
- bring the information together and estimate the most likely ground conditions, and how far actual ground conditions could conceivably vary from these
- identify all hazards that might possibly occur and the risks posed to any foreseeable types of construction
- collate the information in the form of a geotechnical risk register
- provide a report to communicate the information obtained to the client, to future designers and to constructors.

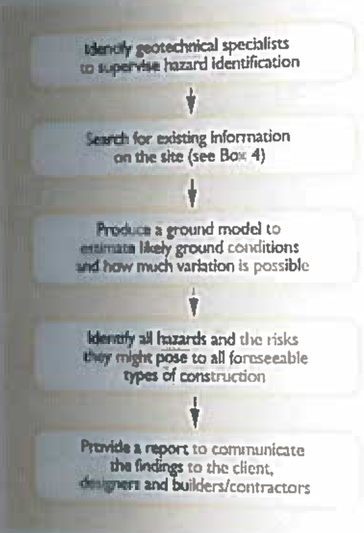


Figure 8 Geotechnical hazard identification

- Topographic maps (current and out-of-print)
- Air photographs (current and out-of-print)
- Geological maps and records
- Soil survey maps and records
- Previous site investigation reports
- Geotechnical books and journal papers
- Records for existing construction
- Geological books and journal papers
- Well records
- Mining records
- Archaeological society records

Box 4 Sources of information on site conditions

On the basis of geotechnical hazard identification it will be possible to assess the level of vulnerability of the proposed project to geotechnical risk. Projects that have the following characteristics are likely to be particularly risky from a geotechnical point of view:[28]

- where ground-related or underground work represents a high proportion of the overall project completion cost (e.g. roads, railways, tunnels, deep basements, docks and harbours, dams and hydro schemes)
- where highly complex, difficult to describe, or very poor ground conditions exist
- where there is a complex or highly risky boundary with, or close to, third parties and neighbouring structures, or where there are demanding requirements with

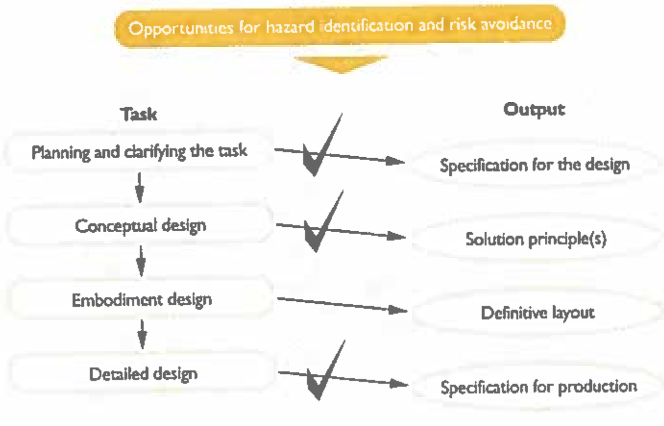


Figure 9 Stages in systematic engineering design (Pahl and Beitz, 1996[29])

regard to permissible ground movements (e.g. deep basements at inner-city sites, silo storage complexes)

- where it is likely that contractors without experience of the local ground conditions may be used, either because the project is large or because it requires highly specialised techniques.

It is essential that such projects should have a formal geotechnical risk management system, and the process of risk management should extend at least from project conception through to commissioning. While geotechnical hazard identification requires only short-term specialist geological and geotechnical advice, in cases where a high level of risk is perceived (e.g. if it is possible that existing slopes on the site might be unstable) a geotechnical expert, or in the case of large projects, a panel of experts, should be engaged for the duration of the project. This should help to ensure a thorough and continuous geotechnical risk management process.

The importance of effective design

Effective design offers one of the best ways of minimising geotechnical risk. For design to be effective it should:

- be systematic, so that key stages are not missed out (Figure 9)
- correctly determine the essential project requirements
- use conceptual design as a means of identifying project definitions and methods of construction that are least at risk from ground conditions that might be present on site, and provide the optimum solution to the design need
- use analytical techniques that recognise that ground conditions are uncertain
- check the design by comparison with current or precedent practice in similar ground conditions.

Design is becoming increasingly fragmented, as specialist consultants and contractors are used, and as new forms of construction management are introduced. Design is a continuous process, requiring regular review to ensure that the client's needs are being met. It is important that arrangements are made to ensure that information on ground conditions is communicated to all those involved in the project. Reassessment of the design should be carried out throughout construction and, where necessary, the operation and decommissioning phases of a project. Good communication between client, designers and constructors, and a team approach to risk management are essential.

PROCUREMENT AND GEOTECHNICAL RISK MANAGEMENT

Procurement methods have important implications for geotechnical risk management. Experience suggests that under fully designed, schedule of rates, re-measured types of contract (e.g. the traditional Institution of Civil Engineers Conditions of Contracts) it is the client that bears most of the geotechnical risk, which is typically expressed as 'unforeseen ground conditions'. While some major clients (e.g. property developers) prefer to take the geotechnical risk themselves, particularly where they are involved in numerous repetitive building projects which are generally unlikely to be particularly sensitive to ground conditions, many others no longer find this acceptable, and increasingly use forms of contract (e.g. lump sum, fixed price design and build contracts) that place ground-related risk with their construction professionals and companies (Figure 10). Whatever the method of procurement and the form of contract, geotechnical risks will be best managed when geotechnical engineers representing all the parties concerned are brought together as early as possible in the project.

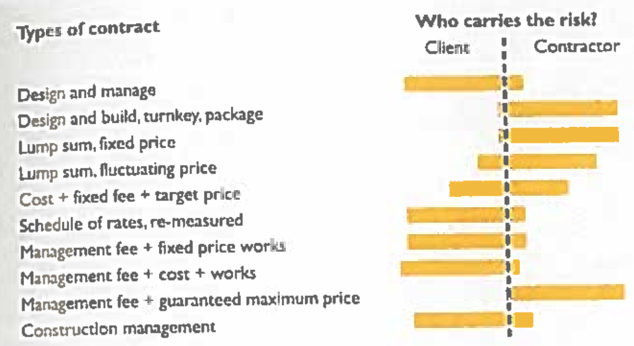


Figure 10 Who carries the risk (Flanagan and Norman, 1993[30])?

Conventionally, disputes concerning geotechnical matters have been settled either by litigation or by arbitration. There is evidence that neither these methods, nor those involving adjudication, mediation or expert determination, are regarded as particularly satisfactory.[32] Negotiation is perceived to be the best method of dispute resolution, but because of the particular nature of geotechnical claims it is better to avoid disputes if possible. Using agreed model ground conditions (in the form either of an agreed model conditions report or a geotechnical design summary report) can provide a sound basis for negotiation when separate contracts are used for design and for construction.[32] The joint appointment by all parties to a contract of a Disputes Review Board or a Geotechnical Advisory Panel to advise independently on the technical merits of disputes may also help to speed up dispute resolution, thus saving considerable time and money.[32]

Partnering and term contracting are also finding favour with major client bodies, which are also increasingly restricting their tender lists in order to make their supply chain management more effective. Such arrangements make rapid and effective dispute resolution more likely in the event that unforeseen problems occur, since construction companies are likely to take a longer term business view. However, these arrangements

> 'Partnering involves two or more organisations working together to improve performance through agreeing mutual objectives, devising ways for resolving any disputes and committing themselves to continuous improvement, measuring progress and sharing the gains'.
>
> **(Construction Task Force, 1998[1])**

do not offer totally effective geotechnical risk control, since clients may pay an unreasonably high price for asking construction companies to take on unquantifiable or uncontrollable risks.

The principles and methods described in this book are intended, however, to be useful to all those involved in construction, and to apply whatever the procurement framework.

ROLES AND ORGANISATIONS

The processes of building and construction involve a number of roles:

- the client
- the project manager
- the designer
- the constructor.

There is no longer, however, a clear and unambiguous relationship between these roles and the work carried out by each organisation involved in construction. For example, a civil engineering contractor undertaking a DBFO (design, build, finance, operate) contract might reasonably consider himself to be the client for the work. He would typically undertake at least part of the design, and have other elements of design completed by design consultants, and by specialist subcontractors or subconsultants. Many clients employ a project manager, to ensure that key systems are put in place, and larger clients may employ design specialists who, at least in the early stages of design development, will carry out particular elements of the preliminary design.

In Chapters 4 to 6 we identify roles for *clients*, *designers* and *constructors*. These terms are not intended to be synonymous with the terms *employer*, *engineer* and *contractor*, or any other terms used in construction contracts. To a subcontractor the main contractor is a client. A designer may be employed by the client, by a main works contractor, by a specialist contractor, by a civil or structural engineering consulting practice, or by an architectural practice. The project manager's function may be fulfilled by the client, the designer or the constructor. This should be borne in mind when reading the following chapters of this book.

CHAPTER 4

THE CLIENT'S ROLE

KEY SUMMARY POINTS

Early geotechnical advice enables identification of any potential significant effects of ground conditions

- Clients should be clear about their fundamental construction objectives, if additional costs and delays are to be minimised.
- Since construction can often be a risky business, clients or their project managers need to establish the client's risk tolerance at the start of a project.
- Clients should take an active role to ensure that key elements of management (such as risk management) are put in place early during pre-project planning.
- Geotechnical risks can be substantial, and should be managed alongside the other risks inherent in building and construction works.
- Early investment in good geotechnical advice will allow the identification of projects that could be significantly affected by ground conditions.
- The geotechnical risk management process, including the creation of a geotechnical risk register, should be started as early as possible during a project.
- Methods of managing geotechnical risks should be identified during pre-project planning.
- The vulnerability of each project to geotechnical risks should be assessed, so that high-risk projects can be given special consideration.
- The impacts of the contract between the client and the constructor on the distribution of risk should be considered, as should the possible beneficial effects of term contracting and partnering.

INTRODUCTION

Clients will seek value for money, but equally importantly need certainty of outcome for their projects, in terms of:

- **time taken for construction**
- **cost and, increasingly, whole-life cost**
- **quality (Box 5).**

Construction can be a risky business for many reasons, but not least because construction delays and additional costs can destroy the profitability of a new project. Therefore, increasingly, experienced clients are taking an active role in new construction in order to make sure that key elements of management are put in place. This chapter describes some of the actions that a client can take to ensure that geotechnical risks are minimised.

- Clients want greater value from their buildings by achieving a clearer focus on meeting functional business needs.
- Clients' immediate priorities are to reduce capital costs and improve the quality of new buildings.
- Clients believe that a longer term, more important issue is reducing running costs and improving the standard of existing buildings.
- Clients believe that significant value improvement and cost reduction can be gained by the integration of design and construction.

(Construction Task Force, 1998[1])

Box 5 Clients' needs

FIRST STEPS IN GEOTECHNICAL RISK MANAGEMENT

Construction clients should take steps to ensure that, as early as possible, they or their project managers

- are sure of their requirements and the uncertainty they are prepared to accept
- start the risk management process
- obtain expert geotechnical advice, to assess the project's exposure to ground-related risk
- identify sites and projects that are particularly vulnerable to geotechnical risk, where special care may be necessary
- identify how, when and by whom risks will be managed
- use conditions of contract that reflect a distribution of risk that is acceptable while providing best value
- ensure that effective dispute resolution procedures are put in place, before construction commences.

Clients should recognise projects, such as tunnels, embankments and dams, that bring with them longer term geotechnical risks that may add significantly to the whole-life cost.

ESTABLISHING THE CLIENT'S REQUIREMENTS (1)

Changes in a client's requirements (particularly when notified late in the building or construction process) are undesirable, and should be avoided where possible. They can lead to delays whilst re-design is carried out, and additional costs due to the disruption of construction. They increase the risk of disruption due to ground-related factors, because the time available to identify risks associated with the changes may be short and the options for managing them will thus be considerably reduced.

Successful design requires that a set of design objectives is developed before conceptual and detailed design are started. Good designs result from careful definitions of need, expressed in the simplest and most general terms. In a geotechnical context, this gives the designer the maximum flexibility in seeking the most robust and cost-effective methods of avoiding and managing geotechnical risks. But, in addition, a major cause of additional expenditure and of delays during building and construction results from clients' decisions to vary their requirements, thus requiring re-design and re-specification, and causing disruption to the programme.

ASSESSING THE CLIENT'S RISK TOLERANCE (2)

The risk tolerance of the client will affect the way in which risks are managed on any given project. For example, large clients involved in many repetitive medium-sized projects may be prepared to tolerate a much higher cost or time overrun on an individual project than will a small client involved in only an occasional investment in construction. The large client may develop internal company strategies to manage the risk, while the small or occasional client is likely to have to take much greater care to identify, manage and, where possible, lay off risks (particularly geotechnical risks) on a project-by-project basis.

STARTING THE RISK MANAGEMENT PROCESS (3)

The client (or his project manager) should ensure that a risk management system, covering all the types of risk inherent in the project, is put in place during pre-project planning.

For both technical and health and safety risks, record keeping and communication are important. A risk register needs to be started and passed on to all other organisations involved throughout the project, to ensure that all the risks perceived during project conception are dealt with during design or construction.

For certain types of project (typically concerned with infrastructure) there may well be long-term, operational issues that need to be taken into account. For example, road and railway embankment and cutting stability, and track and pavement performance, can lead to maintenance during the design life that far outstrips the initial construction cost. Clients need to ensure that as far as possible their requirements for whole-life cost are recognised by their designers, and are taken into account in the risk management process.

INTEGRATING GEOTECHNICAL RISK MANAGEMENT (4)

All types of risk should be considered at an early stage, as part of the general risk management process for a project

Ground-related risks should be considered at an early stage, as part of the general risk management process for a project, alongside, for example, health and safety risks, financial risks and environmental risks.

Management systems and techniques aimed at financial risk and health and safety risk can also be used for ground-related risk

Clearly, ground-related risk is just one class of risk that must be dealt with. The law requires that systems be put in place to ensure the health and safety of those who will construct and those who will ultimately use a new construction. A prudent client will also wish to ensure that the financial uncertainties involved are properly managed. However, for many projects ground-related risk will be a major cause of financial uncertainty, and in certain cases ground conditions will bring significant health and safety risks. Management systems and techniques aimed at financial risk and health and safety risk can also, generally, be used for ground-related risk. It is important to recognise when ground-related risk is significant, and to ensure that it is considered alongside the other risks to the project.

GETTING APPROPRIATE GEOTECHNICAL ADVICE (5)

It is important to recognise when ground-related risk is significant and to consider it alongside the other risks to the project

If building or construction could be significantly affected by the ground this needs to be known early, and preferably before making the decision to proceed with a particular form of construction. For small building developments, information on ground-related risks may be required before the development land is purchased.

A judgement can normally be made quickly on the basis of advice from a specialist. It is essential that the client, project manager or designer consults a geotechnical adviser early during pre-project planning. Appropriate persons and companies for such work are listed in the British Geotechnical Society's Geotechnical Directory of the UK.[33]

INVESTING EARLY TO IDENTIFY RISKS (6)

The geotechnical adviser will carry out a preliminary geotechnical risk analysis by:

- identifying the geotechnical hazards that might possibly be present on the proposed construction site
- assessing the vulnerability of the proposed type of construction to the geotechnical risks arising from those hazards
- estimating the potential cost and time increases if risks were to materialise
- showing the benefits of further geotechnical work, where it might be cost effective
- identifying minimum criteria for ground investigation at the proposed site.

The results of the preliminary analysis should include a geotechnical risk register and a short geotechnical summary report

The results of this work should include a geotechnical risk register, and a short geotechnical summary report, assessing the potential impact of geotechnical factors on the project, and how, when and by whom the risks might be dealt with, from a technical viewpoint. It should advise on whether any further work should be carried out to determine ground conditions with sufficient certainty for the project to proceed. These documents should be passed on throughout the project, to ensure that all the geotechnical risks perceived during project conception are dealt with during design or construction.

The risk register and summary report should be passed on throughout the project, so that all perceived risks are dealt with

ASSESSING THE VULNERABILITY OF THE PROJECT TO GEOTECHNICAL RISKS (7)

In most building and construction projects it can be expected that geotechnical risks will not be large, and routine ground investigation, properly planned and resourced, along with competent design, can be expected to be sufficient to ensure that any ground-related problems can be dealt with during construction. However, geotechnically sensitive projects, or constructions built on sites where there may be major hazards,

'Project owners must recognise that there are certain types of projects that simply cry out for a more sophisticated approach to doing the subsurface portion of the work'.

(Brierley, 1998[28])

will need special consideration. Even under such circumstances most of the risk can be avoided by good conceptual design, carried out by experienced geotechnical professionals at the very start of the project.

Risky projects, whether large or small, and projects where the application of sophisticated and detailed ground-related design can produce significant savings of time or construction cost should be identified at this early stage, to ensure that the highest level of geotechnical expertise is brought to bear.

Sophisticated analytical, design and monitoring techniques can sometimes be used to make savings, but specialist geotechnical consultants and contractors will be needed. Given the added complexity, and the likely time necessary for such work, it should normally be commissioned only if it can be justified by significant savings to the programme or to cost.

DECIDING HOW RISKS CAN BEST BE MANAGED (8)

Clients need to decide who will take on the various risks to the project. Certain risks (e.g. unusually poor weather slowing construction) may be insurable, but most ground-related risk must be taken either by the client or by the constructor. Contracting arrangements will apportion risk in a variety of ways (see Figure 10), some giving the major responsibility for design risk to the client and others giving it to the contractor.

> 'Subsurface projects present an enormous risk for the primary project 'stakeholders', i.e. the owner and contractor. Realistically, not all risk for subsurface conditions can be entirely avoided or eliminated'.
>
> (Hatem, 1998[34])

No construction project is risk free. It is important that clients select a type of contractual arrangement for construction that reflects their wishes with regard to the apportionment of any residual risk that may remain after design, since unforeseen ground and groundwater conditions, or the unexpected behaviour of foundations, retaining structures, slopes and earthworks may lead to expensive re-design and delay in completing the work.

> 'No construction project is risk free. Risk can be managed, minimised, shared, transferred, or accepted. It cannot be ignored'.
>
> (Latham, 1994[35])

IDENTIFYING METHODS OF DISPUTE RESOLUTION (9)

The additional costs resulting from unforeseen behaviour of the ground can lead not only to disputes during construction, but also to expensive arbitration or litigation.

For large clients there may be relatively little relationship between the type of contract used and the difficulty with which disputes may be resolved, since they can use their purchasing power to encourage constructors to take a longer term view of ground-related losses. For such clients it is worth investigating partnering, collaboration and the use of term contracts, since these are known to help ease the process of negotiation and settlement.

For small and occasional clients, whose construction requirements are limited and infrequent, considerably more care is required in selecting suitable contracts and geotechnical advisers. Many building and construction companies considerably outdo their clients and designers in terms of turnover, assets and technical resource, and can be at something of an advantage during any dispute or legal proceedings. There can be no doubt that the best contractual arrangements are those where the technical resources of the client, the designer and the constructor are combined in order to overcome ground-related difficulties as they become apparent.

Whatever the procurement method, sound project management can assist in geotechnical risk control. However, in view of the uncertainties involved, difficulties during construction should always be anticipated, and formal dispute avoidance procedures introduced.

CHAPTER 5

THE DESIGNER'S ROLE

KEY SUMMARY POINTS

- Good engineering design provides one of the most effective ways of managing geotechnical risk.
- Geotechnical hazard and risk identification are a fundamental part of good conceptual geotechnical design.
- Risk analysis techniques, based on a systematic use of expert opinion, provide an effective framework within which to identify and assess the importance of geotechnical risks.
- Designers should recognise that ground conditions are always uncertain, and should adopt design strategies that are effective in coping with uncertainty.
- Design should be systematic, should correctly identify the client's needs and risk tolerance, and should emphasise conceptual design.
- The amount of ground investigation should be appropriate to the degree of geotechnical risk on the project.
- Designers should also recognise the limited accuracy of many geotechnical design calculations.
- The results of risk analysis, and design responses to risks, should be summarised in a risk register.
- At the end of design the risk register, and all the geotechnical information, should be passed to the constructor and to the cient.

INTRODUCTION

Potentially, good engineering design provides one of the most effective ways of managing geotechnical design

Potentially, good engineering design provides one of the most effective ways of managing geotechnical risk. However, at present much geotechnical design is based on an oversimplistic approach:

- **Ground investigation is carried out using boreholes (and sometimes exploratory pits). Best practice requires that the ground investigation is planned on the basis of existing information on ground conditions, collected during a desk study, but this is relatively rare for building and small-scale construction.**
- **A conceptual 'ground model' is created, based either on the most likely ground conditions that are envisaged, or on a pessimistic but generalised interpretation. Such a model is unlikely to be geologically representative.**
- **Perceived limit states are analysed, and components (e.g. foundations, slopes and retaining walls) dimensioned to give a margin against failure.**

This process may be adequate for building and construction projects with relatively little groundwork, and where ground conditions are simple or well known. But it can be wholly inadequate when ground conditions are more important, either because the structure is particularly sensitive to ground conditions or ground movements, or because the ground is unusually variable or poor.

Too often there is too little thought put into investigating the ground on site

Too often there is too little thought put into investigating the ground on site, and:

- **critical ground conditions go undiscovered**
- **the boreholes and trial pits do not investigate all the ground subsequently affected by construction**
- **the parameters determined during the investigation are either not relevant to the problems that need to be analysed during detailed design, or they are determined with such inaccuracy that calculations using them give wildly inaccurate results.**

Geotechnical design should be systematic and recognise the uncertainties associated with the ground

The design process should be integrated within a risk management system

To be effective, geotechnical design should be systematic, and should recognise the uncertainties associated with the ground. The design process should be integrated within a risk management system, to ensure that uncertainties are dealt with effectively.

IDENTIFYING THE CLIENT'S NEEDS AND RISK TOLERANCE (10)

The first stage of systematic geotechnical design requires the designer to determine as simply and precisely as possible the fundamental requirements of the client. An important part of this is to understand and interpret the client's risk tolerance.

Most clients have little or no engineering knowledge, few preconceived ideas about how their needs can be met, and no idea of, or interest in, geotechnical matters. This is helpful, since expressing the geotechnical needs of the project in the most general way leads to a design specification against which the final design can be checked, while not prejudging the technical solution.

In order to fulfil the design specification it is necessary to understand the functions and subfunctions of the various parts of the proposed project, and to satisfy their requirements. The design specification might call for 10,000 m^2 of usable office space, with under-office parking. The geotechnical designer would typically have to consider a wide range of issues, including vertical support for building loads, lateral support for basement excavations, dewatering, pavement design for access roads, and slope design for temporary works and for permanent landscaping.

CARRYING OUT GEOTECHNICAL HAZARD AND RISK IDENTIFICATION (11)

In geotechnical risk management the first and most important step is the identification of hazards and their associated risks

In geotechnical risk management the first and most important step is the identification of hazards and their associated risks. In the UK a great deal can be found from the existing information (such as topographical and geological maps, books and journal papers, and air photographs and satellite images) that is sometimes used for a traditional desk study. However, hazard identification is fundamentally a different process – rather than using the data to predict the likely ground conditions, the purpose is to speculate about unfavourable conditions that might be encountered, and to use experience to produce a catalogue of the risks that must be managed in order to achieve relative certainty during construction (see Figure 8).

USING GEOTECHNICAL RISK ANALYSIS (12)

The steps in geotechnical risk analysis are:

1. If not already done by the client, creation of a 'team' of geotechnical advisers (for a simple building job this might in fact comprise a single geotechnical engineer, but for large construction projects a specialist consultancy or an expert panel with a minimum of three experienced geotechnical engineers/geologists would be required).
2. Collection of published and unpublished data on the ground conditions at the site.
3. Identification of the possible range of forms of construction (e.g. for foundations, basements and retaining structures) that might be used.
4. Brainstorming to identify geotechnical hazards and risks to different forms of construction, based on existing information and experience.
5. Use of group experience to rank risks according to their probability of occurrence and their impact on construction.
6. If not previously done by the client or project manager, establishment of a formal risk register (Boxes 6 and 7; see Appendix A).
7. Association of risks with the different phases of the project.
8. Estimation of costs and variances, and probability (based on group experience or using software) (see Appendix B).
9. Identification of possible ways of avoiding, managing, minimising, sharing or transferring risk, and the level of residual risk that is acceptable.
10. Agreement as to who will take action to control each risk, and who will carry the financial risk in each case.

Scale	Likelihood	Chance per section of work
4	Probable	>1 in 2
3	Likely	1 in 10 to 1 in 2
2	Unlikely	1 in 100 to 1 in 10
1	Negligible	<1 in 100

Scale	Effect	Increase in cost or time (% of cost or time)
4	Very high	>10
3	High	4–10
2	Low	1–4
1	Very low	<1

Degree of risk (R) = Likelihood (L) x Effect (E)

Using the above tables, if the effect is judged to be 'high' and the likelihood is judged to be 'unlikely', then

Degree of risk = 3 x 2 = 6

Box 6 An example of risk analysis

Risk ID	Hazard	Undesirable event	Consequence	Risk before control L	E	R
1a	Weak or loose soils at founding level	Soil fails under foundation load	Foundation failure	2	4	8
1b		Excessive foundation settlement	Damage to superstructure	3	3	9
2	Acid or sulphate bearing soil	Chemical attack on foundation concrete	Foundation failure	3	2	6
3a	High groundwater level	Soil destabilised	Collapse of foundation trenches	2	3	6
3b		Groundwater in foundation trenches	Water in trenches affects concreting	2	2	4

Degree of risk	Risk level	Action required
1–4	Trivial	None
5–8	Significant	Consider more cost-effective solutions or improvements at no additional cost
9–12	Substantial	Work must not start until risk has been reduced Additional resource required
13–16	Intolerable	Work must not start until risk has been reduced If risk cannot be reduced, project should not proceed

Box 7 A simplified part of a risk register for a building

For risk analysis to be effective it is important both that a thorough search and review of existing ground-related information is carried out, and that sufficient experience, both geotechnical and geological, is brought to bear in identifying hazards and possible risks and consequences. At this point it is necessary to identify how geotechnical risks will be managed:

- the client may be prepared to accept certain risks
- the design should be able to avoid many risks
- where risks cannot be avoided, they can be designed for
- some risks (e.g. temporary works foundations) are better allocated to the constructor to deal with during building

- other risks (e.g. from piling of foundations) may be allocated (with some element of design liability) to specialist subcontractors.

> 'I have made my greatest engineering contributions not by solving difficult problems but by avoiding them'.
>
> (Conlon, 1989[36])

- Plant selection
- Drillability
- Obstructions
- Casing length
- Pile length
- Groundwater
- Plant stability
- Concrete deliveries
- Spoil disposal
- Contamination

Box 8 Perceived hazards for the example of a bored pile construction (AMEC Civil Engineering Ltd)

MANAGING RISKS THROUGH ENGINEERING DESIGN (13)

Good engineering design provides one of the most effective ways of minimising or eliminating ground-related risk. Designers need to appreciate that ground conditions can never be known with certainty, because of the natural variability of the ground from place to place, and with depth (see Figure 1). In addition, ground properties, such as strength, stiffness and permeability, vary much more widely than do those of other construction materials such as steel or concrete (Figure 11), and there are many different mechanisms by which the ground can cause difficulties for construction (Box 8).

> '[Engineering design is the] use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform prespecified functions with the maximum economy and efficiency'.
>
> (Fielden, 1963[37])

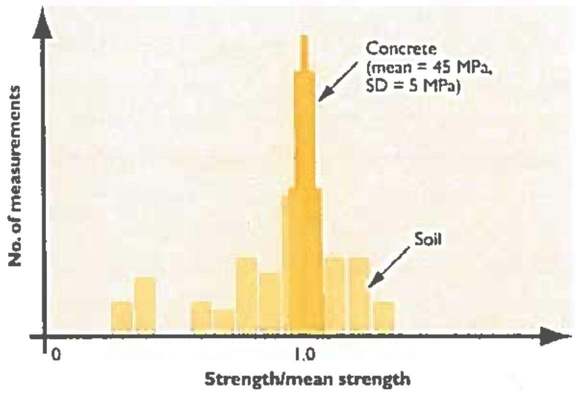


Figure 11 The variability in the strength of the ground and of concrete

Even when ground conditions are well known, and design is undertaken by leading experts using the best methods available, routine geotechnical calculations are often not very accurate (see Figure 2). Therefore, designs should be robust enough to accommodate possible variations in:

- the behaviour of the ground, compared with that predicted

as well as

- the type of ground from place to place across the site
- groundwater levels.

ADOPTING SYSTEMATIC DESIGN (14)

Geotechnical design should be carried out systematically

Geotechnical design should be carried out systematically (see Figure 2 and Box 9), ensuring that the following elements are included:

- conscious and careful expression of the client's needs

Systematic design uses a predefined staged approach to design, in order to ensure that the client's need is correctly identified, optimal solutions are found and that creativity is maximised.

Box 9 Systematic design

Conceptual design identifies an appropriate design solution by qualitatively assessing the strengths and weaknesses of a range of possible design variants, without recourse to detailed analyses.

Box 10 Conceptual design

Analysis is the process of breaking down a design into its constituent parts, and of calculating the behaviour of each of those parts.

Box 11 Analysis

- identification of potential hazards
- recognition of the ways in which hazards can present a risk either to construction work or to the finished project
- assessment of the client's tolerance to risk
- conceptual design (Box 10) to identify required functions and develop design variants for each function
- selection of the most effective forms of construction to optimise performance and to reduce cost and construction time, while minimising the vulnerability of the project to variations in ground conditions, whether known or possible
- planning of ground investigations both to investigate the probable ground conditions and to provide parameters for all the limit states to be analysed during detailed design
- careful detailed analysis (Box 11) and design detailing.

'The desk study and walk-over survey are the two essential components of ground investigation. Other parts (for example, boring, drilling and testing) may sometimes be omitted, but these parts of the site investigation process must always be carried out'.

(Clayton et al., 1995[38])

EMPHASISING CONCEPTUAL DESIGN (15)

A good design provides a robust defence against geotechnical risks, while being cost-effective, state-of-the-art and simple to construct

A good design will provide a robust defence against geotechnical risks, while being cost-effective, state-of-the-art and simple to construct. The conceptual design process consciously breaks down the project into these functions and subfunctions, and finds solutions for each, using a combination of precedent practice (Box 12), hazard avoidance, judgement and experience. In a well-managed design process the design variants developed at this stage to satisfy each function or sub-function will be objectively judged against the design specification. The best combination of solutions will then be selected bearing in mind a range of qualities, such as fitness for purpose, likely cost, simplicity, certainty of outcome, and environmental and health and safety impact (Box 13).

Design using precedent practice examines successful existing design solutions and uses them as a basis for future designs.

Box 12 Design using precedent practice

Minimum uncertainty	The best design is the one which has the least exposure to geotechnical risk.
Simplicity	The best design contains the least parts.
Constructability	The best design allows the most efficient construction.
State-of-the-art	The best design maximises the application of recent research findings.
Optimisation	The best design has evolved from quantitative evaluation (inculding cost) of alternative designs.

(Bieniawski, 1993[39])

Box 13 A set of criteria for selecting the best geotechnical design

'[Engineering judgement is a] feel for the appropriateness of a solution, from the narrowest technical details to the broadest concepts of planning …'.

(Peck, 1969[40])

Conceptual design should include a systems approach as a counterbalance to the bottom-up process of analysis. Systems thinking questions the assumption that component parts of a system are the same when separated out as when they are part of the whole. In geotechnical design it is important to search for unfavourable interactions (e.g. between soil movements and structural loads – 'soil–structure interaction' – or between foundation loading and slope instability), since these can sometimes be critical (Figure 12).

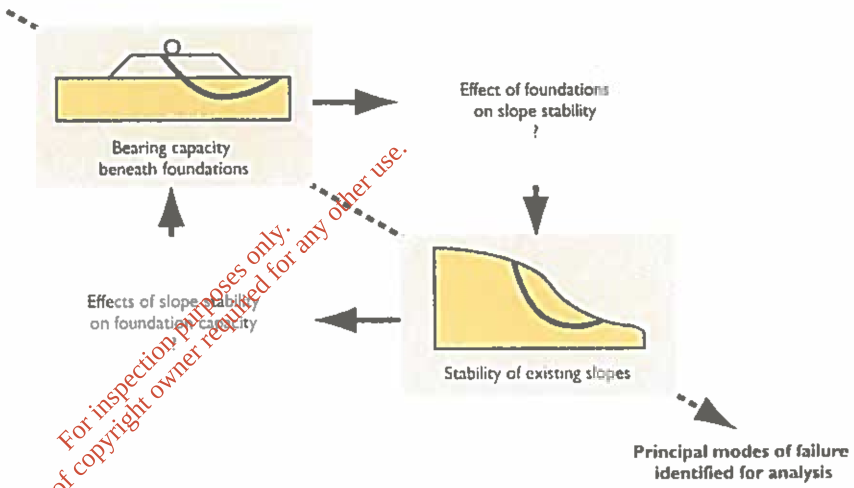


Figure 12 A systems approach, using interaction matrices, to identifying unfavourable design interactions (after Hudson, 1992[41])

'Systems thinking questions the assumption that component parts of a system are the same when separated out as when they are part of the whole. For example the reductionist tends to neglect the interaction between ground and structure, whereas it would form a central question in the mind of a systems thinker'.

(Blockley, 1993[42])

Hazard avoidance is undoubtedly one of the major components of geotechnical conceptual design

Hazard avoidance is undoubtedly one of the major components of geotechnical conceptual design. Conlon[36] reports what must be a common feeling among most experienced geotechnical engineers, that he has made his greatest engineering contributions not by solving difficult problems but by avoiding them. In many situations

- Using slope drainage and re-grading to control existing slope instability.
- Using composite geofabric–clay (GC) liners and a leak-detection system (double liner) for landfill liner design, to prevent leachate reaching the groundwater.

Box 14 Examples of 'defence in depth'

hazards can be avoided simply by an appropriate relocation of a structure (e.g. to avoid building over an in-filled quarry). Where particularly critical mechanisms of failure cannot be avoided they should be prevented from occurring by using more than one defensive measure, the so-called 'defence in depth' (Box 14).

MAKING GROUND INVESTIGATION EFFECTIVE (16)

Once the optimum design concept has been identified, ground investigation should take place to provide the information so that detailed design can proceed. Geotechnical analyses require a knowledge of the ground conditions, and particularly the likely

- geometry of the ground,
- its properties, and
- the groundwater conditions,

together with estimates of how much they might vary, or how they might be improved by ground treatment. Ground investigation (boreholes, laboratory and field testing) should be planned to test the conceptual ground model derived from examination of desk study and walk-over survey data, to provide further information on perceived hazards and to give the geotechnical parameters required for analysis.

Ground investigation (boreholes, laboratory and field testing) should be planned to test the conceptual ground model

Analyses (see Box 11) for routine detailed design are typically carried out on the basis of either:

- information obtained from limited ground investigation, using design assumptions in accordance with general practice

or

- the results of very detailed and costly ground investigation, typically using advanced numerical modelling.

Very detailed ground investigation should only be done where there are significant geotechnical risks or where clear benefits can be obtained from the adoption of a sophisticated geotechnical approach

Only in cases where there are significant geotechnical risks or where clear benefits can be obtained from the adoption of a sophisticated geotechnical approach will it be advisable to carry out very detailed ground investigation. Most design will be based on limited ground investigation, and the likely shortcomings of this must be recognised by the designer.

Most design will be based on limited ground investigation, and the likely shortcomings of this must be recognised by the designer

RECOGNISING THE LIMITED ACCURACY OF GEOTECHNICAL CALCULATIONS (17)

During detailed design, little reliance should be placed on deterministic 'best-shot' analyses, since these will often lack accuracy and provide only an incomplete assessment of likely construction problems. Five approaches can be helpful when using limited ground investigation following formal hazard identification:

- Peer review can be used to ensure that key mechanisms of failure are not overlooked, that realistic parameters are selected and that design calculations are performed competently and correctly.
- Sensitivity analyses (or probabilistic calculations using a spreadsheet add-in such as @RISK) allow the designer to appreciate the effects of uncertain parameters on the results of analyses (Figure 13).

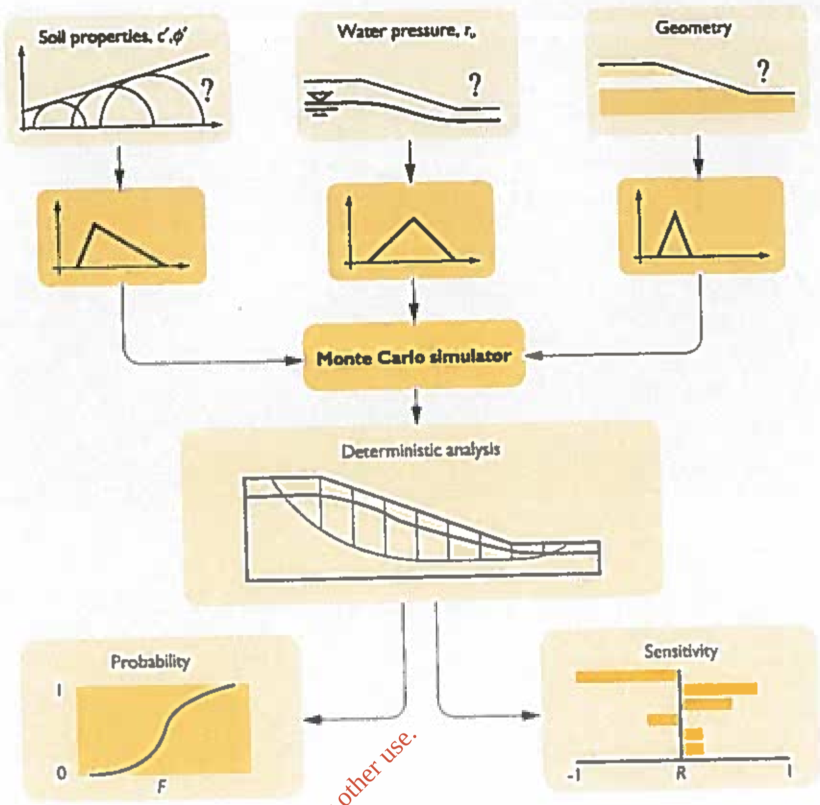


Figure 13 An example of a simple risk model (using Monte Carlo simulation) of slope instability

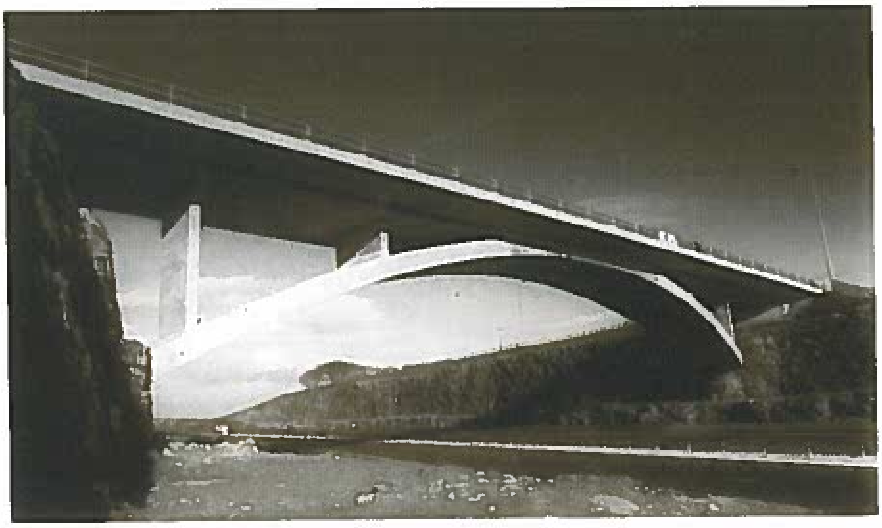
- Key failure mechanisms can be guarded against by adopting more than one defensive strategy. ('Defence in depth' using a 'belt and braces' approach.)
- Observation and monitoring of ground conditions should be used during construction, to ensure that design assumptions have been sufficiently representative for the geotechnical design to perform satisfactorily.
- Where design can be made flexible, monitoring of key components can be formalised in the observational method.[43]

UPDATING THE RISK REGISTER AND COMMUNICATING WITH CONSTRUCTORS (18)

As design provides what are judged to be effective risk reduction strategies, the risks that are controlled can be cancelled in the risk register. Residual risk can then be focused on and suitable ownership (during construction, commissioning and use) defined. If major geotechnical risks remain after design then the project may not be able to proceed, or a further phase of more specialist design (perhaps using high-level geotechnical expertise) may be required.

Ground-related data should be made freely available to all potential parties to building and construction projects

Ground-related data, including the rationale for ground investigation and its interpretation, should be made freely available to all potential parties to building and construction projects. For projects taking an extended time from conception to completion, or those involving significant subcontracting or temporary works, the adequacy of ground data should be reviewed on a regular basis, since the design concept can be expected to change from time to time.



CHAPTER 6

THE CONSTRUCTOR'S ROLE

KEY SUMMARY POINTS

- Ground-related risks have most impact on clients and constructors; increasingly clients are adopting methods of contracting by which they seek to transfer more risk to the constructor.
- The uncertainties associated with the ground can represent a considerable opportunity to a well-organised constructor.
- The constructor's geotechnical risk management strategy should recognise the impact of the contractual framework within which the work is to take place.
- The constructor should start risk management as early as possible, during the tender or negotiation period. If a risk register is not received from the designer or client, the constructor should start one immediately.
- The risk register should be updated regularly, particularly in the light of proposed temporary works and specialist construction techniques.
- Wherever the constructor takes on design responsibility, a geotechnical design review should be carried out, to ensure that geotechnical risks have been effectively managed.
- The risks associated with ground-related construction techniques, for example temporary works and foundation construction, should be assessed as soon as they become known.
- The results of the constructor's geotechnical risk management should be communicated to any specialist groundworks subcontractors or geotechnical designers that are subsequently employed on the project.
- Ground conditions should be observed, monitored and recorded during construction. The results may be helpful in detecting construction defects, and should be made available to designers, to allow re-design if necessary.
- In certain circumstances it may be useful to monitor key parts of construction or to use the observational method.
- The results of observation and monitoring should be fed back to designers during construction, to ensure that defects are identified, methods of construction are changed where beneficial and re-design is carried out where necessary.
- At the end of the project the data collected during risk management should be used to provide feedback on the effectiveness of the procedures used.

INTRODUCTION

Ground-related risks have most impact on clients and constructors

Ground-related risks have most impact on clients and constructors. Traditionally, in civil engineering constructors have been responsible for much of the temporary works design risk, but increasingly clients are adopting methods of contracting by which they seek to transfer other areas of construction risk to the constructor. Thus the conditions of contract for design and build, DBFO (design, build, finance, operate), etc., are on the increase, and major clients are using partnering, term contracting and the Private Finance Initiative (PFI) to promote effective dispute resolution.

Risk management systems that incorporate geotechnical risks and ensure an effective use of resource offer considerable opportunities to a constructor

To a client, ground-related construction risk is likely to be a largely negative factor, but for the construction industry it can represent a considerable opportunity. Robust geotechnical design coupled with systematic risk management can reduce uncertainty to acceptable levels, while sophisticated geotechnical analyses can, for some projects, add significant value or reduce construction costs and construction time. Risk management systems that incorporate geotechnical risks and ensure an effective use of resources therefore offer considerable opportunities to a constructor.

RECOGNISING HOW THE CONTRACT APPORTIONS RISK (19)

Constructors' risks resulting from variations in ground conditions are significantly affected by the conditions of contract used by the client.

The method of managing the contractor's risk needs to be appropriate to the contract conditions in use

The method of managing the contractor's risk needs to be appropriate to the contract conditions in use. Where the client, through the contract, effectively accepts some of the ground-related risk (e.g. the well-known Clause 12 of the ICE Conditions of Contract), then the constructor should introduce systems to ensure that all unforeseen ground conditions are recognised and recorded, and their impact on the time and cost of construction are evaluated.

Where ground-related risk is passed on to the constructor, variations in ground conditions that might have a negative effect on the project need to be recognised at the earliest opportunity so that re-design or different methods of construction can be considered.

STARTING GEOTECHNICAL RISK MANAGEMENT FOR CONSTRUCTION (20)

Geotechnical hazards and risks should be identified and analysed during the tender or contract negotiation period

In all cases, a risk management system (see Figure 7) should be introduced, or extended to include the ground-related risk, as soon as possible. Geotechnical hazards and risks should be identified and analysed during the tender or contract negotiation period. Risks associated with temporary works, which may not previously have been foreseen, need to be included. Risk modelling to include the financial implications of ground-related risk may be helpful.

Permanent works design should be reviewed in the light of construction methods

A risk register (see Box 7 and Appendix A) should be received from either the client or the designer. Recognising that many of the details of construction will not previously have been known, the adequacy of the permanent works design should be considered. The risk register should be reviewed and augmented before the start of construction, in the light of the proposed construction methods. It should also be reviewed regularly during construction, to ensure that risks have, as far as is practically possible, been

> In the absence of an existing risk register, the constructor and associated technical advisers should carry out geotechnical hazard and risk identification

reduced to an acceptable level and are relevant to the conditions actually encountered.

In the absence of an existing risk register, the constructor and associated technical advisers should carry out geotechnical hazard and risk identification (see Chapter 5). At this stage the form of temporary works, which are often constructed on soft, variable, near-surface ground, and are particularly risky, will be known. Often the most effective way of controlling temporary works risk is by producing flexible designs, coupled with observation, investigation and characterisation of ground conditions at the time of construction. Where there are significant ground-related temporary works risks, geotechnical specialists should be brought to site to make an assessment during construction. Additional ground investigation may be necessary.

REVIEWING GEOTECHNICAL ASPECTS OF PERMANENT WORKS DESIGN (21)

> A review of geotechnical aspects of the permanent works design should be carried out as soon as possible

> Both geotechnical risks and opportunities where the re-design of geotechnical elements of the work could make construction safer, faster or cheaper should be identified

Wherever constructors take on design responsibility, be it for permanent or for temporary works, they should ensure that their design professionals adopt the guidelines set out above in order that geotechnical hazards are identified and risks managed.

A review of geotechnical aspects of the permanent works design should be carried out as soon as possible, and in addition to reviewing geotechnical risks should identify opportunities where the re-design of geotechnical elements of the work could make construction safer, faster or cheaper. Where ground conditions have a significant effect on either the programme or the cost, it may be that different methods of construction can yield significant risk reductions or savings. As an example, an inappropriate choice of pile type during design can have a very large impact on cost, completion time and disputes. The delays associated with changing the type of pile to be used to support a structure, even during the early stages of construction, may be preferable to the construction problems of using the wrong type of pile.

IDENTIFYING THE EFFECTS OF GROUND-RELATED CONSTRUCTION TECHNIQUES (22)

> More ground investigation may be necessary in order to provide the additional data necessary for detailed design of temporary works and specialist groundworks

The techniques to be used for ground-related construction (e.g. piling, dewatering of excavations, methods of temporary support) are increasingly being selected by constructors. Cost, previous experience of satisfactory performance, and limited conceptual design to avoid problems are typically used by the constructor as a means of selecting the particular methods to be used on any given site. The particular methods chosen and their associated specialist equipment will bring new geotechnical risks that must be added to the risk register, and managed. More ground investigation may be necessary at this stage, in order to provide the additional data necessary for detailed design of temporary works and specialist groundworks.

COMMUNICATING (23)

> Where either design or construction is subcontracted, the lead constructor should disseminate information on expected ground conditions, and make relevant information from the risk register available

Where either design or construction is subcontracted it is important that the lead constructor disseminates information on expected ground conditions and makes available relevant information from the risk register. Specialist groundworks contractors need to be included in the risk management process so that they can feed their expertise and experience into the risk register and the continuing process of geotechnical risk analysis and response.

OBSERVING AND RECORDING GROUND CONDITIONS (24)

During construction the contractor should, as far as is practical, observe, monitor and record actual ground conditions and behaviour. The risk register should be updated as new information becomes available, and anticipated risks either do not materialise or are dealt with during construction.

Under conditions of contract where the client bears the majority of the ground-related risk, such data are vital in supporting claims for additional payment resulting from difficulties due to unforeseen ground conditions. They will also allow the designer to assess the adequacy of the project design.

Comparison of observed and expected ground conditions can give early warning of impending problems, allowing design changes to be made before additional costs and delays become significant

Whether or not the contractor is taking the risk, comparison of observed and expected ground conditions can give early warning of impending problems, allowing design changes to be made before additional costs and delays become significant. The designers, wherever they are employed, should be immediately notified whenever ground conditions deviate significantly from those expected.

MONITORING AND THE OBSERVATIONAL METHOD (25)

In certain circumstances, either for high-risk projects (e.g. urban tunnels, earth dams, nuclear power facilities) or where the permanent or temporary works design can be modified during construction to take advantage of new information, it may be worthwhile to make measurements of key indicators (e.g. prop loads in excavations or ground surface settlements) during construction. Monitoring is complex, expensive and requires expert geotechnical input during construction, but can be particularly worthwhile where large parameter uncertainties (e.g. relating to the stiffness of the ground) are thought to exist and conservative design has a major impact on construction cost.

PROVIDING FEEDBACK (26)

The results of observation and monitoring during construction should be fed back to designers as they become available

The results of observation and monitoring during construction should be fed back to designers as it becomes available, to ensure any unexpected behaviour is detected, so that construction defects are identified, methods of construction are changed where beneficial, and re-design can be carried out if necessary.

Following construction, the data collected during geotechnical risk management should be reviewed by all parties concerned with the project, to allow continuous improvement of the risk management system.

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APPENDIX A

RISK REGISTERS

INTRODUCTION

Risk registers are becoming widely used as a means of documenting perceived risks and their importance, and recording actions taken to manage them. A risk register can be a very simple document, and is a powerful means of communication when information is to be shared between the various organisations, or indeed between parts of the same organisation working on a particular building or construction project.

This appendix identifies the key components of a risk register, and then gives examples of geotechnical registers that have been used by a number of major construction companies. At present there is no agreed standard format for a risk register to follow. Users are invited to adopt those elements of the examples given that best suit their needs

HOW RISK REGISTERS ARE MADE AND USED

Risk registers are frequently used in their simplest form as part of the process of managing health and safety risk. The Health and Safety Executive (HSE) gives an extremely concise guide to the process in their pamphlets on *Managing Health and Safety*[44] and *Five Steps to Risk Assessment*.[45] This section describes the components that build to form a typical risk register.

The risk management system

Risk assessment takes place within a risk management system (see Figure 7) that must first be created by senior personnel (directors and managers) in the organisation carrying it out. At the outset it is imperative that senior management within the organisation defines a policy for risk management. In making the policy the organisation should consider and spell out its objectives, once it has assessed its current costs and the likely costs and benefits of introducing formal geotechnical risk management procedures. This policy, once defined, can be used as the basis for:

- developing procedures to be routinely followed
- allocating responsibilities for ensuring effective risk management
- ensuring sufficient resource is available, in terms of personnel and facilities
- providing training where necessary
- setting up communications between different parts of the organisation and with other organisations
- reviewing the effectiveness of both the procedures and the management system on a regular basis.

Risk assessment and risk analysis

According to the HSE, risk assessment consists of the following steps:

1. look for hazards
2. decide who might be harmed, and how
3. evaluate the risks and decide whether the existing precautions are adequate or whether more should be done

4. record the findings
5. review the assessment and revise it if necessary.

The key elements of geotechnical risk assessment and analysis are similar. The following represents a synthesis of the practice currently used by a number of companies in the UK:

1. Speculate as to the geotechnical hazards that might exist on the site.
2. Identify the types of construction that could be used.
3. Decide on the risks that could be associated with the combination of possible forms of construction, and the ground conditions.
4. Rank the risks according to likelihood and effect (for example, in terms of increase of cost, or construction time).
5. Decide on the type of action that is needed on the basis of the severity of each risk.
6. Associate each risk with a particular phase of the project.
7. Identify how each risk can best be managed, and by whom.
8. Record the actions taken to manage each risk.
9. Reassess the severity of each risk after action has been taken.
10. Review the risk register at regular intervals, to add new risks and remove risks that have been dealt with.
11. Communicate.

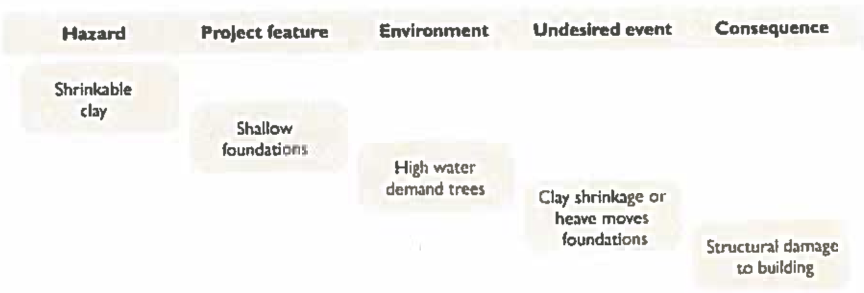
Many risk assessment systems do not, unlike the HSE, differentiate between hazards and risks. This distinction is not essential, but is useful for ground-related risk because one of the best ways of dealing with geotechnical risk is to avoid it.

During a risk assessment for a small building site, the following hazards might be identified as possible on the site:

- old landfill
- contaminated land
- shrinkable clay
- sulphate bearing or acidic soils
- trees and hedgerows
- high groundwater
- dissolution features (in chalk or limestone)
- a sloping site
- frost-susceptible soils
- mining activity
- old in-filled quarries or trenches
- solution features (in limestone or chalk)
- soft spots
- archaeological remains.

Whether these hazards translate into risk will depend on a number of factors, such as:

- the location of buildings within the site
- the type and depth of foundations used
- the sensitivity of the structure to differential settlement
- the type of concrete used for foundations.



Box A.1 Building on shrinkable clay

As an example, consider the use of shallow strip foundations for a building on shrinkable clay. This might be considered risky, for example if there are trees or hedges growing on the site. Box A.1 shows how the consequence (in this case structural damage to the building) depends on a number of factors, including the project feature, the environment and the nature of the undesired event. Attention to any or all of the factors linking the hazard to the consequence can reduce risk. For example, the buildings could be located away from trees and hedges, or they could be placed on piled rather than spread foundations. If the groundwater was found to be sufficiently high, there would be little chance of shrinkage or heave, since the water demand of the trees could be satisfied without desiccating and thereby shrinking the clay.

Whether or not risks can be avoided, it is sensible to estimate their severity. This process is known as *risk analysis*. The degree of risk is the expected impact of damage, loss or harm from a given hazard, under particular circumstances. It is normal to express risk as:

Degree of risk = Likelihood x Effect

The likelihood that a given event will occur is judged on a qualitative scale, as shown by the two examples below.

Scale	Likelihood	Chance, per section of work
4	Probable	>1 in 2
3	Likely	1 in 10 to 1 in2
2	Unlikely	1 in 100 to 1 in 10
1	Negligible	<1 in 100

Scale	Likelihood	Chance, per section of work
5	Almost certain	>70%
4	Probable	50–70%
3	Likely	30–50%
2	Unlikely	10–30%
1	Negligible	<10%

The effect of a risk once the unfavourable event actually occurs (sometimes termed the *impact* or *consequence*), is also assessed qualitatively, by using expert opinion within a consistent framework.

Risk results from the combination of a hazard and the vulnerability of what is to be built. Even though it is often possible to assess the likely loss, the importance of any given risk depends on the risk tolerance of the person or organisation taking the risk. To a small builder the loss a few thousand pounds will be extremely serious, but for a major developer this might be inconsequential.

Because risk tolerance depends on each individual and organisation, it is necessary to establish a scale of risk for each company, for each major type of risk (e.g. financial, health and safety, environmental) and sometimes for individual projects. An example is given in the table below.

Scale	Effect	Increase of cost or time (% of cost or time)
4	Very high	>10%
3	High	4–10%
2	Low	1–4%
1	Very low	<1%

A scale of 1 to 4 or 1 to 5 is typical. The 1 to 4 scale gives limited options, and no central point to allow experts to 'sit on the fence'. Those using the system are asked to respond in terms of their judgement of the possible effect of a given risk, checking this against the numerical values given in the right-hand column.

The result of multiplying these two assessments together, to obtain the degree of risk, is judged against another qualitative scale, an example of which is given below.

Degree of risk	Risk level	Action required
1–4	Trivial	None
5–8	Significant	Consider more cost-effective solutions or improvements at no extra cost
9–12	Substantial	Work must not start until risk has been reduced Additional resource required
13–16	Intolerable	Work must not start until risk has been reduced If risk cannot be reduced, project should not proceed

The data given in these three tables express the risk sensitivity of the users. Again, only four or five levels are used. Importantly, actions to be taken for each risk class are predetermined as part of the risk management policy of the organisation.

Responding to risk

The classical strategy when responding to risks takes the following form:

- *avoid*, or
- if unavoidable, *transfer*, or
- if non-transferable, *mitigate*, or
- if unable to mitigate, *accept and manage*.

Ideally, only trivial risks should be accepted and managed, but in practice this is not always possible. In the example given above, the risks from building with shallow foundations on an old and infilled quarry could be *avoided* by locating the quarry and re-siting the buildings away from it. The risks could be *transferred*, either to another party (e.g. by employing a designer with professional indemnity insurance to consider the problem) or to another set of risks (e.g. by using piled foundations). The risks could be *mitigated* through a process of ground treatment, coupled with a stiffer foundation raft. If none of these options was either available or appropriate, the risk could be *accepted and managed*, perhaps using observation of the ground conditions in foundation trenches, during construction, to warn of the actual occurrence of the risk.

During any given project, risk assessments will be made not only for different purposes (e.g. health and safety, finance), but also by the different organisations involved in the contract (e.g. client, designer, builder). There are many different stages at which geotechnical risks can be dealt with, for example during pre-project planning, design, construction, or the subsequent use of the building, construction or infrastructure. Each risk assessment should try to identify not only how each risk can be dealt with, but also by whom, and when it is best tackled. For example, on a building development geotechnical risks may be passing between the developer, the builder, the architect, the structural engineer and a specialist groundworks contractor. Good communication and clear delegation of responsibility for risks are essential.

Communicating: the risk register

A risk register is simply a compact means of recording all these data and any decisions made, so that information on risks can be effectively communicated within each organisation and between organisations. A typical risk register (which can be assembled on a standard spreadsheet) might contain the following:

- all the hazards on the site
- the risks identified as resulting from those hazards
- the estimated degree of risk from each
- the planned response
- at what stage of the project the response will be made, and by whom
- the estimated effect of the response
- who carries the financial consequences for the risk, should it occur.

An example of part of a risk register is given in Boxes A.2 and A.3. The management system should include a policy that defines at what stages, and how frequently, the risk register should be updated. For example, many of the geotechnical risks passed to the designer should be eliminated during design, and need to be recorded as such in the register. Risks remaining during construction need to be understood by the builder and developer. As ground conditions are exposed they can be reassessed, and responded to if necessary.

Risk ID	Hazard	Undesirable event	Consequence	Risk before control L	E	R
1a	Weak or loose soils at founding level	Soil fails under foundation load	Foundation failure	2	4	8
1b		Excessive foundation settlement	Damage to superstructure	3	3	9
2	Acid or sulphate bearing soil	Chemical attack on foundation concrete	Foundation failure	3	2	6
3a	High groundwater level	Soil destabilised	Collapse of foundation trenches	2	3	6
3b		Groundwater in foundation trenches	Water in trenches affects concreting	2	2	4

L, likelihood; E, effect; R, degree of risk.

Box A.2 ***Example of part of a risk register for a small building – initial risk analysis***

Risk ID	Consequence	Response	When and by whom	Risk after control L	E	R	Financial risk carried by
1a	Foundation failure	Examine soils in foundation trenches when excavated Take deeper if necessary	During construction Groundworks contractor	1	4	4	Builder
1b	Damage to superstructure	Design foundations and superstructure to minimise the effects of differential movement	During design Structural and geotechnical designers	3	1	3	Developer
2	Foundation failure	Test samples of soil for pH and sulphate content Use relevant type of concrete	During ground investigation Site investigation contractor	1	1	1	Developer
3a	Collapse of foundation trenches	Determine groundwater level Use trench support if necessary	During ground investigation Groundworks contractor	1	2	2	Builder
3b	Water in trenches affects concreting	Determine groundwater level at start of work Pump from sumps	During ground investigation Groundworks contractor	1	2	2	Builder

L, likelihood; E, effect; R, degree of risk.

Box A.3 ***Example of part of a risk register for a small building – response***

EXAMPLES OF RISK REGISTERS

This section gives examples of risk registers used for recent projects, provided by some of the UK's leading construction companies. A brief introduction gives the context in which each was developed, and describes its key components.

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Three examples are presented here. Figure A.1 is a small extract of selected items from the risk registers in use on a major construction project in the south-east of England. Items identified would represent a hazard to construction operations or cause variations in quantity and time (e.g. to install stabilising nails to slopes, or even specialised redesign of pavement formation supports). The constructor is made aware of the design issues and items to be included in his costs. Monthly review of the constructor's register addresses changes in importance and future planning.

Figure A.2 is a generic example used to assess risks to the design of temporary works in construction, which needs to address bearing capacity (e.g. heavy crane tracks, excavation slopes). The items identified become a 'check-list' to which should be added project-specific hazards. This list should also expand from 'lessons learned' as a reminder on future projects.

Designer's hazard identification
Date 12 May 99

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No.	WBS	Hazard	Mitigation plan	No.	Action	By whom	By when	Closed	Reason for closure
25	330	Dene holes in Area 1 – risk of alignment collapse during/after construction	Probing required before construction and further SI asap to reduce risks in most likely locations	1	Information and warnings to be included in H&S plan	SG	01 Oct 98	Y	Included in contract documents
				2	Avoided, closed out	MD	09 Mar 99	Y	Avoided
789	330	Mineral workings – lignite Area 5	1. Check local history and relevant mining records 2. Develop contingency plan in the event of a chance encounter	1	Keep contractor informed of findings	SG	01 Oct 98	Y	Field team responsible
				2	Include information in H&S plan	SG	01 Oct 98	Y	Included in documents
				3	Inform contractor of findings	TR		N	
3354	330	Risk to structures from high sulphate and chloride levels	Design structures to resist attack, including provision of additional membranes where feasible to isolate from sulphate attack. Refer to ground investigation reports	1	Include geotechnical information in tender documents	BG	18 Jun 97	Y	Action completed
				2	It has been determined that there is no need for additional membranes	PK	09 Mar 99	Y	
				3	Design to follow BRE Digest 363 for cement ratio	PK		Y	

Constructor's register
Date 20 Jan 00

No.	Risk	Owner	Mitigation plan	Last review	Critical date	Importance	Action	Closed
2822	Footbridge piling, unknown services or obstructions	KG	Additional ground investigation	26/07/00	Closed	1	Trial holes	Y
5215	Unexpected land contamination found	CE	Apply previously prepared detailed procedure	19/01/00	Ongoing	1	Control plan No. 00007-01	
3.5	Dene holes	CE	Establish existence	19/01/00	Ongoing	1	Radiological surveys, historical records	
3.14	Swallow holes/ solution features	CE	Establish existence	19/01/00	Ongoing	2	Radiological surveys, historical records	
11.4	Lignite mining	KG	Investigate as necessary	19/01/00	Ongoing	1	Allow for removal	

Figure A.1 Selected items from the risk register

Figure A.3 is an adaptation of the generic form for a current project where an offshore jack-up platform is applying loads of 500 tonne per leg to an irregular rocky seabed. Contact stresses can exceed 150 MPa, so it is essential that inspections demonstrate safe locations during leg preloading sequences and during operations.

Figure A.4 shows the risk data sheet.

Bovis Lend Lease Ltd

This risk register is representative of the format used throughout Bovis Lend Lease Ltd, from the management of safety risk to strategic business risk. Bovis Lend Lease Ltd is a major global manager of construction projects and uses risk management at all levels to improve the chances of achieving success for itself and, most importantly, its clients.

Risk registers are used to:

- record the extent to which risks have been identified – predominantly from pooling the knowledge and experience of all those involved in the project
- gain an appreciation for the risks' potential to affect the objectives defined
- record what is being done to minimise this potential degradation and derive benefits from unforeseen opportunities.

Risk management is an important aid to the project team, since it introduces a discipline to the appreciation of uncertainty. The company has found that it is invariably uncertainty that causes difficulty to teams, rather than the complexities of the project. Important facets of the risk register are:

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Construction Division Specialist Businesses	**Contract/Tender** **Project No.**	**Risk register** **GENERIC**

PROBABILITY (P)		IMPACT/ Consequence (I)		TIME and COST Impact (£) *Amend to suit contract*		Risk Rating	Risk P × I = R	Response
Very likely	5	Very high	5	*>10 weeks on completion*	*> 1m*	Intolerable	17 to 25	Unacceptable
Probable	4	High	4	*>1 week on completion*	*100k to 1m*	Intolerable	13 to 16	Unacceptable
Likely	3	Medium	3	*>4 weeks: <1 week on completion*	*10k to 100k*	Substantial	9 to 12	Early attention
Unlikely	2	Low	2	*1 to 4 weeks: none on completion*	*1k to 10k*	Tolerable	5 to 8	Regular attention
Negligible	1	Very low	1	*<1 week to activity: none on completion*	*<1000*	Trivial	1 to 4	Monitor

	PROBABILITY				
	Negligible	Unlikely	Likely	Probable	Very likely
	1	2	3	4	5
CONSEQUENCE 5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

HAZARD/RISK	CAUSE	BEFORE CONTROL P	I	R	IMPACT/ Consequence	RESPONSE/ Controls Avoid, transfer, mitigation, control	AFTER CONTROL P	I	R	TIME	COST	Risk sheet	OWNER	Review date	Status
1 **Bearing capacity**	Weak soils	5	5	25	Collapse	Calculate maximum bearing capacity	2	4	8						
						Define maximum dimensions	2	3	6						
						Investigate ground to 2*B depth	2	4	8						
	Sloping ground	3	4	12	Collapse	Reduce bearing capacity	2	4	8						
	Mine workings/voids	5	5	25	Collapse	Investigate ground to minimum 20m into rock	2	4	8						
	Formation preparation	3	4	12	Excessive settlement	Inspection before blinding	2	3	6						
	Formation blinding	3	4	12	Excessive volume	Care during final excavation	2	2	6						
	Chemical attack of concrete	3	5	15	Gradual structural failure	Sample and test soil and groundwater	2	3	6						
bk **Cut slope**															
Depth of slope	Over dig	5	5	25	Slope failure	Define limits by design	2	4	8						
Gradient of slope	Space available	5	5	25	Slope failure	Define limits by design	2	4	8						
						Inspect and modify if needed	2	4	8						
Top surcharge	Plant or spoil	5	5	25	Slope failure	Define limits by design	2	4	8						
Strata in slope	Inclined strata	4	5	20	Slope failure	Investigate by boreholes or trial pits	2	4	8						
Strata below slope	Inclined strata	4	5	20	Slope failure	Investigate by boreholes to D below slope toe	2	4	8						
Strata strength	Too weak	4	5	20	Slope failure	Investigate by boreholes, samples and tests	2	4	8						
	Short term/long term	4	5	20	Slope failure	Investigate by boreholes, samples and tests	2	4	8						
Groundwater pressure	Excess pressure	4	5	20	Slope failure	Install and monitor piezometers	2	4	8						
Heave of ground	Stress relief	4	4	16	Structures disrupted	Tests on clays	2	4	8						
Spoil disposal	Deep excavation	4	4	16	Cost of disposal	Test for re-use. Eng and contamination	2	3	6						
						Test for disposal. Eng and contamination	2	3	6						

Figure A.2 A generic example

AMEC Capital Projects Limited

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Construction Division
Specialist Businesses

Contract/Tender EXAMPLE 3
Project No. 00/063

Risk register
9/4/00

PROBABILITY (P)		IMPACT/ Consequence (I)		TIME and COST Impact (£) *Amend to suit contract*		Risk Rating	Risk P × I = R	Response
Very likely	5	Very high	5	>10 weeks on completion	> 1m	Intolerable	17 to 25	Unacceptable
Probable	4	High	4	>1 week on completion	100k to 1m	Intolerable	13 to 16	Unacceptable
Likely	3	Medium	3	>4 weeks; <1 week on completion	10k to 100k	Substantial	9 to 12	Early attention
Unlikely	2	Low	2	1 to 4 weeks; none on completion	1k to 10k	Tolerable	5 to 8	Regular attention
Negligible	1	Very low	1	<1 week to activity; none on completion	<1000	Trivial	1 to 4	Monitor

CONSEQUENCE	PROBABILITY: Negligible 1	Unlikely 2	Likely 3	Probable 4	Very likely 5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

	HAZARD/RISK	CAUSE	BEFORE CONTROL P	I	R	IMPACT/ Consequence	RESPONSE/ Controls Avoid, transfer, mitigation, control	AFTER CONTROL P	I	R	OWNER	Risk sheet	Review date	Status
1	At position N1, leg punches into seabed	Ground condition	5	5	25	Prevents platform operating, delays works	Review of borehole data	2	5	10	Des1	1	20/07/00	Closed
							Calculations to estimate limits	2	4	8	Des1		25/07/00	Closed
							Video seabed surveys	2	4	8	Des2		11/08/00	Closed
							Controlled preloading of legs	1	4	4	Des2		12/08/00	Closed
2	Position S1, leg punches into seabed	Ground condition	5	5	25	Prevents platform operating, delays works	Review of borehole data	2	5	10	Des1	2	20/07/00	Closed
							Calculations to estimate limits	2	4	8	Des1		25/07/00	Closed
							Video seabed surveys	2	4	8	Des1		28/08/00	Closed
							Controlled preloading of legs	1	4	4	Des1		29/08/00	Closed
3	Position S2, leg punches into seabed	Ground condition	5	5	25	Prevents platform operating, delays works	Review of borehole data	2	5	10	Des1	3	20/07/00	Closed
							Calculations to estimate limits	2	4	8	Des1		25/07/00	Closed
							Video seabed surveys	2	4	8			20/07/00	Active
							Controlled preloading of legs	1	4	4	Des1			Active
4	Position N2, leg punches into seabed	Ground condition	5	5	25	Prevents platform operating, delays works	Review of borehole data	2	5	10	Des1	4	20/07/00	Closed
							Calculations to estimate limits	2	4	8	Des1		25/07/00	Closed
							Video seabed surveys	2	4	8				Active
							Controlled preloading of legs	1	4	4				Active

Figure A.3 An adaptation of the generic form

- an identity for the risk item which can be used for tracking and, if necessary, to create links with other risks or log in a knowledge bank for future learning
- sufficient description of the risk to explain what the real concern is
- a source to obtain more information if required
- what is being done to 'control' or otherwise manage the likelihood of the risk occurring, or its impact if it does, or both

AMEC Capital Projects Ltd

Construction Division
Specialist Businesses

Risk data sheet

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Project	**EXAMPLE Jack-up platform Position N1**						Risk No.	1.00
							Risk owner	Con1
Area of risk	Temporary works						Risk status	Closed
Risk category	Ground conditions						Date updated	25/08/00
Risk name	Leg support							
Risk description	Leg shoe punches into seabed in unexpected way at position N1							
Causes	Ground conditions at leg positions not known							
	Locations too distant from borehole data							
	Ground different to borehole data							
Impact	Prevents platform operating, delays works							
Risk rating	Probability	5	Impact	5	Rating	25	Response	H
Controls	Proper review of borehole data							
	Video surveys to check general seabed conditions							
	Video surveys to check seabed at leg positions when first lowered							
	Controlled leg preloading sequence before jack out of water							
	Controlled preloading of each leg to loads greater than normal working load							
Risk rating	Probability	1	Impact	4	Rating	4	Response	M
Comments on impact costs and time								
Inspection and preload sequence can take 3 days to complete								
Action plans					Action owner		Action reviewed	
Review existing ground data					Des1		20/07/00	
Calculate estimated contact conditions					Des1		25/07/00	
Review video survey pre-positioning					Des1		11/08/00	
Controlled preloading sequence					Des1		13/08/00	
							Closed	
Lessons learned								
1. Brittle localised failure of hard rock seabeds can lead to shock loading of leg grippers								
2. Video checks need good visibility and low tidal flows								
3. In marginal and deteriorating sea conditions it may be necessary to place some load on legs to stabilise the platform before the initial seabed inspection is carried out								

Figure A.4 Risk data sheet

- who is responsible
- an expansion capability to track progress as illustrated in this example.

These fields provide the basic management information for the team to endeavour to reduce risk.

The company believes that many enhancements are possible. A first consideration would be to add a methodology to prioritise management action to the most significant

No.	Hazard/item	Ass't ref.	Risk control measures	Risk owner	Comments	Rev.
1000	Excavation piling near cofferdam · Undermining of toe	S&G Designer 22.12.99	Stability of cofferdam depends on adequate toe embedment. All excavation near the cofferdam to be cleared with Principal Contractor first, who is to seek advice where necessary from Cofferdam Designer and S&G Designer	Principal Contractor	Final building does not rely on cofferdam for structural strength. Meeting held with Cofferdam Designer and design approach agreed. S&G Designer has designed accordingly. Subcontractor to include in method statement	B
1001	Overloading cofferdam road · Structural failure	S&G Designer 22.12.99	Cofferdam road has limit on surcharge loading, as shown on Cofferdam Designer's drawings. Principal Designer to advise all Subcontractors	Principal Contractor	Include in general method statement	B
1002	Piling · Rotating equipment and plant · Spinning off spool	S&G Designer 10.03.00	Piling Subcontractor to protect rotating equipment. Provide banksman to rig driver. Consider alternative ways of removing spoil, rather than spinning	Principal Contractor	Banksman used to assist driver. Exclusion zone around rig. Works complete	B
1003	Piling – open bores · Falling · Bore collapse	S&G Designer 10.03.00	Piling Subcontractor to provide adequate protection against falling down bore. Temporary bore casings kept above piling mat to provide some protection	Principal Contractor	Bores protected by exposed casings and handrails. Works complete	B
1004	Piling – elevated water table in Thanet Sands ·Rising water leading to flooding	S&G Designer 10.03.00	Water ingress assessed as being too slow to be a major hazard to people. Dewatering system in operation, maintaining a water table between −30.0 and −23.0 m OD. Subcontractor may need to use bentonite or similar slurry to maintain bore stability. Piling must not commence until dewatering has taken effect, and lowered the water sufficiently	Principal Contractor	Dewatering continued throughout works and monitored daily. Works complete	B
1005	Piling – projecting reinforcement · Physical injury to persons	S&G Designer 10.03.00	Subcontractor to address. Use top hat protection or similar	Principal Contractor	Top hats used. Works complete	B
1006	Gas build up in enclosed spaces · O_2 depletion · Explosion	S&G Designer 10.03.00	Potential methane generation from alluvial soils and dock silt deposits. Possible CO_2 generation from chalk trapped below Lambeth Clay, until released by pile bore. Principal Contractor to inform Subcontractor of risks and control measures	Principal Contractor	Piling works complete. To be continually monitored during excavation. Include in Principal Contractor's risk assessment	B
1007	World War II bombs · Explosion	S&G Designer 10.03.00	Area subject to heavy bombing in World War II. Buried bombs may cause an explosion if hit. Fully brief all operatives. Mitigation very difficult	Principal Contractor	Include in Principal Contractor's risk assessment	B
1008	Piling – overhead obstructions, including railway · Accidental strike	S&G Designer 10.03.00	Rail bridge crosses adjacent road, offering limited headroom to plant delivery. Underside of rail bridge structure at approx. +12 m OD, to be confirmed by survey. Particular care to be taken when moving plant	Principal Contractor	Include in site logistics plan. Piling now complete	B
1009	Below-slab drainage · Trenches and shoring collapse · Flooding of trenches · Falling into trenches	M&E Designer 17.03.00	Design mitigation limited. Dewatering in place. Trenches to be adequately protected from collapse. Usual precautions re. ladders and stop boards/hand rails	Principal Contractor	Ensure covered in Subcontractor's safety plan	B
1010	Below-slab drainage · Working with reinforcement cage	M&E Designer 17.03.00	Drainage installation programmed to suit steel fixing. Reinforcement bar ends to be protected. Use suitable PPE	Principal Contractor	Check included in Subcontractor's safety plans	B
1011	Below-slab drainage · Confined spaces, gas build-up	M&E Designer 17.03.00	If necessary, follow guidance in 'Safe Working in Sewers and Sewage Works' manual	Principal Contractor	Check included in Subcontractor's safety plans	B
1012	Below-slab drainage · Manual handling – pipes and fittings, pumps · Storage of pipe stacks – collapse	M&E Designer 17.03.00	Pipes, fittings and pumps are heavy. Manual handling assessment required. Ensure pipe stacks are adequately restrained	Principal Contractor	Check included in Subcontractor's safety plans	B
1013	Below-slab drainage · Falling into finished sumps and manholes · Tripping over gullies	M&E Designer 17.03.00	Manhole covers to be provided and bolted down as soon as possible. Prior to this, temporary steel covers to be provided and secured	Principal Contractor	Check included in Subcontractor's safety plans	B
1014	Below-slab drainage · Weils disease (leptospiral jaundice)	M&E Designer 17.03.00	Personal hygiene, cover all cuts and abrasions. Inform operatives of hazards	Principal Contractor	Check included in Subcontractor's safety plans	B
1015	Ground works · Collapse of ground and/or flooding	S&G Designer 27.03.00	Refer to existing ground investigation and piezometric information from Principal Contractor. In addition, a sand layer has been identified within the upper parts of the Lambeth Clay in some areas of the site. It is unclear whether this affects Building X or not. The sand layer contains water at the same piezometric level as the upper aquifer or dock water, and will cause ground above to boil	Principal Contractor	Included in tender information and discussed at tender meetings with Substructure Contractors	B

M&E Designer, Mechanical and Electrical Designer; S&G Designer, Structural and Geotechnical Designer

Figure A.5 Health and safety risk register

issues. This 'assessment' can be a simple low/medium/high banding, or an increasingly sophisticated quantification of probability, impact and functions thereof. There is always a danger that this assessment may become a detailed statistical analysis, forgetting that the important aspect is to manage down the negative side of the risks. But, on the other hand, statistical analysis can provide the only objectivity when making complex financial decisions, especially between different scenarios or across a portfolio of work.

The example given in Figure A.5 is a health and safety risk register for the construction of the substructure of a large office development, including the installation of a cofferdam, drainage of the area, installation of piles and construction of a two-level reinforced concrete basement. The register was developed by the planning supervisor in conjunction with the designers and contractors. Ownership of the register remains with the planning supervisor throughout the construction period. The register has been used to enable designers to identify risks, pass on information to contractors, and reduce and where possible eliminate risks throughout the design and construction period. It will be used to identify any residual risks to the owners and operators of the completed building, by ensuring that relevant information is included in the health and safety file. Items are background shaded when no further action is required, thereby clearly showing the current risks.

Experience has shown that, because this is a live document, used and amended throughout the contract, it is most useful. Although it is purely a health and safety risk register, it can also be used to identify financial risk in the broadest sense.

Ove Arup and Partners

This risk register was compiled in one workshop session, for a large brownfield development in the UK, comprising a number of leisure and residential buildings, transport interchanges and power-production facilities. The site has existing buildings to be re-used, some listed, and neighbouring properties. Chemical contamination was expected, as was complex geology. This risk register was to deal with ground-related matters only.

The risk register was developed by consulting engineers, and involving the management contractors, as a tool for giving strategic advice to the owner.

The example in Figure A.6 shows the results of the 'prior to risk control measures (RCM)' assessment, and the control measures put forward in the workshop. The example register is not complete, in terms of either the length, scope or control measures proposed. It is an indicative, selected list of hazards from a real project risk register. In addition, the complete register includes columns for post-RCM assessment (not shown here), under the headings:

- RCM owner
- Post-RCM
  - severity (in terms of capital cost, programme and safety)
  - comments/actions and timing of RCM
  - action owner.

These columns are used to demonstrate the effectiveness of the RCM proposed and to indicate ownership of residual risk, and could be run several times to investigate different scenarios.

Site Development Risk Management Register – Project X
Reference : **Date: 17/05/00** **Status : Information** **ARUP**

CATEGORY	RISK No.	HAZARD	LIKELIHOOD	PRIOR TO RCM – SEVERITY – Capital cost	SEVERITY – Programme	SEVERITY – Safety	RISK – Capital cost	RISK – Programme	RISK – Safety	RISK CONTROL MEASURE (RCM)
	1	Unidentified services causing delays/ obstructions during construction	5	4	4		20	20	0	Undertake desk study. Identify and enquire of all stats. Survey location of services. Seek approvals for diversions. Divert as necessary. Plan diversion temporary works. Programme to allow for diversions (including design). Assess effects of services diversions on nearby structures (needs early consultation)
	78	Redesign due to proposed tunnel across the site	5	4	4		20	20	0	Early liaison with utility to determine statutory rights and any earlier safeguarding. Determine utility intentions. Discuss alternative routes across site. Design to incorporate utility requirements if necessary
	79	Constraints on layout due to land owned by others	5	4	4		20	20	0	Early liaison with utility to determine statutory rights and any earlier agreements. Design to incorporate utility requirements if necessary
	84	Difficulties in achieving the proposed development programme/scope of works	5	4	4		20	20	0	Identify and manage risks. Identify all activities and programme accordingly. Avoid unrealistic programme. Adhere to deadlines through scheme development and design process into construction. Identify contingency measures. Undertake quantified risk assessment on programme to highlight activities most likely to affect programme
	8	Existing foundations in building obstruct future foundations and services	4	4	4		16	16	0	Obtain as-built drawings. Confirm as-built drawings by direct investigation. Consider trial pits, coring and geophysical techniques. Design solution and construction method to recognise likelihood of unexpected obstructions as well as those identified. Route services to avoid high risk areas
	9	Obstructions to new foundations and services from existing foundations outside building footprint	4	4	4		16	16	0	See No. 8
	35	Damage to neighbouring viaduct during construction causes disruption to rail services	4	4	4		16	16	0	Design permanent and temporary works to safeguard viaduct. Use appropriate construction techniques to minimise ground movements and vibrations. Consider advance strengthening works. Undertake critical works in engineering hours. Undertake movement/vibration monitoring during works. Establish trigger and action levels for movements and agree action plans with viaduct owner and project team
	50	Impact on construction and performance of new foundations due to geological uncertainties	5	3	3		15	15	0	Site investigation to determine extent and depth of uncertainties using boreholes, probes. Geophysics probably not likely to be successful
	68	Incompatible stiffness between piles/ shallow foundations affects performance of structures	5	3	3		15	15	0	Design foundations so stiffness compatibility not an issue. Investigate properties of existing foundations and ground so behaviour can be predicted confidently
	5	Obstructions formed by tunnels/shafts inside and outside building	4	3	4		12	16	0	Desk study. Obtain drawings and records. Confirm on site by survey within tunnels (if accessible). Possibility of relocation of services within existing tunnels
	37	Unknown/poor conditions of neighbouring viaduct affects construction methods/layout of nearby structures	4	3	4		12	16	0	Obtain as-built drawings of structure. Undertake detailed condition survey. Undertake investigation of foundations (trial pits, coreholes, etc.). Need advance notice to viaduct owner. Select construction methods to minimise potential impact. Undertake any strengthening measures in advance – to be agreed with viaduct owner
	67	Damage caused by differential settlements within building footprint after construction	4	3	4		12	16	0	See No. 68
	14	Programme delays due to approval of temporary works by utility/neighbour taking excessive time	4	3	3		12	12	0	Undertake early liaison with utility/neighbour. Consider regular progress meetings. Identify who is right person to speak to early on. Identify need for possessions very early on as long lead time
	16	Reuse of existing foundations dictates rigid constraint to development layout	4	3	3		12	12	0	Regular liaison with architects and structural engineers
	18	Insufficient durability/capacity of existing foundations prevents re-use	4	3	3		12	12	0	Sample and test foundation materials (e.g. by coring). Consider load testing isolated foundations. Adopt redundancy and robustness in design
	25	Delay to programme due to Heritage approvals for works to listed structures	4	3	3		12	12	0	Early liaison with EH and other interested parties. Regular meetings to report progress and maintain confidence. Establish programme for approvals process
	52	Geological features reduce load carrying capacity of new foundations	4	3	3		12	12	0	Design capacity to be downrated to take account of geological features. Avoid using uncertain soils to develop capacity. Identify extent of features and properties of soil by adequate borehole/probing coverage and soil tests
	53	Detrimental effect of unknown geological features on perimeter wall/foundations	4	3	3		12	12	0	Design capacity to be downrated to take account of features of soil. Avoid using affected areas to develop capacity. Identify extent of features and properties of soil by adequate borehole/probing coverage and soil tests. Take perimeter wall below affected areas. Action plan if affected areas more extensive than anticipated. See also No. 50
	54	Uncertainty of performance and constructability of foundations in geological features	4	3	3		12	12	0	Trial bores in potentially affected areas. Load tests on piles to confirm capacity. Possible use of support during pile construction (e.g. bentonite, casing)
	59	Failure of strategy adopted for groundwater control delays construction	4	3	3		12	12	0	Establish site-wide strategy for groundwater control and foundation construction. Consider long-term groundwater control measures taking advantage of perimeter cut-off to reduce requirement for control within site
	70	Proposed structure does not fit existing foundation layout/capacity	5	2	2		10	10	0	Avoid drift of building footprint at design stage. Develop alternative foundation strategy if foundations not found to be in expected locations. Survey in advance where possible
	88	Restriction on piling within the building due to restricted access and/or working space	5	2	2		10	10	0	Assessment of access and working space prior to piling works commencing. Possible temporary removal or relocation of existing braces. Use of appropriate low-headroom plant where necessary
	11	Disused tunnels – risk of collapse/ obstructions to foundations	3	3	3		9	9	0	Desk study. Identify location of old tunnels. Break out or fill in where possible. Establish condition in advance. Cap off water ingress in advance if possible
	12	Long lead-in times for services diversion delays works – all utilities	3	3	3		9	9	0	Identify which utilities require diversion/upgrading. Make early contact with STATS. Establish lead-in times for design and procurement. Check on seasonal limitations on diversions

Figure A.6 Site development risk management risk register

Site Development Risk Management Register – Project X
Reference :
Date: 17/05/00
Status : Information

ARUP

CATEGORY	RISK No.	HAZARD	PRIOR TO RCM LIKELIHOOD	SEVERITY Capital cost	SEVERITY Programme	SEVERITY Safety	RISK Capital cost	RISK Programme	RISK Safety	RISK CONTROL MEASURE (RCM)
	26	Movement within building due to temporary works/new foundations, etc., damage building fabric	3	3	3		9	9	0	Adopt appropriate construction methods. Prop as required. Carry out detailed analysis in advance. Monitor and control during construction. Carry out structural condition survey in advance to design propping measures. Discuss allowable temporary works and reinstatement with EH
	51	Presence of geological features affects capacity of existing foundations to be re-used in new works	3	3	3		9	9	0	Identify location of foundations in relation to features and assess bearing capacity and settlement behaviour. Design in redundancy if re-using existing foundations
	55	Unexpected groundwater inflow caused by permeable infill within geological features	3	3	3		9	9	0	Identify extent of features. Design temporary/permanent works to take known features into account. Adopt contingency measures if extent greater than expected
	62	Settlement damage to existing foundations during use of well point dewatering techniques	3	3	3		9	9	0	Limit extent of dewatering by careful design/site testing. Limit extent by cut-offs around site. Monitor settlement effects during dewatering and control if necessary
	71	Impact on temporary works programme and ground movement mitigation strategy of late relocation of deep basements/re-zoning of site use	3	3	3		9	9	0	Early freeze on basement locations. Design team to be aware of implications of late changes in basement layouts
	41	LA requirements for upgrade to surrounding roads affects start of work on site	3	3	2		9	6	0	Consult with LA. Check planning requirements
	83	Selection of quality of basement construction and maintenance/future pumping does not match client's expectations	3	3	2		9	6	0	Inform client of options/costs of different qualities of basement watertightness. Affect choice of construction method
	82	Programme delays due to late re-design as development proceeds	4	2	4		8	16	0	See No. 71
	13	Delays due to discovery of obstructions during construction of tunnel surrounding site	4	2	2		8	8	0	Desk study. Trial pits and probing to identify location of obstructions. Determine relationship with perimeter walls, viaduct and services
	38	Limitations on applicable construction techniques due to nearby location of viaduct	4	2	2		8	8	0	Early liaison with viaduct owner. See also Nos 35, 37, 14
	57	Delays due to response/approvals from EA relating to lower aquifer contamination issues (piling, basement construction)	4	2	2		8	8	0	Early liaison with EA on mitigation measures
	39	Nearby roads – protracted lead time for approvals from local authority	3	2	4		6	12	0	Liaison with LA. Allow for lead time in programme. See also No. 41
	81	Lack of availability of plant for enabling/ foundation works	3	2	4		6	12	0	Allow sufficient time for tender and construction. Liaison with approved contractors at an early stage in the procurement process. Avoid reliance on any one technique or type of plant
	24	Archaeological discoveries – lengthy lead-in time for approvals and time for execution of mitigation strategy	3	2	3		6	9	0	Early liaison with the LA, EH, other interested parties. Archaeological watching brief during excavation. Archaeological mitigation strategy needed in case remains encountered
	65	Large groundwater inflows due to unexpectedly high permeabilities of ground	3	2	3		6	9	0	Site investigation to reduce site permeability uncertainties. Allow sufficient redundancy in the design of groundwater pumping systems to site to allow for uncertainties
	74	Approval withheld for wayleaves to install ground anchors for earth-retaining structures	3	2	3		6	9	0	Identify retaining structures where anchors required and owners of land under which they pass. Determine procedure and time required for consents to be given. Consider alternative methods of support, e.g. propping
	3	Delays by utility in issuing approvals for development adjacent to utility services	2	3	3		6	6	0	Early liaison with utility. Agree programme for submissions and approvals
	6	Flooding of building due to failure of pumping systems or sudden inflow of groundwater (basement currently being pumped)	3	2	2		6	6	0	Determine source and magnitude of current inflow. Provide cut-off to inflow. Dewater locally or across site. Provide adequate sumps and pump capacity to deal with inflows
	21	Long lead time for approvals for foreshore development	3	2	2		6	6	0	Undertake early liaison with EA/PLA. Agree programme for submissions and approvals. Determine whether physical modelling required to assess effects of development and arrange
	32	Contamination 'hotspots' during the works delays earthworks/site clearance	3	2	2		6	6	0	Identify extent of contamination by review of former site processes and undertake ground investigation. Establish procedures for testing materials on-site and contingency plans for dealing with unexpected contaminants
	40	Damage to existing highway from development	3	2	2		6	6	0	Undertake early liaison with LA. Agree programme for submissions and approvals. Agree limit of acceptable movements with LA. Determine effects of ground movements and plan extent of temporary/permanent works to avoid damage
	46	Damage to surrounding residential development due to groundwater lowering from site dewatering	3	2	2		6	6	0	Provide cut-off around site. Monitor groundwater levels outside site and control rate of dewatering accordingly. Assess susceptibility of ground beneath nearby structures to settlement due to dewatering
	47	Damage to existing structures due to excavation	2	3	3		6	6	0	Accurately determine location of structure and vulnerability to ground movements. Design temporary works to avoid damage during construction
	61	Damage and effects to foundations/neighbours due to dewatering techniques	3	2	2		6	6	0	See No. 46
	63	Effects on neighbours using dewatering techniques	3	2	2		6	6	0	See No. 46

Figure A.6 ***Site development risk management risk register (continued)***

Site Development Risk Management Register – Project X **Date: 17/05/00** **Status : Information** ARUP
Reference :

CATEGORY	RISK No.	HAZARD	PRIOR TO RCM							RISK CONTROL MEASURE (RCM)
			LIKELIHOOD	SEVERITY			RISK			
				Capital cost	Programme	Safety	Capital cost	Programme	Safety	
	66	Limitations on disposal of groundwater	2	3	3		6	6	0	Estimate flow quantities during dewatering. Undertake early discussions with EA regarding disposal of groundwater. Develop strategy for cleaning up effluent prior to disposal (requires knowledge of likely contaminants). Investigate fallback disposal of water
	85	Damage to building due to ground movements caused by site excavation	3	2	2		6	6	0	Adopt appropriate construction methods. Undertake movement/vibration monitoring during works. Establish trigger and action levels for movements and agree plans with project team and affected parties
	29	Removal of excessive amounts of contaminated material	2	3	2		6	4	0	Carry out desk study and site investigation to determine nature and extent of contaminated spoil prior to excavation. Establish site procedures to identify contaminated material and whether it can be processed/placed on site or needs to be taken away
	72	'Professional objectors' delay the scheme	2	2	4		4	8	0	Keep local residents and interest groups well informed as to development proposals from early stage. Hold regular meetings with residents. Identify action groups and liaise accordingly
	45	Delay in programme due to approval for use of listed structure	2	2	3		4	6	0	Liase with EH and LA regarding plans for development from early stage
	4	Impact on design due to location of utility services	2	2	2		4	4	0	Identify precise location of services and agree constraints on nearby development with utility at earliest opportunity. Avoid heavily loaded foundations in vicinity of services
	10	Design delayed due to as-built drawings of existing structures not being available	2	2	2		4	4	0	Identify holders and obtain as-built drawings. Design should be insensitive to precise location of existing structures if they are to be left in place, e.g. foundations
	27	Groundwater contamination – leachates affect neighbouring properties or hinder site works	2	2	2		4	4	0	Carry out desk study and site investigation to determine nature and extent of contaminated groundwater prior to excavation. Establish site procedures to identify contaminated groundwater – treat on site or take away in tankers
	28	Design changes due to late identification of contamination strategy by client/developers	2	2	2		4	4	0	Establish clear guidelines in consultation with client/EA/LA for quality of site with respect to residual contamination at end of development on a site wide or package basis. Need to determine end use of different areas of site. Consider risk-based techniques to determine allowable contaminant levels
	31	Changes in environmental legislation – uncertainty in scope and impact/lead time	2	2	2		4	4	0	Review upcoming legislation and potential effects on site works and future classification of site with respect to contamination
	58	Damage to neighbouring properties by heave due to excavation	2	2	2		4	4	0	Undertake ground movement assessment and determine likely effects on nearby properties. Carry out condition surveys if necessary. Advise team of responsibilities under Party Wall Act
	87	Hazardous gas within made ground, alluvium and peat layers affecting occupiers of the development	2	2	1		4	2	0	Site investigation to determine possible hazardous gas concentrations. If levels are greater than guideline values, incorporate mitigation strategy into design
	15	Delays to relocation and construction of the temporary power supply affect remainder of programme	1	3	5		3	5	0	Identify critical activities in relocation of supply. Ensure that site clearance and construction activities are given priority where necessary. Schedule outages and hook-up for periods of low demand
	2	Risk of unknown service affecting development	1	3	3		3	3	0	See No. 4
	86	Damage to new development roadways due to poor subgrade material	3	1	1		3	3	0	Site investigation to determine the extent and depth of the surface materials. Design to make adequate provisions for the site conditions
	75	Flooding of the site	1	2	3		2	3	0	Ensure that existing flood protection works are maintained. Provide pumps on site or keep available offsite in the event of burst water mains or heavy rainfall
	7	Buried structures – location and nature may affect perimeter wall construction	1	2	2		2	2	0	Determine location of structures and design permanent/temporary works to avoid them or carefully demolish them
	34	Delays/damage due to discovery of unexploded wartime ordnance during the works	2	1	1		2	2	0	Determine likelihood of UXBs being present from wartime records. Undertake survey by direct/indirect methods. Establish procedures to identify and make safe potential ordnance during groundworks/piling. Determine potential effects of detonation on tunnels and other sensitive underground structures
	64	Unknown groundwater flow direction and influence of river affects groundworks	2	1	1		2	2	0	Undertake hydrogeological study of site based on historical data and site measurements. Determine whether proposed site groundwater control measures are sensitive to knowledge of regional groundwater behaviour
	36	Delays due to long lead time for approval for temporary/permanent works from utility								See No. 14
	48	Approvals for monitoring regime for ground movements								Liaise with owners of adjacent properties or their representatives regarding requirements for monitoring
	49	Damage to neighbouring structures due to ground movement								See No. 58
	73	Refusal by third parties to approve use of ground anchors extending outside site								Undertake early negotiations with neighbours, LA in particular, regarding use of temporary ground anchors outside property boundary. Research precedents. Establish alternative methods if permission denied

Figure A.6 Site development risk management risk register (continued)

APPENDIX B

RISK SOFTWARE

INTRODUCTION

It is thought that software tools will in future become increasingly important for risk management teams, although at present there is little evidence that risk management software is in widespread use in the construction industry.

At the time of writing there appeared to be no software packages aimed specifically at geotechnical risk management. However, a large and rapidly growing number of packages are available for risk management in general. This appendix brings together the results of a review carried out in 1998, as part of this project, and a more recent and limited survey of current practice in the organisations represented by the Steering Group of this project.

THE 1998 SURVEY

Information on various software suppliers and their products was obtained from internet websites, brochures, correspondence via e-mail, and from comments made by respondents to a questionnaire. The *Project Risk Management Software Directory,*[46] produced by the Association for Project Management Special Interest Group on Risk Management, and the software directory of the Construction Industry Computing Association[47] provide regularly updated lists of products and suppliers.

In 1998, 31 suppliers were identified. The software fell into the following broad categories:

- risk identification and management
- risk assessment software
- decision-making software
- data management systems.

A summary of the software identified during this survey is given in Table B.1.

Risk identification and management

This category of software is focused on the identification and management of risk throughout the project cycle. Where risk identification forms a major part, the software is usually targeted at a specific industry, but the software can also be general purpose. The software is usually developed around a database that can be used for the identification of risks. It offers the opportunity of a qualitative risk assessment (rating system), but usually also allows for performing a quantitative assessment (calculation through simulation). It therefore includes all the elements of the risk management process, namely the identification of risks, categorising the risks, and managing and monitoring the risk throughout the project cycle. Examples of this type of software are TRIMS, Ris3, PROAct, Project Risk, CARMA's Risk Tools and REMIS. It is believed that some of these software packages will be suitable for managing geotechnical risk.

Risk assessment software

The second category comprises general-purpose software that can be used to evaluate the probability of a certain outcome, calculated for a specific model. This type of software comes in a variety of formats, namely:

Table B.1 Summary of software for risk management identified during the 1998 survey

Supplier	Software	Website	Application	Suitable for application in geotechnics?
Palisade software	@RISK PrecisionTree TopRank BestFit RISKview	http://www.palisade.com	General-purpose software with a wide application in the decision-making process and specifically risk assessment	Yes (risk assessment)
MBRM	Add-in tool-kits	http://www.mbrm.com	Analyse the present value of cash flows, investments or associated derivatives	Yes (but only where cash flows are considered)
Decisioneering software	Analytica Crystal Ball	http://www.decisioneering.com	Analytica is a graphical tool for modelling systems Crystal Ball is a general-purpose spreadsheet add-in for risk assessment	Yes (risk assessment)
JBF Associates	DECIDE BRAVO RMPlanner	http://www.jbfa.com/	Different software aimed at the decision-making process. DECIDE facilitates choosing between alternatives	Yes (risk assessment) Availability and support in the UK may be a problem
DACI	Design Master	http://www.cyberspy.com/~daci	Design tool for solving an equation by obtaining the probability distribution of the range of solutions	Yes (but not ideal since it only provides the solution to an equation)
Eastern Software Publishing	DPL	http://www.eastern-software.com	General-purpose graphical modelling tool based on decision trees and influence diagrams	Yes (risk assessment)
TerraMar Information Systems	DynRisk	http://mattemac22.uio.no/dynrisk/dr.html	General-purpose graphical modelling tool for risk assessment	Yes (risk assessment)
Figtree International	Figtree RMIS	http://www.figtree.co.uk	Administrative database which can be used for risk assessment	Possibly (if geotechnical data can be input in a sensible way)
Futura International	Futura	http://c10.cyberspace.fi/futura/	Software to support structured risk analysis based on the Lichtenberg method. Provides an integrated approach to risk assessment	Yes (risk assessment)
Welcom Software Technology	OpenPlan Desktop OpenPlan Professional	http://www.welcom.com/	Project management software with the built-in functionality of Monte Carlo simulation	Yes (risk assessment)
Computerline	PLANTRAC-MARSHAL for PLANTRAC-OUTLOOK	http://ourworld.compuserve.com/homepages/computerline/	Project management software with PLANTRAC-MARSHAL providing the Monte Carlo simulation function	Yes (risk assessment)
Katmar Software	PRA	http://users.lia.net/katmar/	The evaluation of capital costs on projects	Yes (calculating contingency allowance in budget)
Risk Decisions	Predict! Risk Analyser Predict! Risk Controller	–	Both quantitative and qualitative risk analysis and management of project schedules created with project management software	Yes (risk assessment and management)
Primavera Systems	Primavera Project Planner 2.0 Monte Carlo 3.0 for Primavera	http://www.primavera.com	Project planning software with a risk assessment function optional	Yes (risk assessment)
Engineering Management Servies	PROAct	http://rcinc.com/em2.html	Database orientated decision support tool allowing for both qualitative and quantitative assessment of risk	Yes (risk assessment)
ABT Corporation	Project Risk	http://www.abtcorp.com/ (no information on specific software)	Tool to facilitate the risk management process, containing a knowledge database that is specifically geared to IT system development projects	Unlikely (knowledge database needs to be adapted)
PCF	QEI Exec	http://www.pcfltd.demon.co.uk/	Project management tool that uses a structured data model for cost and schedule controlling	Yes (risk identification)
Jerry FitzGerald & Associates	RANK-IT	http://ourworld.compuserve.com/homepages/JerArdra	Risk ranking in conjunction with a Delphi team	Yes (risk assessment)
Dependency, Risk & Decision Support	RAT	http://www.dependency.com/index.html	General-purpose modelling tool for enhancing decision-making, taking into account uncertainty	Yes (risk assessment)
HVR Consulting Services Limited	REMIS	http://www.hvr-csl.co.uk/	General-purpose database application for the identification, assessment and management of risk	Yes (risk management)
Centre of Defence Analysis (DERA)	Ris[3]	http://www.dera.gov.uk (no information on software)	General-purpose risk management (qualitative assessment)	Yes (risk assessment and management)
Van Hall Institute	Risc-Human	http://www.vhall.nl/bca/pgsim/english.htm	Software for determining human exposure to soil contaminants	Yes (but in supporting the risk assessment process)
COBRA software	Risk Consultant	http://www.ewen.co.uk/ewen/csd.htm	Vulnerability of organisation's systems (security)	No
CARMA	Risk Tools	http://www.risk-reward.com/ (no information on software)	General-purpose risk management software system for risk management throughout the project cycle	Yes (risk management)
CSK software	Risk-in-Time	http://www.csksoftware.com	Risk management specifically for the financial sector	No
Eastern Software Publishing	RISK+	http://www.eastern-software.com	Add-in software for Microsoft Project allowing the impact of uncertainty to be assessed	Yes (risk assessment)
Eastern Software Publishing	RiskMaster	http://www.eastern-software.com	Graphical risk analysis tool for assessing the quantitative and qualitative aspects of risk management	Yes (risk assessment)
RiskWatch Software	RiskWatch	http://www.riskwatch.com	Vulnerability of organisation's systems (security)	No
Dyadem	RMP-Pro PHA-Pro RiskSafe 98	http://www.dyadem.com/	Software aimed at assessing and managing health and safety related risks	No
Stradplan	STRAD	http://www.btinternet.com/~stradspan/	Software for supporting decisions, based on the strategic-choice approach	Yes (risk identification)
BMPCEO software	TRIMS	http://www.bmpcoe.org	Risk management in the manufacturing industry	Possibly (if knowledge database is adapted)

- Software that can import a model created in a spreadsheet or a project management software application and then perform a simulation using this model. Examples of this type of software include Predict! Risk Analyser, PRA and RiskMaster.
- Add-in software packages that are designed to give the application that is used to describe the model (e.g. Excel or Microsoft Project) a probabilistic assessment capability. Examples of this type of software include Crystal Ball and @RISK spreadsheet add-in software and @RISK, PLANTRAC-MARSFAL, RISK+ and Monte Carlo for P3 project management add-in software.

These types of software are useful for assessing the uncertainty within a model or project schedule, and generally use Monte Carlo simulation techniques. It is, however, difficult to take into account uncertainties that are not specifically related to any of the elements or activities in the model. Furthermore, this type of software is generally not well suited as a risk management tool. Actions with 'action by' dates, which are required as part of the risk management process, generally cannot be included in the software.

Decision-making software

The next group of software is categorised as decision-making software, although this description may be misleading to some extent since some of the software packages are well suited to risk assessment. The major difference between these software packages and the risk assessment software described above is that a model is constructed graphically. This allows more freedom than, for example, using a spreadsheet. The software comes in a variety of formats, including the following:

- Software that is based on fault and event trees. Software of this format includes Precision Tree, DPL and BRAVO.
- Software with which a model can be created graphically using nodes to describe elements and arrows to describe the relationship between various elements. Software of this format includes Analytica, RAT and DynRisk.
- Software that is aimed at facilitating the decision-making process. This type of software is generally based on a specific approach to decision-making, and examples include Futura, RANK-IT and STRAD.

This category of software is therefore essentially for decision-making, but also allows for uncertainty/risks to be taken into account. It is general purpose and can also be used for assessing geotechnical risks.

Data management systems

The last category comprises large systems built around a database and designed for the processing of data, essentially automating administrative work. These systems can be general purpose, or for a specific industry. Once a large database is available for a specific organisation, it may then be possible to use these data for future risk assessments. These systems are expensive and generally are not ideally suited for the management of geotechnical risk. Examples of these types of software are Risk-in-Time and Figtree RMIS. Systems for the evaluation of a company's systems security, for example Risk Consultant and RiskWatch, may also fall into this category.

User survey results

In addition to a survey of software, a survey to investigate the use of IT and software to manage geotechnical risks was carried out, using questionnaires. A four-page questionnaire was prepared and approved by the Department of the Environment, Transport and the Regions (DETR). The questionnaire was accompanied by a covering letter signed by The Institution of Civil Engineers (ICE).

To expedite the survey the following method for distributing the questionnaire was adopted. A list of companies was prepared using the Contractors File 1998 (NCE) and the Geotechnical Services File 1998 (Ground Engineering). The BGS (1996/1997) register was also consulted. The companies contacted can be divided into the following broad categories:

- consultants – environmental
- consultants – geotechnical
- consultants – multidisciplinary
- contractors – general
- contractors – geotechnical
- contractors – site investigation.

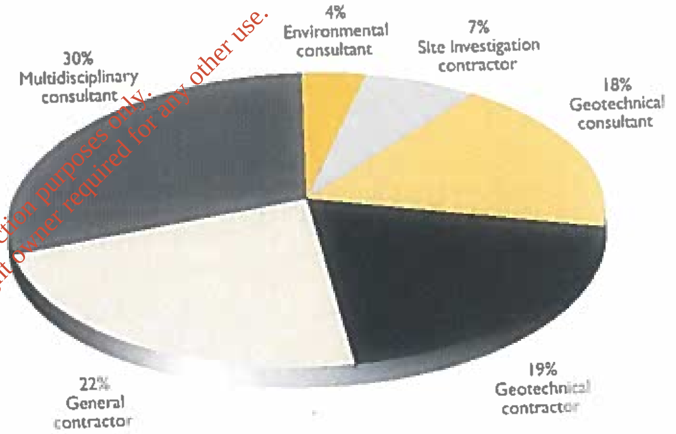


Figure B.1 Distribution of questionnaires sent, by type of organisation

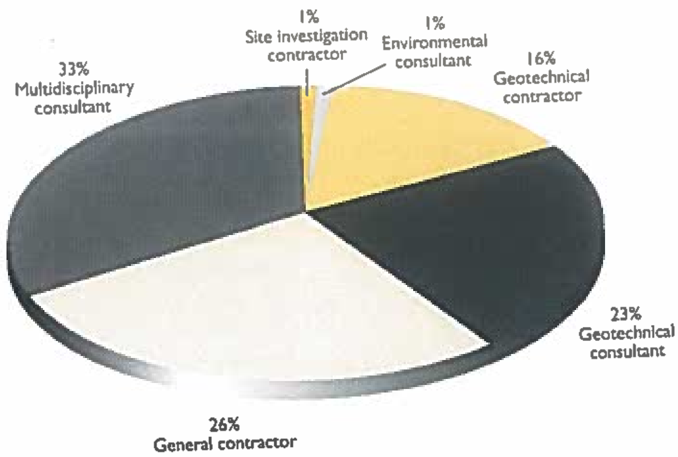


Figure B.2 Distribution of replies to questionnaires, by type of organisation

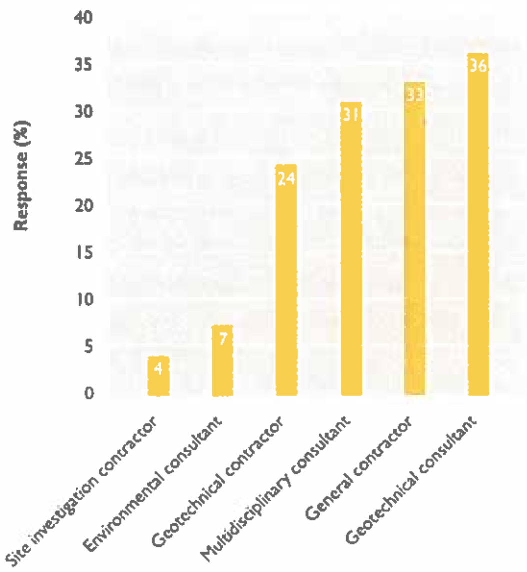


Figure B.3 Replies received per questionnaire, by type of organisation

In total 250 questionnaires were distributed, and 70 (a response rate of 28%) were returned. Although an attempt was made to distribute the questionnaires evenly, environmental consultants and site investigation contractors were less well represented than were the other categories (Figure B.1). Unfortunately, few companies in these two categories responded, and so the survey was not representative of these two groups (Figures B.2 and B.3).

The importance of risk management was confirmed by the high percentage (86%) of respondents that indicated that risk management should form part of pre-project planning. In practice, however, only 70% of them employed any form of risk management procedures. The use of risk management procedures among the various categories of companies showed that only 50% of geotechnical consultants used any form of risk management procedure, while 70% or more of the companies in the other categories adopted risk management procedures. The respondents were requested to give details of the risk management procedures they employed. The majority of respondents (74%) used either formal or informal risk management procedures, while a minority indicated that they relied on individual personnel to identify and manage risks (12%). Fourteen per cent indicated that the risk management procedures they employed were related to Health and Safety (CDM) regulations.

Of the respondents that used risk management procedures, only 30% (equivalent to about 20% of the companies that responded) used software as part of these procedures. The distribution of software used among the different categories of companies is shown in Figure B.4. It is interesting to note that the use of software for risk management is most common among contractors and also seems to be restricted to larger organisations. Two of the responding companies indicated that although they did own risk management software they rarely used it, and therefore they did not complete the questions related to risk management software.

The different software packages employed are summarised in Figure B.5. Primavera Systems' software for project planning and the add-in Monte Carlo packages were the ones most frequently mentioned. The use of risk management software during the project cycle is summarised in Figure B.6. It appears that such software is most commonly used during project appraisal.

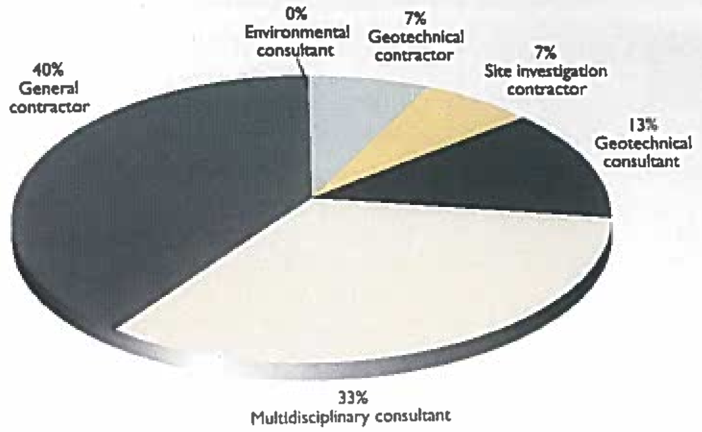


Figure B.4 ***Distribution of risk software by type of company***

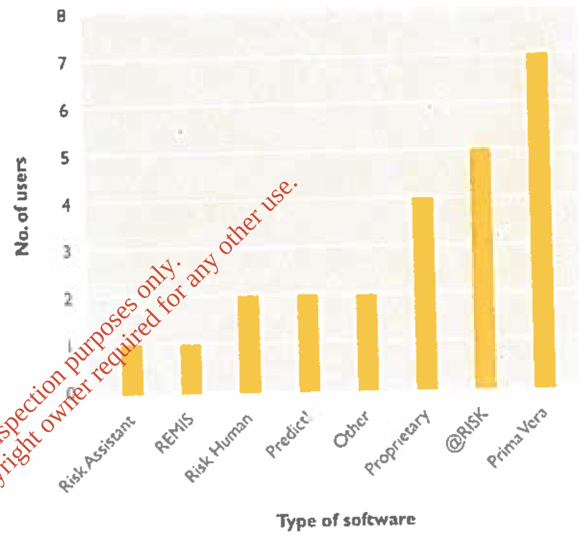


Figure B.5 ***Reported risk software use***

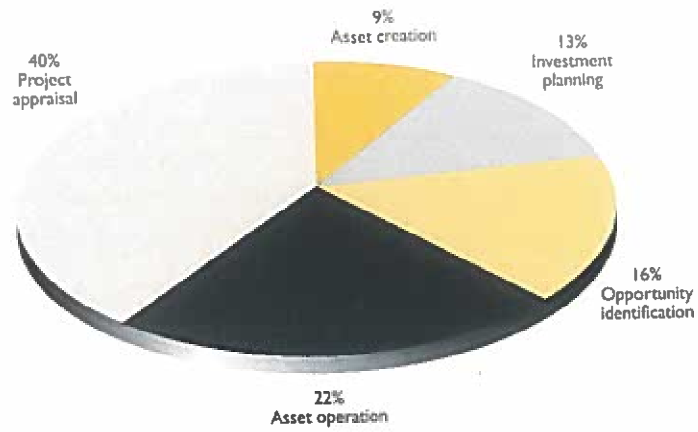


Figure B.6 ***Usage of risk management software***

Of the respondents using software for risk management, one-third indicated that they had found risk management software lacking in some respect. Four companies employed staff specifically for the use of risk management software and thought that this was economically viable.

Summary

There is now a considerable amount of software available for project risk management. In the 1998 survey none was found to have been specifically developed for geotechnical risk, but there were several categories that were nonetheless considered useful.

Although in our survey almost 90% of respondents indicated that risk management should form part of pre-project planning, only 70% employed any form of risk management procedures, and of these only 30% used software for this purpose. Primavera Systems' software seemed to be the most commonly used.

Of the various categories of companies, geotechnical companies appeared to make least use of risk management procedures and software. Almost 60% of the companies that used software for risk management were contractors, and in general the users seemed to be the larger contractors and consultants.

One-third of the respondents that used risk management software indicated that they had found software for risk management lacking in some respect.

Only a small percentage of companies employed staff solely for using risk management software, while the majority of those using risk management software believed that it was central to the satisfactory performance of their organisation.

RECENT DEVELOPMENTS

The growth of software for risk management appears to have continued since 1998. The current edition of the *Project Risk Management Software Directory*[46] lists over 40 different products, together with brief descriptions of their functions, their price and suppliers' names and addresses.

Despite this, a recent informal survey of Steering Group members for the DETR/ICE Geotechnical Risk Management project revealed that relatively few had any knowledge of the use of specialist risk software within their companies. Significantly, the major use of software was to produce risk registers (see Appendix A), and this was generally carried out using MS Excel.

During the progress of this project there have been parallel developments by the CIRIA construction risk management project, and following its report.[8] The software[11] and an associated report[12] are expected to become available in 2001. The description given below is based on a beta version of CIRIA RiskCom v.1.2 dated 10 August 2000, tested on Excel 2000 within a Windows 98 environment. The software is compatible with Windows 95, 98 and NT4, and will work either with Excel 97 or Excel 2000. The software is mounted via Windows Explorer.

RiskCom is a simple Excel-based tool that produces a risk register. It is intended to help users manage risks associated at a number of levels (e.g. an entire business, a particular project, a single activity within a project). It provides a framework within which systematic risk management can be carried out even by relatively inexperienced personnel, but makes no attempt at quantitative risk analysis. There is extensive help within the software, to guide the user through the process, and examples are given. There is also provision to modify the software to reflect company preferences.

The assessment process is divided into five steps, which broadly follow the PRAM process:

- The assessment to be carried out is defined.
- Risks are identified, and can be allocated to an area of a project or to a project activity. Opportunities can be noted.
- Risk assessment is carried out in terms of likelihood and consequence, and a rating is produced for each risk. Assessments and ratings can be generated using either a low/medium/high grading or 0 to 1 scale.
- Responses to risks are identified, together with their likely cost. Risk owners can be identified, and the fact that control measures have been put in place can be recorded.
- Reports are produced, including the top ten risks to the project as a whole (according to risk rating), the ten most imminent risks, the ten most serious risks faced by any specified owner, and the ten most imminent control measures.

The resulting spreadsheet can be distributed electronically to other team members, who can modify it in Excel or using RiskCom.

APPENDIX C

CASE HISTORIES

HOW FLEXIBILITY CAN HELP CONTROL ADDITIONAL COSTS

This case record gives an example of how unexpected geotechnical conditions can be overcome. Due to the urgency of having a proposed factory operational, a construction management approach was adopted and a construction manager was appointed. No ground investigation was carried out. The construction manager selected local consultants for the design through a tender and negotiation process.

During the subsequent site investigation it was found that the soil conditions were unfavourable. The use of traditional piled foundations would have increased the cost of the project by 25% and meant that the client's budget was exceeded.

Although the design was in a fairly advanced stage it was possible, because a construction management approach was being used, to investigate other solutions, for example other foundation alternatives or even moving the facility. In the end an alternative foundation design was adopted and the project was completed within the client's budget and a month earlier than programmed.

RISK MANAGEMENT ON A TUNNELLING PROJECT

Tunnelling is a high-risk form of construction. This case history, which concerns the construction of approximately 11 km of 3.6 m diameter tunnels and nine shafts between 15 and 25 m deep, as part of a sewage transfer system, shows how progressive clients are using systematic management to control geotechnical risks.

During the project a formal approach to risk management was adopted. Geotechnical risks were an important factor during the development of the conceptual solution. The risk management procedures included holding risk workshops, where risks were identified during brainstorming sessions. Risks were included in a risk register and all the risks were assessed using both qualitative and quantitative methods. Values were assigned to the risks and the period over which they could occur was also included in the risk register.

Based on this information the risks were assigned to either the client or the contractor, or in some cases shared. Risks owned by the contractor were included in the target cost. A risk budget was prepared for the risks owned by the client. For this type of contract the maximum cost of the project is not fixed, and the client therefore decided to take out insurance that would pay any costs above the sum of the target cost and risk budget.

The value of risks in the risk budget was reassessed on a monthly basis, and every 3 months costs that had not been realised were subtracted from the risk budget. This allowed the client to assign the money to other projects as risks were closed out.

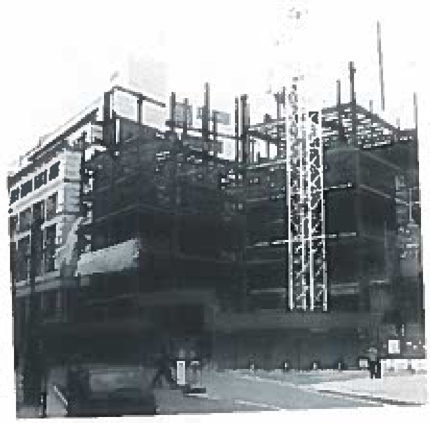
UNEXPECTED GROUND CONDITIONS ON AN INNER CITY SITE

The demolishing of an existing building and the construction of a new piled steel-frame office block, consisting of eight floors and two basement levels, provided some major challenges. The new development involved an additional basement level, and therefore the existing basement slab, up to 3.5 m thick in areas, had to be removed.

Risks identification was carried out during pre-project planning, using brainstorming sessions and meetings with the main works designer and trade contractors. The impact of the risks was assessed qualitatively and, where possible, designed for.

Despite the care taken during planning and design, unexpected ground conditions still occurred:

- The level of the London clay was, on average, approximately 1 m lower than expected and more casing had to be used during piling.
- In some areas man-made obstructions (building rubble) proved to be a problem during pile installation. This necessitated additional work, which was done outside normal working hours.
- Archaeological remains were found, despite considerable efforts during site investigation to determine whether any might be present.



TRANSFERRING GEOTECHNICAL RISKS TO THE CONTRACTOR

This case study shows the value of obtaining more information on ground conditions during preproject planning for large, potentially high-risk projects. The construction of three new parallel gas turbine repowering units immediately to the south of an existing power station included enlarging the existing platform area, which was approximately 10–15 m below ground level, for the construction of the new facility. Approximately 350,000 m^3 of material was to be excavated and placed in landforms around the power station.

Six tenderers were initially involved, and after an elimination process negotiations commenced with three of them. Because of ground-related claims during the construction of the existing power station, the client wanted to transfer the geotechnical risks to the contractor. However, none of the three contractors was willing to accept the geotechnical risk based on the information included in the tender, which consisted only of the site investigation for the original construction. Because it was a priority for the client to transfer the geotechnical risks to the contractor and because it would speed up the programme, the client decided to conduct a further, detailed geotechnical investigation. He appointed a geotechnical consultant for this purpose and requested the three contractors to submit proposals for the site investigation they would require before they would be prepared to accept the ground-related risks. The successful contractor subsequently accepted the ground-related risks, and at a reduced price, making allowance for the fact that in his original price he had included for the cost of a site investigation.

Appendix 3a

SGI Report 20th July 2004

Date	Registration number
July 20, 2004	2-0403-163
Your date	Your reference

Our reference
Per-Evert Bengtsson

AGEC Ltd
Att. Turlough Johnston
5 Kilcarrig Street
Bagenalstown
Co. Carlow
Ireland

Interim Report

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

1. COMMISSION

On commission by AGEC Ltd, Bagenalstown, Ireland, the Swedish Geotechnical Institute (SGI) is currently performing laboratory testing on soil samples from the site Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland.

The aim of the laboratory testing is to give advice on choice of type of binder and binder quantity for stabilisation of peat and mineral soil just below the peat.

Mass stabilisation of peat with different kinds of binder is a technique that has been used in Finland and Sweden but as of yet not in Ireland.

The results so far from the laboratory tests are presented in this report.

The results from the laboratory testing and earlier experiences will finally lead to a proposal for binder type and binder quantities to be used in field trials in-situ. These in turn will serve as a basis for decision on the binder type and binder quantity to be used for the planned constructions. The mixing and curing conditions in the laboratory are normally more favourable than the in-situ mixing so the field trials are a necessary part in the final choice of binder type and binder quantities.

Swedish Geotechnical Institute
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2. LABORATORY TESTING

2.1 General

The laboratory testing performed at SGI includes testing of samples received from Ireland containing peat and also mineral soils from the layers just below the peat.

The tests includes classification tests, chemical tests and environmental tests.

The tests include

- classification (BFR T21:1982, Swedish Council for Building Research)
- Von Post
- Natural water content (SS 027116, edition 3)
- Bulk density (Unit weight) (SS 027114, edition 2)
- Liquid limit (SS 027120, edition 2)
- Plastic limit (SS 027121, edition 2)
- Loss on ignition (SS 027105, edition 1, temperature 450 °C or 950 °C)

- Grain size distribution (SS 027123, edition 2)
- Unconfined compression test (SS 027128, edition 1)
- Oedometer test (SS 027129, edition 1)

- Sulphide content (SGI Report No 27E)
- Chloride content (SS 028120-1)
- Carbonate content (SGI Report No 27E)
- Content of humic acids/TOC (SS-EN 1484)
- pH (SS 028122-2)
- conductivity (SS-EN 27881-1)
- redox on pore water (SGI-method)

- total content of metal and trace elements
- avalability (NT ENVIR 003)
- batch tests with analyses of main component (Ca. Al. S ets) and trace elements (EN 12457-2 and EN12457-3)

Mixing tests are being performed with Irish cement as binder. Initially Irish cement of quality 32.5N were used but later on Irish cement of quality 42.5N has been used.

Tests with Irish cement in combination with Irish sand as binder have also been performed. The use of sand have in earlier mass-stabilisation projects been favourable to improve the mixing ability of the stabilised soil. However, it has normally not given any notable increase in shear strength.

The laboratory procedure for preparation of stabilised samples is according to SGI procedure following the principles given in the EuroSoilStab Design Guide Chapter 6.4.3.

2.2 Natural soil

In all, samples from nine boreholes have been received at SGI.

The samples from borehole PS05, PS21 and PS22 which were received 2004-03-22 have been characterized and samples from borehole PS21 and PS22 used for inital mixing tests.

Samples from borehole PS23 (TPS23A) and borehole PS35 were recevided 2004-04-16 and has been used for more comprehensive mixing tests.

Samples from borehole PH1 and PH2 were received 2004-05-13. Samples from borehole PH3 and PH4 were received 2004-05-26. The samples from borehole PH1, PH2, PH3 and PH4 are intended to be used for a separate study on the influence of high content of phosphate.

Peat samples from Borehole PS05.
From this borehole peat samples are from the depth 0.9 – 2.1 m below ground level. Results from the laboratory tests are presented in ANNEX 1.

Peat samples from Borehole PS21.
From this borehole peat samples are from the depth 0.9 - 2.7 m below ground level. Results from the laboratory tests are presented in ANNEX 2.

Peat samples from Borehole PS22.
From this borehole peat samples are from the depth 0.6 - 2.4 m below ground level. Results from the laboratory tests are presented in ANNEX 3.

Peat samples from Borehole PS23 (TPS23A).
From this borehole peat samples are from the depth 0.70 – 1.70 m below ground level. Results from the laboratory tests are presented in ANNEX 4. Determination of loss on ignition is ongoing.

Mineral soil from Borehole PS23 (TPS23A).
From this borehole 'mineral soil' samples are from the depth 1.70 – 2.40 m below ground level. Results from the laboratory tests are presented in ANNEX 5.

Peat samples from Borehole PS35.
From this borehole peat samples are from the depth 1.0 – 3.10 m below ground level. Results from the laboratory tests are presented in ANNEX 4. Determination of loss on ignition is ongoing.

Mineral soil from Borehole PS35.
From this borehole 'mineral soil' samples are from the depth 3.1 - 3.50 m below ground level. Results from the laboratory tests are presented in ANNEX 5.

Peat samples from borehole PH1, PH2, PH3 and PH4.
From these boreholes peat samples from the depth 0.05-0.25 m below ground level. Results from the laboratory tests are presented in ANNEX 6.

2.3 Sand from Ireland

The grain size distribution has been determined on two individual samples taken from the delivered Irish sand to SGI. Results are presented in ANNEX 7.

Samples for determination of total content of metals and trace elements (environmental test) has been sent to the laboratory Analytica and the results are presented in ANNEX 7.

2.4 Cement from Ireland
The Irish cement used in the stabilisation of peat from borehole PS21 and PS22 is of quality 32.5N. At SGI the loss on ignition has been determined. Results are presented in ANNEX 8.

Samples for determination of total content of metals and trace elements (environmental test) for the cement 32.5N has been sent to the laboratory Analytica and the results are presented in ANNEX 8.

The same type of testing (loss on ignition and total content of metals and trace elements) is ongoing for the cement 42.5N.

Irish cement of quality 42.5N has been used as cement binder for all the remaining stabilised peat and mineral soil samples.

2.5 Stabilised peat samples from PS21 and PS22.
Peat samples from the tubes from PS21 and PS22 (whole depth) were premixed with a dough mixer for about 10 to 15 minutes. It is possible to premix a maximum of 35 to 40 kg of peat per 'batch'.

The binder Irish cement 32.5N were introduced in the amounts 150, 200 and 250 kg/m^3 of peat. Mixing of the mixture of peat and cement were performed for 5 minutes with a dough mixer. The mixing could be compared to the mixing of the ingredients to a bread. A maximum of 5 to 6 kg of stabilised soil is possible per 'batch'.

The stabilised soil were placed in layer by layer in plastic tubes with an inner diameter of 68,6 mm. Each layer where even out by a small 'steel' footing. The length of the sample is measured and is about 220 mm. The density of the sample were determined and the samples placed in a water container where the sample have a filterstone at both ends to allow suction/drainage of free water to the sample.

The load used during curing (18 kPa) were placed 45 minutes after the mixing was finished. The load applied consists of a steel bar with a diameter somewhat smaller than the inner diameter of the tube and a length corresponding to a sample load of 18 kPa. The steel bar is marked with a scale that makes it possible to measure the compression of the sample at curing by noting the position of the upper end of the sampling tube compared to the scale.

The temperature during curing is room temperature of about 20 °C.

The vertical compression of samples were measured after 1 day and 3 days curing time and directly before the sample were taken to be tested by unconfined compression test.

At predetermined times after mixing, the samples where tested by unconfined compression test. Before testing the bulk density of the sample were determined. The water content were determined on remains from the cutting of the sample.

In all 16 samples were prepared, 4 samples with a binder content of 150 kg/m^3, 8 samples with 200 kg/m^3 and 4 samples with 250 kg/m^3.

Unconfined compression tests have been performed at curing ages of 7, 14, 28 and 90 days. The results from the tests are given in ANNEX 9.

The results indicates a shear strength after 28 days curing time (binder cement 32.5N) of
- about 60 kPa for a binder quantity of 150 kg/m^3
- about 120 kPa for 200 and 250 kg/m^3.

And it indicates a shear strength after 90 days curing time (binder cement 32.5N) of
- about 75 kPa for a quantity of 150 kg/m^3
- about 130 kPa for 200 kg/m^3
- about 175 kPa for 250 kg/m^3.

2.6 Stabilised peat samples from borehole PS23 (TPS23A).
Peat samples from the tubes from PS23 (TPS23A) (whole depth 0.7-1.7 m) were used and samples prepared in the same manner as above for PS21 and PS22, see chapter 2.5.

The binder Irish cement 42.5 N were introduced in the amounts 50, 100, 150, 200 and 250 kg/m^3. Sample diameter is 68,6 mm and the samples were loaded during curing (18 kPa). The temperature during curing is room temperature of about 20 °C.

The vertical compression of samples were measured during curing and directly before the sample were taken to be tested by unconfined compression test.

At predetermined times after mixing, the samples were tested by unconfined compression test. Before testing the bulk density of the sample were determined. The water content were determined on remains from the cutting of the sample.

In all 20 samples were prepared, 4 samples with a binder quantity of 50 kg/m^3, 4 samples with 100 kg/m^3, 4 samples with 150 kg/m^3, 4 samples with 200 kg/m^3 and 4 samples with 250 kg/m^3.

Unconfined compression tests have so far been performed at a curing age of 28 days. The remaining 10 samples are scheduled to be tested after 90 days curing time. The results from the tests are given in ANNEX 10.

The results indicates a shear strength after 28 days curing time (binder cement 42.5N) of
- about 15 kPa for a binder quantity of 50 kg/m^3
- about 40 kPa for 100 kg/m^3
- about 80 kPa for 150 kg/m^3
- about 100 kPa for 200 kg/m^3
- about 130 kPa for 250 kg/m^3.

2.7 Stabilised peat samples from borehole PS35, depth 2.1-3.1 m.
Peat samples from the tubes from PS35 (depth 2.1-3.1 m) were used and samples prepared in the same manner as above, see chapter 2.5.

The binder Irish cement 42.5 N were introduced in the amounts 150, 200 and 250 kg/m^3. Sample diameter is 68,6 mm and the samples were loaded during curing (18 kPa). The temperature during curing is room temperature of about 20 °C.

The vertical compression of samples were measured during curing and directly before the sample were taken to be tested by unconfined compression test.

At predetermined times after mixing, the samples were tested by unconfined compression test. Before testing the bulk density of the sample were determined. The water content were determined on remains from the cutting of the sample.

In all 20 samples were prepared, 8 samples with a binder quantity of 150 kg/m^3, 8 samples with 200 kg/m^3 and 4 samples with 250 kg/m^3.

Unconfined compression test has so far been performed at curing ages of 7, 14 and 28 days. The remaining 6 samples are scheduled to be tested after 90 days curing time. The results from the tests are given in ANNEX 11.

The results indicates a shear strength after 28 days curing time (binder cement 42.5N) of
- about 80 kPa for 150 kg/m^3
- about 110 kPa for 200 kg/m^3
- about 180 kPa for 250 kg/m^3.

2.8 Stabilised peat samples from borehole PS35, depth 1.1-2.1 m.
Peat samples from the tubes from PS35 (depth 1.1-2.1 m) were used and samples prepared in the same manner as above, see chapter 2.5.

The binder in this case was a combination of Irish sand and Irish cement 42.5 N. The Irish sand have the quantity 100 kg/m^3 and the Irish cement 42.5 N were introduced in the quantity 50, 100 and 150 kg/m^3. Sample diameter is 68,6 mm and the samples were loaded during curing (18 kPa). The temperature during curing is room temperature of about 20 °C.

The vertical compression of samples were measured during curing and directly before the sample were taken to be tested by unconfined compression test.

At predetermined times after mixing, the samples were tested by unconfined compression test. Before testing the bulk density of the sample were determined. The water content were determined on remains from the cutting of the sample.

In all 12 samples were prepared,
- 4 samples with a binder quantity of sand 100 kg/m^3 and cement 50 kg/m^3
- 4 samples with sand 100 kg/m^3 and cement 100 kg/m^3
- 4 samples with sand 100 kg/m^3 and cement 150 kg/m^3.

Unconfined compression tests have so far been performed at a curing age of 28 days. The remaining 6 samples are scheduled to be tested after 90 days curing time. The results from the tests are given in ANNEX 12.

The results indicates a shear strength after 28 days curing time (binder cement 42.5N) of

- about 25 kPa for sand 100 kg/m^3 and cement 50 kg/m^3
- about 50 kPa for sand 100 kg/m^3 and cement 100 kg/m^3
- about 95 kPa for sand 100 kg/m^3 and cement 150 kg/m^3.

2.9 Stabilised 'mineral soil' samples from borehole PS23 (TPS23A), depth 1.70-2.10 m.
'Mineral soil' samples from the tubes from PS23 (TPS23A) (depth 1.70-1.80 m and depth 1.80-2.10 m) were used and samples prepared in the same manner as above, see chapter 2.5.

The binder was Irish cement 42.5 N and were introduced in the amounts 200 kg/m^3 for samples from depth 1.70-1.80 m and 100 kg/m^3 for samples from depth 1.80-2.10 m. Sample diameter is 50,0 mm and the samples were not loaded during curing. The temperature during curing is room temperature of about 20 °C.

At predetermined times after mixing, the samples were tested by unconfined compression test. Before testing the bulk density of the sample were determined. The water content were determined on remains from the cutting of the samples.

In all 6 samples were prepared , 2 samples for depth 1.70-1.80 m with a binder quantity of cement 200 kg/m^3 and 4 samples for depth 1.80-2.10 m with a binder quantity of cement of 100 kg/m^3.

Unconfined compression test has so far been performed at a curing age of 28 days. The remaining 2 samples are scheduled to be tested after 90 days curing time. The results from the tests are given in ANNEX 13.

The results indicates a shear strength after 28 days curing time (binder cement 42.5N) of

- about 130 kPa for depth 1.70-1.80 m and cement 200 kg/m^3
- about 75 kPa for depth 1.80-2.10 m and cement 100 kg/m^3.

2.10 Stabilised 'mineral soil' samples from borehole PS35, depth 3.10-3.35 m.
'Mineral soil' samples from the tubes from PS35 (depth 3.10-3.35 m) were used and samples prepared in the same manner as above, see chapter 2.5.

The binder was Irish cement 42.5 N and were introduced in the amount 200 kg/m^3. Sample diameter is 50,0 mm and the samples were loaded during curing (18 kPa). The temperature during curing is room temperature of about 20 °C.

The vertical compression of samples were measured during curing and directly before the sample were taken to be tested by unconfined compression test.

At predetermined times after mixing, the samples were tested by unconfined compression test. Before testing the bulk density of the sample were determined. The water content were determined on remains from the cutting of the sample.

In all 4 samples were prepared with a binder quantity of cement 200 kg/m^3.

Unconfined compression test has been performed at a curing age of 7 and 28 days. The results from the tests are given in ANNEX 13.

The results indicates a shear strength after 28 days curing time (binder cement 42.5N) of
- about 50 kPa with cement 200 kg/m^3

2.11 Stabilised peat samples from borehole PS23 (TPS23A) and PS35 for oedometer test.
Peat samples from the tubes from PS23 (TPS23A) at depth 1.0-1.2 m and PS35 at depth 2.6-2.8 m were used and samples prepared in the same manner as above, see chapter 2.5.

The binder Irish cement 42.5 N were introduced in the amounts 200 kg/m^3. Sample diameter is 100,0 mm and the samples were loaded during curing (18 kPa). The temperature during curing is room temperature of about 20 °C.

The vertical compression of samples were measured during curing and directly before the sample were taken to be tested by oedometer test.

Before testing the bulk density of the sample were determined. The water content were determined on remains from the cutting of the sample.

In all four samples were prepared, 2 samples from PS23 (TPS23A) at depth 1.0-1.2 m and 2 samples from PS35 at depth 2.6-2.8 m.

The oedometer tests on three samples are ongoing and the samples were mounted into the oedometer at a curing age of 28 days. The remaining sample from PS23 (TPS23A) at depth 1.0-1.2 m can be used for future testing. The results from the tests so far are given in ANNEX 14.

The results indicates a clearly softer behaviour than the results indicated from the unconfined compression tests.

2.12 Testing for environmental impact.
Test for the environmental impact have been scheduled. Total content tests and batch tests on both natural soil and stabilised soil are proposed.

Swedish Geotechnical Institute
Dept. of Geotechnical Design

Per-Evert Bengtsson
Project manager

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 1. Peat samples from borehole PS05

ANNEX 1:1 Summary

PS05_wL

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on peat samples

Borehole : PS05

Depth m	Depth m	Length m	Density t/m³	Filling [1]	w_n^{mean} %	Von Post	Loss on ignition %	Liquid limit w_L %	Plastic limit w_P %
1,10	1,20	0,10	0,92	( )	1088	5-6	98,1	1003	
1,20	1,40	0,20							
1,40	1,50	0,10	0,83	( )	1131	6-7	98,2	1042	
1,50	1,70	0,20							
1,70	1,80	0,10	0,91	( )	1252	6-7	98,1	1079	
1,80	2,00	0,20							
2,00	2,10	0,10	0,94	( )	899	8	97,8	802	235

[1] ( ) = The peat sample is not filling the whole sampling tube diameter (gives to low density)

Per-Evert Bengtsson, SGI

Laboratory_Classification_SGI_040414

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 2. Peat samples from borehole PS21

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on peat samples

Borehole : **PS21**

Depth m	Depth m	Length m	Density t/m³	Filling ¹⁾	w_n^{mean} %	von Post	Loss on ignition %	Liquid limit w_L %	Plastic limit w_P %
1,00	1,10	0,10	0,91	( )	1103	6	97,6	1103	
1,10	1,30	0,20							
1,30	1,40	0,10	1,00		1255	6-7	97,8	1082	
1,40	1,60	0,20							
1,60	1,70	0,10	0,98		1104	7	97,8	854	320
1,70	1,80	0,10							
1,80	1,90	0,10		(Shoe)					
1,90	1,92	0,02							
1,92	2,12	0,20							
2,12	2,22	0,10	0,95	( )	1152	7-8	97,7	910	324
2,22	2,42	0,20							
2,42	2,52	0,10	0,90	( )	1090	6-7	97,7	939	
2,52	2,61	0,09							
2,61	2,75	0,14		( )	869	6-7	97,9	750	

1) ( ) = The peat sample is not filling the whole sampling tube diameter (gives to low density)

Per-Evert Bengtsson, SGI

Laboratory_Classification_SGI_040414

Summary of chemical laboratory tests performed on peat from borehole PS21.

PS21 @ 1.10-1.30 m.
FeS 0,9%
DOC 37 mg/l
Cloride 31 mg/l
pH 4,9
Resistivity 19,2 mS/m at 25°C
Redox potential 448 mV

PS21 @ 2.22-2.42 m.
FeS 1,0%
DOC 40 mg/l
Cloride 32 mg/l
pH 4,8
Resistivity 18,0 mS/m at 25°C
Redox potential 505 mV

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

SGI
581 93 Linköping

SAMMANSTÄLLNING AV LABORATORIEUNDERSÖKNINGAR

Projekt : AGEC Ltd, Ireland				Dnr 2-0403-0163 Miljönr. 04049 Proj.nr. 11989
Beställare	Registrerad Datum	Lab.undersökning utförd Datum	Av	Utfärdad Datum 04-07-01
Per-Evert Bengtsson	2004-04	2004-04—2004-06	Cto	Teknisk ledare [signature]

Provbeteckning/ Parameter		PS 21 1,10-1,30 m	PS 21 2,22-2,42 m	Metod
FeS	%	0,9	1,0	SGI Rapport 27

Provbeteckning/ Parameter		PS 21 1,10-1,30 m Porvatten	PS 21 2,22-2,42 m Porvatten	Metod
DOC	mg/l	37	40	Utfört av Analytica
Klorid	mg/l	31	32	Utfört av Analytica
pH		4,9	4,8	SS 028122
Ledningsförmåga	mS/m 25°C	19,20	18,01	SS-EN 27888
Redox Eh	mV	448	505	SGI metod

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 3. Peat samples from borehole PS22

ANNEX 3:1 Summary

SGI

2004-07-20

Dnr 2-0403-163
ANNEX 3:1

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on peat samples

Borehole : PS22

Depth m	Depth m	Length m	Density t/m³	Filling [1]	w_n^{mean} %	Von Post	Loss on ignition %	Liquid limit w_L %	Plastic limit w_P %
0,75	0,80	0,05							
0,80	0,90	0,10	0,84	( )	936	6	97,2	936	
0,90	1,10	0,20							
1,10	1,20	0,10	0,85	( )	1066	5-6	97,0	1055	
1,20	1,40	0,20							
1,40	1,50	0,10	0,95	( )	1056	6-7	97,7	973	
1,50	1,60	0,10		(Shoe)					
1,75	1,77	0,02							
1,77	1,87	0,10	0,89	( )	1268	7-8	97,4	885	309
1,87	2,07	0,20							
2,07	2,17	0,10	0,99		1253	6-7	97,7	1080	
2,17	2,37	0,20							
2,37	2,47	0,10	1,00		1014	7-8	97,3	740	267
2,47	2,50	0,03							
2,50	2,60	0,10							

[1] ( ) = The peat sample is not filling the whole sampling tube diameter (gives to low density)

Per-Evert Bengtsson, SGI

Laboratory_Classification_SGI_040414

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 4. Peat samples from borehole TPS23 and PS35

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on peat samples

Borehole : **PS - TPS23** **Sampling tube No 2**

No	Depth m	Depth m	Length m	Density t/m³	Filling [1)]	w_n^1 %	w_n^2 %	w_n^{mean} %	Von Post	Loss on ignition Sample 1 %	Loss on ignition Sample 2 %	Loss on ignition Mean %	For stabilisation m
42	0,80	0,90	0,10		( )	1008	1023	1015	(5)				
41	0,90	1,00	0,10										
40	1,00	1,20	0,20		( )	810	896	853	5				
39	1,20	1,30	0,10										
38	1,30	1,50	0,20		( )	699	762	731	7-8				
37	1,50	1,60	0,10										
36	1,60	1,70	0,10										

[1)] ( ) = The peat sample is not filling the whole sampling tube diameter (gives to low density)

0,00 m

Per-Evert Bengtsson, SGI

Batch_2_Laboratory_Classification_Peat_SGI_040507

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on peat samples

Borehole : PS35 Sampling tube no 1 (depth 1,00-2,10 m) and no 4 (depth 2,10-3,00 m)

No	Depth	Depth	Length	Density	Filling 1)	w_n^1	w_n^2	w_n^{mean}	Von Post	Loss on ignition Sample 1	Loss on ignition Sample 2	Loss on ignition Mean	For stabilisation
	m	m	m	t/m³		%	%	%		%	%	%	m
49	1,18	1,30	0,12										
48	1,30	1,40	0,10			1214	1195	1204	4-5				
47	1,40	1,60	0,20										
46	1,60	1,70	0,10										
45	1,70	1,90	0,20										
44	1,90	2,00	0,10			1041	1031	1036	5-6				
43	2,00	2,10	0,10										
57	2,00	2,10	0,10										
56	2,10	2,20	0,10										
55	2,20	2,30	0,10			1291	1380	1336	7-8				
54	2,30	2,50	0,20										
53	2,50	2,60	0,10										
52	2,60	2,80	0,20										
51	2,80	2,90	0,10			845	838	842	8				
50	2,90	3,00	0,10										

1) ( ) = The [illegible] sample is not filling the whole sampling tube diameter (gives to low density) 0,00 m

Per-Evert Bengtsson, SGI

Batch_2_Laboratory_Classification_Peat_SGI_040507

SGI LABORATORIET

RAPPORT utfärdad av ackrediterat laboratorium
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SAMMANSTÄLLNING AV LABORATORIEUNDERSÖKNINGAR

Beställare: AGEC Ltd, 5 Kilcarrig Street Bagenalstown IRELAND

Corrib Gas Terminal

Tabell

Dnr 2-0403-163

Datum 2004-05-03

Teknisk ledare

Ankomstdatum	Provtagningsredskap	Laboratorieundersökning Datum	Utförd av
040416	Torvprovt. ϕ 100 mm	040429	OA IMK

Sektion/ Borrhål/ Djup	Benämning enligt "Jordarternas indelning och benämning", Geotekniska laboratorieanvisningar del 2. 1981 års system [1]	Densitet [2] ρ t/m³	Vattenkvot [3] w %	Konflytgräns [4] w_L %	Humifieringsgrad [5] von Post	Jordartsbenämning (Anmärkning)
PS TPS23						
0,9-1,0	BRUN MELLANTORV		1015		(5)	Tm
1,2-1,3	BRUN MELLANTORV		(853)*		5	Tm *=Stor spridning
1,5-1,6	BRUN TORV		731		7-8	T
PS-35						
1,3-1,4	BRUN TORV		1204		4-5	T
1,9-2,0	BRUN MELLANTORV		1036		5-6	Tm
2,2-2,3	BRUN TORV		1336		7-8	T
2,8-2,9	BRUNSVART HÖGFÖRMULTNAD TORV		842		8	Th

B10 2004-04-16

1) Baserad på okulär jordartsklassificering. Hänsyn har tagits till förekommande mätdata.
2) Skrymdensitet SS 027114, Utgåva 2
3) Vattenkvot SS 027116, Utgåva 3
4) Konflytgräns SS 027120, Utgåva 2
5) Metoden är ej ackrediterad.
Mätosäkerhet och mätområde för våra metoder redovisas på vår hemsida, www.swedgeo.se.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 5. Mineral soil samples from borehole TPS23A and TPS35

Summary of laboratory test performed on mineral soils from TPS23A and TPS35.

TPS 23A @ 1.70-1.80 m.
Brown-black peat with fragments of sand and gravel.
The peat was firm. Difficult to determine the degree of humification. Looks to contain peat with both high and low degree of humification. Large variations in the two determination of water content
Natural water content 52% and 26%
Liquid limit (fall cone) 71%
Plastic limit 48%
Loss on ignition (450 degree Celsius) 14,0% and 15,0% with mean 14,5%
Loss on ignition (950 degree Celsius) 14,5% and 15,5% with mean 15,0% (on the same samples as for 450 degree Celsius)

TPS 23A @ 1.80-2.10 m.
Brown, slightly organic, sandy, silty clay with fragments of peat.
Natural water content 35% and 29%
Liquid limit (fall cone) 40%
Plastic limit 30%
Grain size distribution (sieving and sedimentation) determined on a small sample (not according to standard) and specific density determined to 2,49 t/m3.
Organic content 4,2% (4,3% and 4,1%).

TPS 23A @ 2.10-2.40 m.
Grey, sandy, silty clay with remains of plants. (The sample looks like a till)
Natural water content 21% and 16%
Liquid limit 21%
Plastic limit 17%
Grain size distribution (sieving and sedimentation) determined on a small sample (not according to standard) and specific density determined to 2,64 t/m3.
Organic content 1,0% (1,0% and 1,0%).

TPS 35 @ 3.10 -3.35 m.
Brownblack highly humified peat with fragments of sand and gravel.
Natural water content 518% and 250%
Liquid limit 267%
Plastic limit 69%
Von Post H9-H10
Loss on ignition (450 degree Celsius) 51,5% and 50,5% with mean 51,0%
Loss on ignition (950 degree Celsius) 53,7% and 53,7% with mean 53,7% (on the same samples as for 450 degree Celsius)

TPS 35 @ 3.35-3.50 m.
Grey silty sand with fragments of gravel and peat.
Natural water content 18% and 17%
Liguid limit not determined (NA)
Plastic limit not determined (NA)
Grain size distribution (sieving) determined on a small sample (not according to standard).
Organic content 1,4% (1,3% and 1,5%).

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
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REPORT is issued by an Accredited Laboratory

SAMMANSTÄLLNING AV LABORATORIEUNDERSÖKNINGAR

Beställare: AGEC Ltd, 5 Kilcarrig Street Bagenalstown IRELAND

Corrib Gas Terminal

Tabell	
Dnr	2-0403-0163
Datum	2004-05-04
Teknisk ledare	

Ankomstdatum	Provtagningsredskap	Laboratorieundersökning Datum	Utförd av
040416		040423-040503	OA IMK

Sektion/ Borrhål/ Djup	Benämning enligt "Jordarternas indelning och benämning", Geotekniska laboratorieanvisningar, del 2. 1981 års system [1]	[2] Vattenkvot w %	[3] Konflytgräns w_L %	[4] Plasticitetsgräns w_P %	Plasticitetstal w_L-w_P %	[5] Humifieringsgrad von Post	Jordartsbenämning (Anmärkning)
TPS-23A							
1,7-1,8	BRUNSVART TORV MED INSLAG AV SAND OCH GRUS	(52)* 26	71	48		-	Torven var fast. Svårt att bestämma humifieringsrad. Såg ut att vara både hög- och lågförmultnad *Stor spridning
1,8-2,1	BRUN, NÅGOT ORGANISK, SANDIG, SILTIG LERA MED INSLAG AV TORV	35 29	40	30			(org.)sa si Le
2,1-2,4	GRÅ, SANDIG, SILTIG LERA MED VÄXTDELAR	21 16	21	17			sa si Le vx (Moränliknande)
PS 35							
3,10-3,35	BRUNSVART HÖGFÖRMULTNAD TORV MED SAND- OCH GRUSINSLAG	518 250	267	69		9-10	Th
3,35-3,50	GRÅ SILTIG SAND MED GRUSINSLAG OCH INSLAG AV TORV	18 17	-	-			si Sa

1) Baserad på okulär jordartsklassificering. Hänsyn har tagits till förekommande mätdata.
2) Vattenkvot, SS 027116, utgåva 3
3) Konflytgräns, SS 027120, utgåva 2
4) Plasticitetsgräns, SS027121, utgåva 2
5) Ej ackrediterad metod
Mätosäkerhet och mätområde för våra metoder redovisas på vår hemsida, www.swedgeo.se.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

SGI LABORATORIET

SWEDAC ACKREDITERING 1148 **RAPPORT**
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SAMMANSTÄLLNING AV LABORATORIEUNDERSÖKNINGAR-TABELL 1

Projekt : Organisk halt				Dnr
				Miljönr. 04049
Beställare	Registrerad Datum	Lab.undersökning utförd Datum	Av	Utfärdad Datum
Inga-Maj Kaller	2004-04	2004-05-05	Mly, Oto	Teknisk ledare

Provbeteckning	Organisk halt (%)	Metod
TPS 23 A 1,8-2,1	4,3 / 4,1	SS 027107
TPS 23 A 2,1-2,4	1,0 / 1,0	SS 027107
PS 35 3,35-3,50	1,3 / 1,5	SS 027107

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ARBETSPROTOKOLL - GLÖDGNINGSFÖRLUST

DNR. 2-0403-0163
DAT. 040428
SIGN. OA

Prov nr: PS234 1,70-1,80

Provbeteckning:

Glödgningstemp.: 450 °C

	F10		F21	
Degel nr:				
Degel vikt (m_1)	21,44	g	21,04	g
Degel + Torrt prov (m_2)	45,39	g	44,78	g
Degel + Glödgat prov (m_3)	42,05	g	41,23	g

Beräkning:

$$\frac{m_2 - m_3}{m_2 - m_1} \cdot 100 = \%$$

F10: $\frac{45.39 - 42.05}{45.39 - 21.44} = \frac{3.34}{23.95} =$

F21: $\frac{44.78 - 41.23}{44.78 - 21.04} = \frac{3.55}{23.74} =$

Glödgningsförlust: 13.95 % 14.95 %

Glödgningsförlust MV: 14.45 %

ARBETSPROTOKOLL - GLÖDGNINGSFÖRLUST

DNR. 2-0403-0163

DAT. ....

SIGN. ....

Prov nr: PS23A 1.70-1.80

Provbeteckning:

Glödgningstemp.: 950 °C

	F10	F21
Degel nr:		
Degel vikt (m_1)	21,44 g	21,04 g
Degel + Torrt prov (m_2)	45,39 g	44,78 g
Degel + Glödgat prov (m_3)	41,92 g	41,10 g

Beräkning:

$$\frac{m_2 - m_3}{m_2 - m_1} \cdot 100 = \%$$

$\frac{45{,}39-41{,}92}{45{,}39-21{,}44} = \frac{3{,}47}{23{,}95}$ $\frac{44{,}78-41{,}10}{44{,}78-21{,}04} = \frac{3{,}68}{23{,}74}$

Glödgningsförlust: 14,49 % 15,50 %

Glödgningsförlust MV: 15,00 %

ARBETSPROTOKOLL - GLÖDGNINGSFÖRLUST

DNR 2-0403-0163
DAT 040428
SIGN OA

Prov nr: PS 35 3,10-3,35

Provbeteckning:

Glödgningstemp.: 450 °C

	F20		F36	
Degel nr:				
Degel vikt (m_1)	21,28	g	21,05	g
Degel + Torrt prov (m_2)	34,13	g	34,15	g
Degel + Glödgat prov (m_3)	27,51	g	27,54	g

Beräkning:

$$\frac{m_2 - m_3}{m_2 - m_1} \cdot 100 = \%$$

F20: $\frac{34.13-27.51}{34.13-21.28} = \frac{6.62}{12.85}$

F36: $\frac{34.15-27.54}{34.15-21.05} = \frac{6.61}{13.10}$

Glödgningsförlust: 51,52 % 50,46 %

Glödgningsförlust MV: 50,99 %

ARBETSPROTOKOLL - GLÖDGNINGSFÖRLUST

DNR. 2-0403-0163
DAT. 040428
SIGN. O/

Prov nr: PS35 3.10-3,35

Provbeteckning:

Glödgningstemp.: 950 °C

Degel nr:	F20	F36
Degel vikt (m_1)	21,28 g	21,05 g
Degel + Torrt prov (m_2)	34,13 g	34,15 g
Degel + Glödgat prov (m_3)	27,23 g	27,11 g

Beräkning:

$$\frac{m_2 - m_3}{m_2 - m_1} \cdot 100 = \%$$

$$\frac{34,13-27,23}{34,13-21,28} = \frac{6,90}{12,85} = \qquad \frac{34,15-27,11}{34,15-21,05} = \frac{7,04}{13,10} =$$

Glödgningsförlust: 53,70 % 53,74 %

Glödgningsförlust MV: 53,72 %

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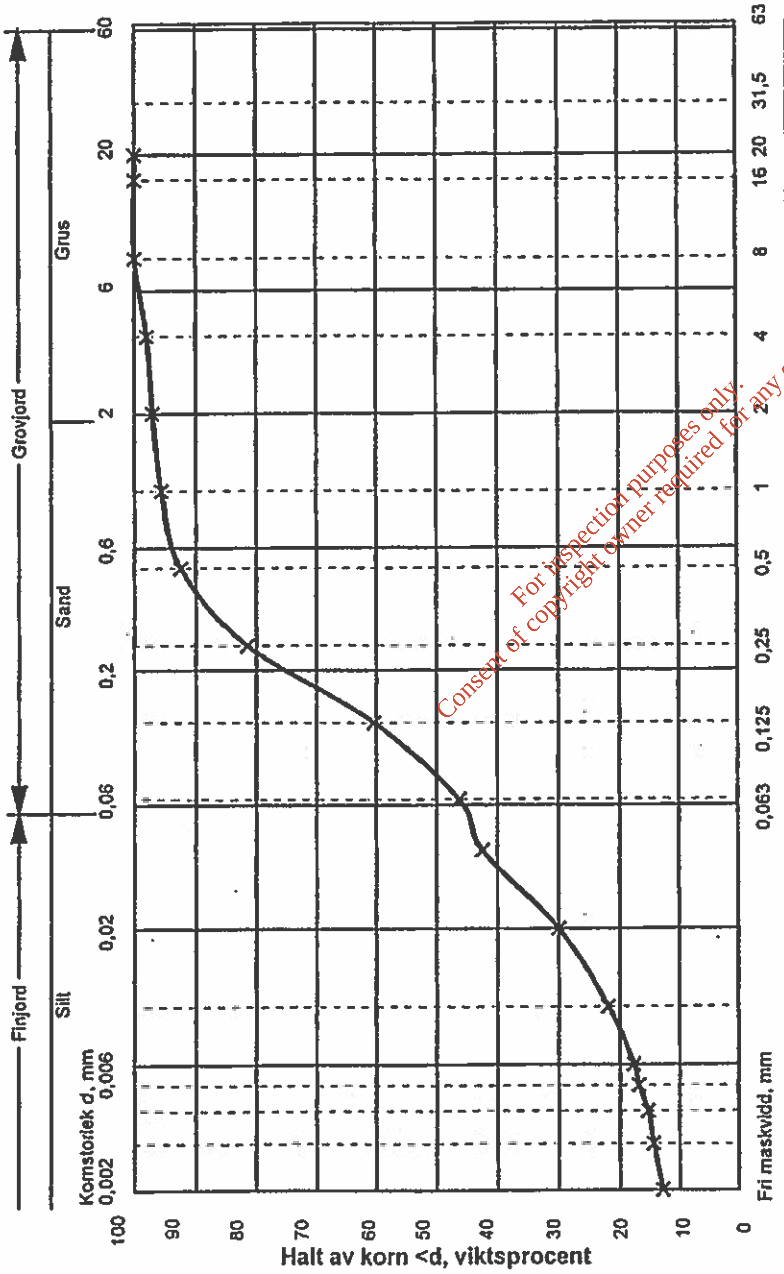
SWEDAC ACKREDITERING

KORNFÖRDELNING FRAKTIONSINDELNING 1981

Corrieb Gas Terminal Beställare: AGEC Ltd, Irland			Diagram 1 (3) Dnr 2-0403-0163
Ankomstdatum 040416	Provtagningsredskap	Laboratorieundersökning Datum 040428--0503 Utförd av SZ	Datum 2004-05-04 Teknisk ledare Inga-Maj Kallin



PROVET ÄR TVÄTTSIKTAT

PROV NR: TPS 23 A
DJUP: 1,8 - 2,1 m

SEDIMENTATIONSFÖRSÖK VÅGKROPPSMETODEN
LERHALT % AV MTRL <0,06 mm: 27
FÖRBEHANDLING:
PROVMÄNGD g: 81

SIKTNING SS 027123 UTGÅVA 2
HALT AV MTRL % >20 mm: 0,0
STÖRSTA KORNSTORLEK mm:
SIKTAD PROVMÄNGD g <20 mm: 181,04
SIKTAD PROVMÄNGD g <63 mm:
TOTAL PROVMÄNGD g: 181,04

ANMÄRKNING: Korndensiteten har bestämts till 2,49 t/m3
Liten provmängd

GRADERINGSTAL $C_u = d_{60}/d_{10}$:
TJÄLFARLIGHETS KLASS ENL ATB VÄG:
MATERIALTYP ENL ATB VÄG:
BENÄMNING AV MTRL <20 mm: saSiLe

Ackrediterat laboratorium utses av Styrelsen för teknisk ackreditering (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17025.
Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat.
Resultaten gäller enbart för de provade materialen.

Programversion 1.2

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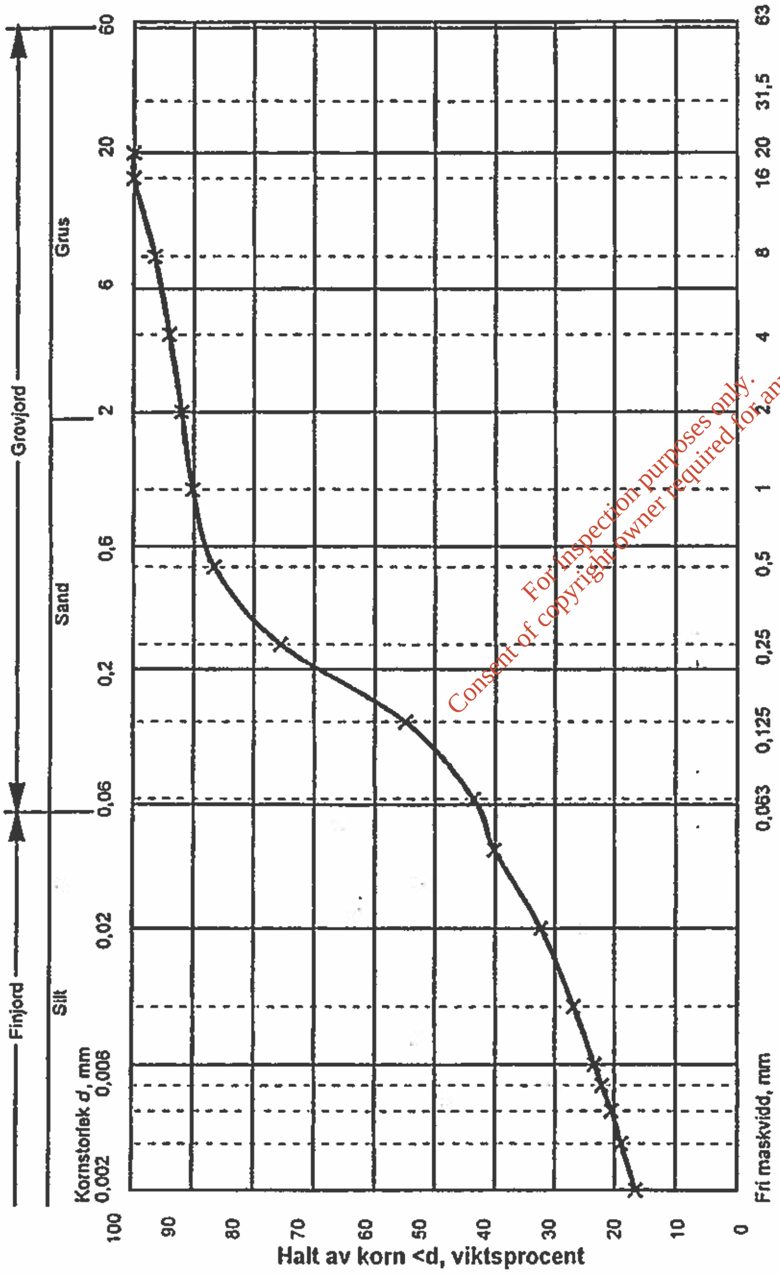
SWEDAC ACKREDITERING

KORNFÖRDELNING FRAKTIONSINDELNING 1981

Corrieb Gas Terminal Beställare: AGEC Ltd, Irland			Diagram	2 (3)
			Dnr	2-0403-0163
Ankomstdatum	Provtagningsredskap	Laboratorieundersökning Datum / Utförd av	Datum	2004-05-04
040416		040428--0503 / SZ	Teknisk ledare	Inga-May Kallur



PROVET ÄR TVÄTTSIKTAT

PROV NR: TPS 23 A
BH/SEKT:
DJUP: 2,1 - 2,4 m

SEDIMENTATIONSFÖRSÖK VÅGKROPPSMETODEN
- LERHALT % AV MTRL <0,06 mm: 38
- FÖRBEHANDLING:
- PROVMÄNGD g: 94

SIKTNING SS 027123 UTGÅVA 1
- HALT AV MTRL % >20 mm: 0,0
- STÖRSTA KORNSTORLEK mm:
- SIKTAD PROVMÄNGD g <20 mm: 227,84
- SIKTAD PROVMÄNGD g <63 mm:
- TOTAL PROVMÄNGD g: 227,84

ANMÄRKNING: Korndensiteten har bestämts till 2,64 t/m3. Liten provmängd

- GRADERINGSTAL $C_u = d_{60}/d_{10}$:
- TJÄLFARLIGHETS KLASS ENL. ATB VÄG:
- MATERIALTYP ENL. ATB VÄG:
- BENÄMNING AV MTRL <20 mm: sa si Le

Ackrediterat laboratorium utses av Styrelsen för teknisk ackreditering (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17025.
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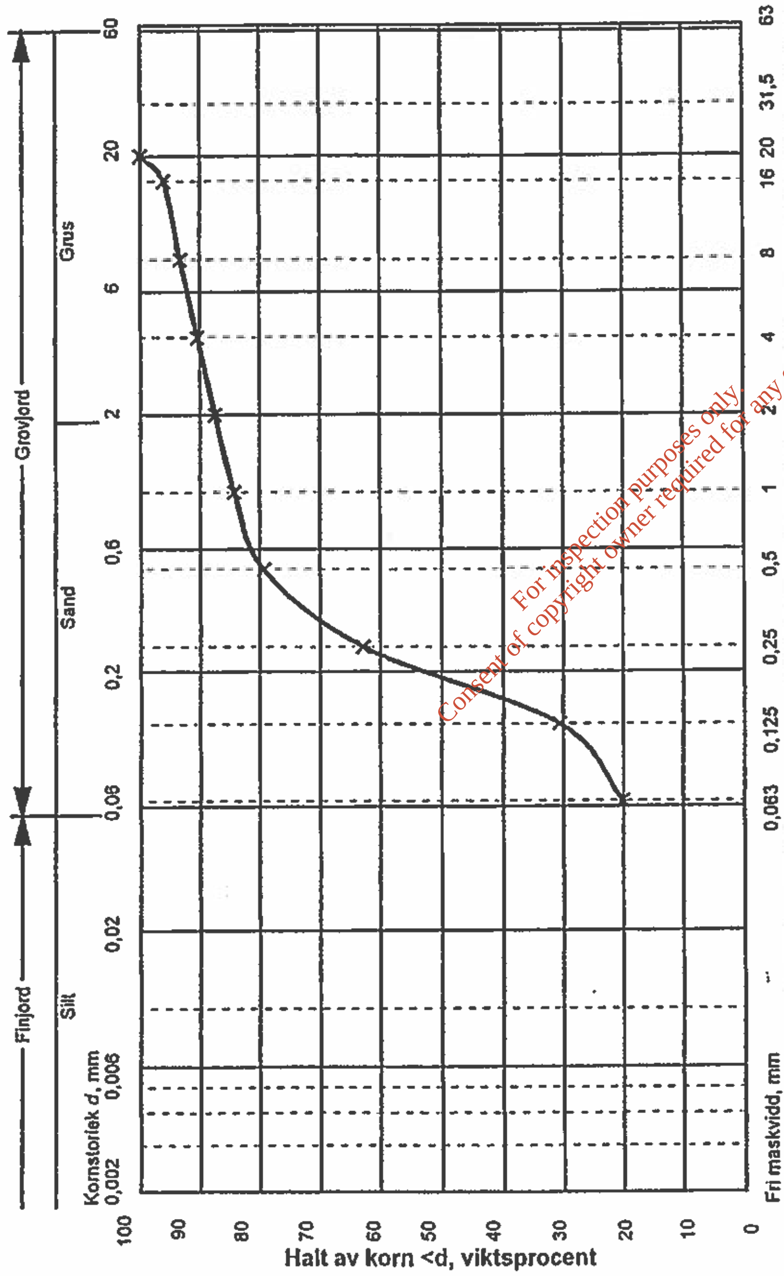
KORNFÖRDELNING FRAKTIONSINDELNING 1981

Corrib Gas Terminal Beställare: AGEC Ltd, Irland			Diagram	3 (3)
			Dnr	2-0403-0163
Ankomstdatum 040416	Provtagningsredskap	Laboratorieundersökning Datum 040428 Utförd av SZ	Datum	2004-05-04
			Teknisk ledare	[signature]



PROVET ÄR TVÄTTSIKTAT	
PROV NR	PS 35
DJUP	3,35 - 3,50 m
SIKTNING SS 027123 UTGÅVA 1	
SEDIMENTATIONSFÖRSÖK VÄGKROPPSMETODEN	
LERHALT % AV MTRL <0,06 mm	
FÖRBEHANDLING	
PROVMÄNGD g	
HALT AV MTRL % >20 mm	3,9
STÖRSTA KORNSTORLEK mm	
SIKTAD PROVMÄNGD g <20 mm	370,6
SIKTAD PROVMÄNGD g <63 mm	
TOTAL PROVMÄNGD g	386
ANMÄRKNING	Liten provmängd
GRADERINGSTAL $C_u = d_{60}/d_{10}$	
TJÄLFARLIGHETS KLASS ENL. ATB VÄG	
MATERIALTYP ENL. ATB VÄG	
BENÄMNING AV MTRL <20 mm	si Sa

Ackrediterat laboratorium utses av Styrelsen för teknisk ackreditering (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17025.
Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat.
Resultaten gäller enbart för de provade materialen.

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Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 6. Peat samples from borehole PH1, PH2, PH3 and PH4

Summary of laboratory test performed on peat from borehole PH1, PH2, PH3 and PH4.

PH1 @ 0.05-0.25 m.
Natural water content 499% and 529%, mean 514%
Carbonate content 0,6%
Phosphate content in porewater 2,4 mg/l
Nitrate content in porewater 0,14 mg/l

PH2 @ 0.05-0.25 m.
Natural water content 1034% and 1006%, mean 1020%
Carbonate content 0,6%
Phosphate content in porewater 1,0 mg/l
Nitrat content in porewater 7,1 mg/l

PH3 @ 0.05-0.25 m.
Natural water content 891% and 903%, mean 897%
Phosphate content on porewater 0,79 mg/l
Nitrate content in porewater 0,27 mg/l

PH4 @ 0.05 -0.25 m.
Natural water content 788% and 831%, mean 809%
Phosphate content on porewater 2,4 mg/l
Nitrate content in porewater 1,2 mg/l

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SAMMANSTÄLLNING AV LABORATORIEUNDERSÖKNINGAR

Projekt : AGEC Ltd, Ireland				Dnr 2-0403-0163 Miljönr. 04049 Proj.nr. 11989
Beställare	Registrerad Datum	Lab.undersökning utförd Datum	Av	Utfärdad Datum 04-07-01
Per-Evert Bengtsson	2004-04	2004-04—2004-06	Cto	Teknisk ledare [signature]

Provbeteckning/ Parameter		PH 1A	PH 1 B	PH 2 A	PH 2 B	Metod
CO_3	%	0,6	0,6	0,6	0,6	SGI Rapport 27

Anm: Avsteg från standarden då försöket utfördes på material <250µm. Materialet var i viss mån hydrofobt.

Provbeteckning/ Parameter		PH 1 Porvatten	PH 2 Porvatten	Metod
Fosfat	mg/l	2,4	1,0	Utfört av Analytica
Nitrit-nitratkväve	mg/l	0,08	1,7	Utfört av Analytica
Nitritkväve	mg/l	<0,010	0,041	Utfört av Analytica
Nitratkväve	mg/l	0,03	1,6	Utfört av Analytica
Nitrat	mg/l	0,14	7,1	Utfört av Analytica

Se bilaga

Ackrediterat laboratorium utses av Styrelsen för teknisk ackreditering (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN ISO 17025.

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat.

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SAMMANSTÄLLNING AV LABORATORIEUNDERSÖKNINGAR

Projekt: AGEC Ltd, Ireland				Dnr 2-0403-0163 Projnr 11989 Miljönr 04049
Beställare	Registrerad Datum	Lab.undersökning utförd Datum	Av	Utfärdad Datum
Per-Evert Bengtsson	2004-04	2004-06	Cto	Teknisk ledare

Provbeteckning / Parameter		PH 3 Porvatten	PH 4 Porvatten	Metod
Fosfat	mg/l	0,79	2,4	
Nitrit-nitratkväve	mg/l	0,06	0,29	
Nitritkväve	mg/l	<0,002	0,009	
Nitratkväve	mg/l	0,06	0,28	
Nitrat	mg/l	0,27	1,2	

Mätosäkerhet och mätområde finns i SGI Kvalitetshandbok och kan erhållas mot förfrågan.

Ackrediterat laboratorium utses av Styrelsen för teknisk ackreditering (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN ISO/IEC 17025.

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat.

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Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 7. Irish sand

SGI 2004-07-20 Dnr 2-0403-163

ANNEX 7:1

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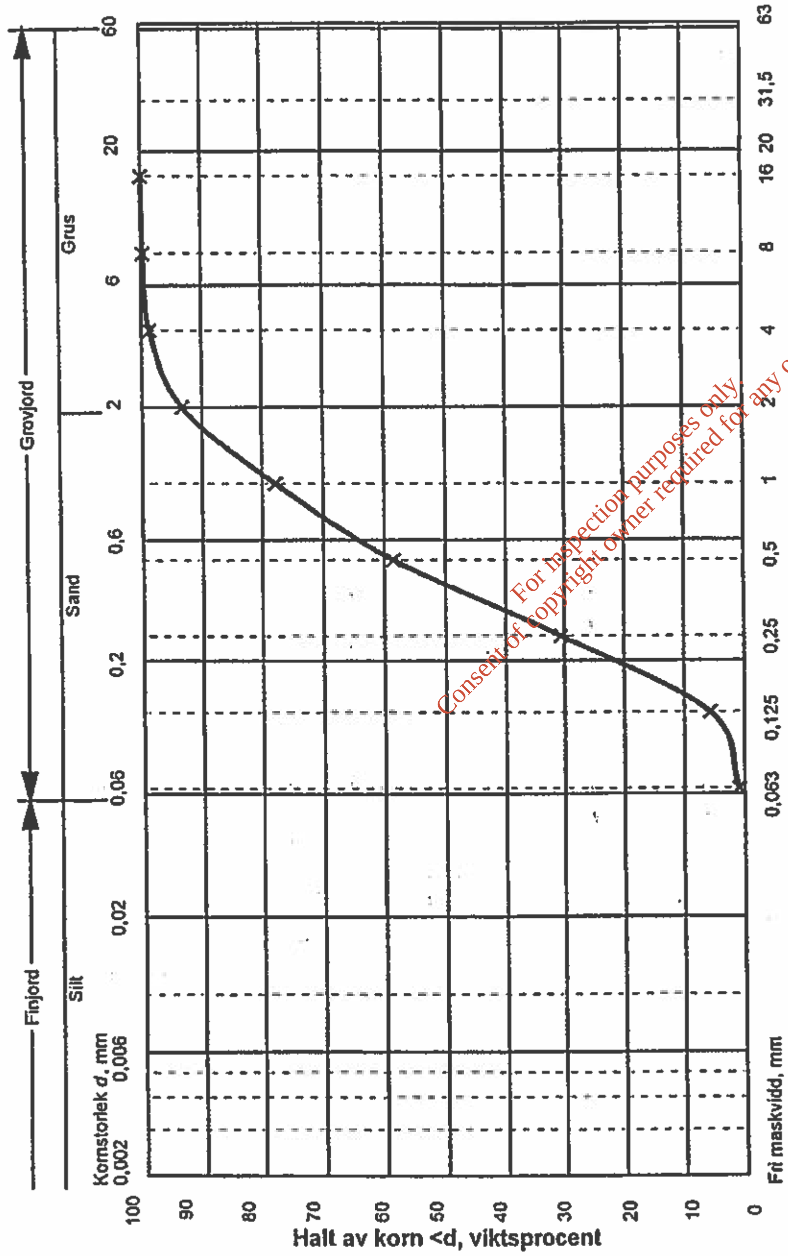
SWEDAC ACKREDITERING

KORNFÖRDELNING FRAKTIONSINDELNING 1981

Corrib Gas Terminal			Diagram 1(2)
			Dnr 2-0403-0163
Ankomstdatum	Provtagningsredskap	Laboratorieundersökning Datum 040329 Utförd av O.A	Datum
			Teknisk ledare



PROVET ÄR EJ TVÄTTSIKTAT
PROV NR: A
SEDIMENTATIONSFÖRSÖK VÅGKROPPSMETODEN
SIKTNING SS 027123
TOTAL PROVMÄNGD g: 16000
SIKTAD PROVMÄNGD g < 20 mm: 260
HALT AV MTRL % > 20 mm: 0,0

Ackrediterat laboratorium utses av Styrelsen för teknisk ackreditering (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 45 001.
Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat.
Resultaten gäller de provade materialen.

Programversion 1.2

Statens geotekniska institut
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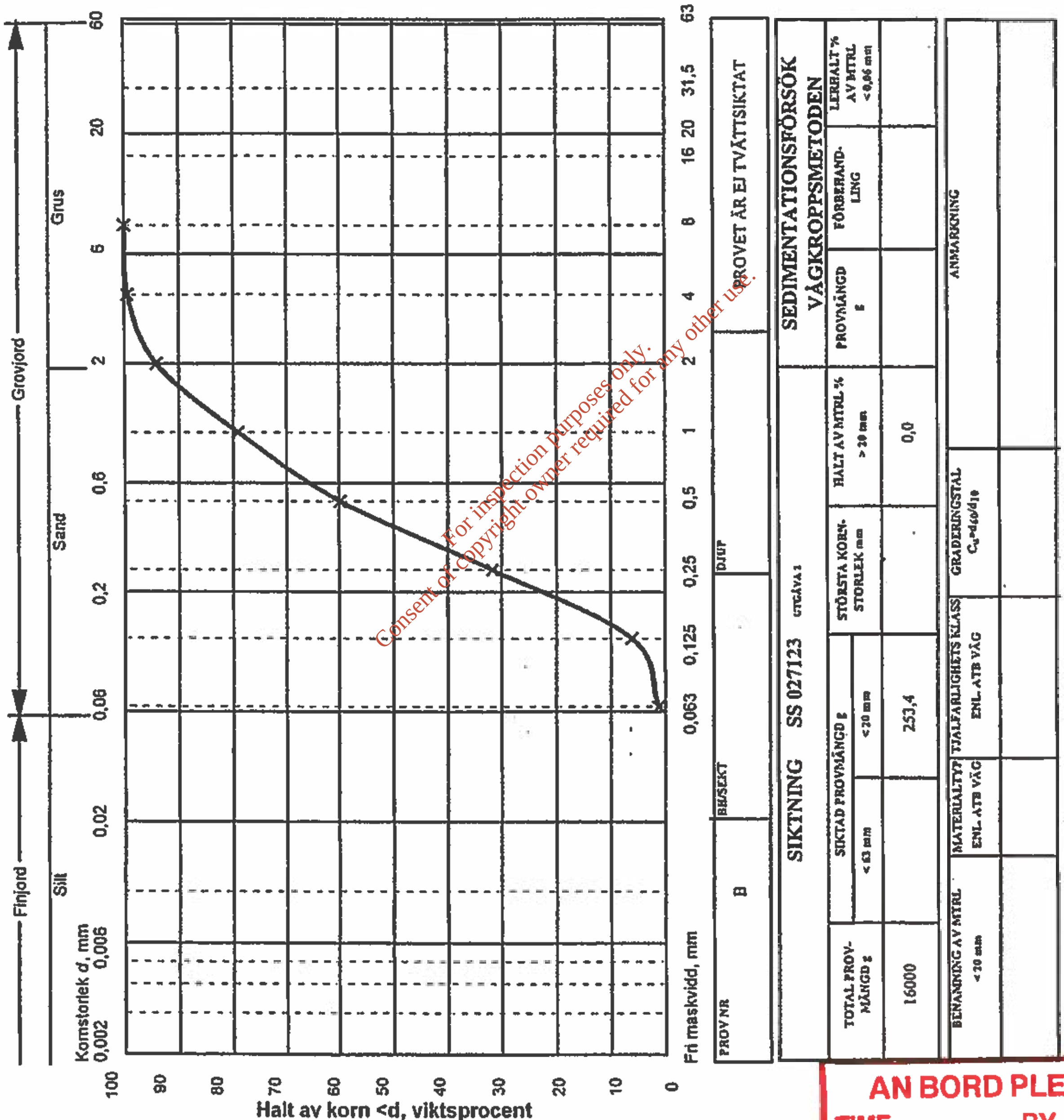
SGI

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

KORNFÖRDELNING FRAKTIONSINDELNING 1981

Corrib Gas Terminal				Diagram 2(2)
				Dnr 2-0403-0163
Ankomstdatum	Provtagningsredskap	Laboratorieundersökning Datum 040329	Utförd av O.A	Datum
				Teknisk ledare



Ackrediterat laboratorium utses av Styrelsen för teknisk ackreditering (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 45 001.
Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat.
Resultaten gäller de provade materialen.

Programversion 1.2

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SGI 2004-07-20 Dnr 2-0403-163
ANNEX 7:3

Analytica

INKOM SGI
2004-05-13

RAPPORT

L0404829

Sidan 1 av 2

Er Order Id:		SGI	
Registrerad:	2004-04-28	Cecilia Toomväli	
Analyserad:	2004-05-10	Miljölab	
Utfärdad:	2004-05-10	Olaus Magnus Väg 35	
		581 93 Linköping	

Analyspaket: **MG1**

Provnummer:	U10136329-00
Beteckning 1:	CGT-sand
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
TS	95,4		%	SS028113	Ni *	5,92		mg/kg TS	ICP-AES
SiO_2 *	72,5		% TS	ICP-AES	Pb *	3,03		mg/kg TS	ICP-QMS
Al_2O_3 *	4,21		% TS	ICP-AES	S *	173		mg/kg TS	ICP-AES
CaO *	10,3		% TS	ICP-AES	Sc *	1,57		mg/kg TS	ICP-AES
Fe_2O_3 *	1,63		% TS	ICP-AES	Sn *	<20		mg/kg TS	ICP-AES
K_2O *	1,25		% TS	ICP-AES	Sr *	240		mg/kg TS	ICP-AES
MgO *	0,681		% TS	ICP-AES	V *	19,3		mg/kg TS	ICP-AES
MnO *	0,0274		% TS	ICP-AES	W *	<60		mg/kg TS	ICP-AES
Na_2O *	0,941		% TS	ICP-AES	Y *	8,42		mg/kg TS	ICP-AES
P_2O_5 *	0,0412		% TS	ICP-AES	Zn *	13,4		mg/kg TS	ICP-AES
TiO_2 *	0,210		% TS	ICP-AES	Zr *	126		mg/kg TS	ICP-AES
Summa *	91,8		% TS	Man.Inm.					
LOI	8,5		% TS	Egen metod					
As *	2,85		mg/kg TS	ICP-QMS					
Ba *	232		mg/kg TS	ICP-AES					
Be *	<0,6		mg/kg TS	ICP-AES					
Cd *	0,140		mg/kg TS	ICP-QMS					
Co *	<2		mg/kg TS	ICP-AES					
Cr *	30,5		mg/kg TS	ICP-AES					
Cu *	6,95		mg/kg TS	ICP-AES					
Hg *	<0,04		mg/kg TS	ICP-QMS					
La *	8,52		mg/kg TS	ICP-AES					
Mo *	<6		mg/kg TS	ICP-AES					
Nb *	<6		mg/kg TS	ICP-AES					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, B, Sb, Se och S gäller: Analysprov har torkats vid 50°C och elementhalterna har TS-korrigerats till 105°C. Upplösning har skett i mikrovågsugn i slutna teflonbehållare med salpetersyra / vatten 1:1. För övriga grundämnen gäller : 0.125 g torkat prov smälts med 0.375 g $LiBO_2$ och upplöses i HNO_3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-MS).

U10136329-00: Co: Förhöjd rapporteringsgräns pga Ca-störning.

Parametrar märkta med * indikerar ej ackrediterade analyser.

AN BORD PLEANÁLA
TIME ______ BY ______
31 AUG 2004
LTR-DATED ______ FROM ______
PL ______

Signatur

Erik Burman
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Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 8. Irish cement 32.5N

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on Irish Cement delivered to SGI

Test performed as loss on ignition on two samples from bag with Irish Cement delivered to SGI

According to standard
SS 027105, edition 1, Temperature 950 °C

Loss on ignition		
Sample 1 %	Sample 2 %	Mean %
1,97	1,93	1,95

Per-Evert Bengtsson, SGI

Laboratory_Irish_Cement_SGI_040402

ARBETSPROTOKOLL - GLÖDGNINGSFÖRLUST

DNR. 2-0403-0163
DAT. 040401
SIGN. OA

Prov nr: Irish Cement (Normal Portland Cement)

Provbeteckning:

Glödgningstemp.: 450 °C

Degel nr:	F31	F25
Degel vikt (m_1)	21.09 g	21.18 g
Degel + Torrt prov (m_2)	48,56 g	45,54 g
Degel + Glödgat prov (m_3)	48,02 g	45,07 g

Beräkning:

$$\frac{m_2 - m_3}{m_2 - m_1} \cdot 100 = \%$$

$$\frac{48,56-48,02}{48,56-21,09} = \frac{0,54}{27,47} \qquad \frac{45,54-45,07}{45,54-21,18} = \frac{0,47}{24,36}$$

Glödgningsförlust: 1,97 % 1,93 %

Glödgningsförlust MV: 1,95 %

SGI 2004-07-20 Dnr 2-0403-163
ANNEX 8:3

Analytica 2004-05-13 **RAPPORT** L0404829

Sidan 2 av 2

Er Order Id:
Registrerad: 2004-04-28
Analyserad: 2004-05-10
Utfärdad: 2004-05-10

SGI
Cecilia Toomväli
Miljölab
Olaus Magnus Väg 35
581 93 Linköping

Analyspaket: **MG1**

Provnummer:	U10136330-00
Beteckning 1:	CGT-Irish Normal Portland
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
TS	99,8		%	SS028113	Ni *	44,3		mg/kg TS	ICP-AES
SiO_2 *	20,3		% TS	ICP-AES	Pb *	13,5		mg/kg TS	ICP-QMS
Al_2O_3 *	4,23		% TS	ICP-AES	S *	10500		mg/kg TS	ICP-AES
CaO *	62,3		% TS	ICP-AES	Sc *	4,63		mg/kg TS	ICP-AES
Fe_2O_3 *	3,11		% TS	ICP-AES	Sn *	<20		mg/kg TS	ICP-AES
K_2O *	0,661		% TS	ICP-AES	Sr *	402		mg/kg TS	ICP-AES
MgO *	2,70		% TS	ICP-AES	V *	268		mg/kg TS	ICP-AES
MnO *	0,272		% TS	ICP-AES	W *	<60		mg/kg TS	ICP-AES
Na_2O *	0,250		% TS	ICP-AES	Y *	27,3		mg/kg TS	ICP-AES
P_2O_5 *	0,0865		% TS	ICP-AES	Zn *	36,8		mg/kg TS	ICP-AES
TiO_2 *	0,165		% TS	ICP-AES	Zr *	60,9		mg/kg TS	ICP-AES
Summa *	94,1		% TS	Man.inm.					
LOI	1,9		% TS	Egen metod					
As *	12,9		mg/kg TS	ICP-QMS					
Ba *	174		mg/kg TS	ICP-AES					
Be *	1,52		mg/kg TS	ICP-AES					
Cd *	0,995		mg/kg TS	ICP-QMS					
Co *	6,67		mg/kg TS	ICP-AES					
Cr *	51,6		mg/kg TS	ICP-AES					
Cu *	45,3		mg/kg TS	ICP-AES					
Hg *	0,0547		mg/kg TS	ICP-QMS					
La *	6,38		mg/kg TS	ICP-AES					
Mo *	<6		mg/kg TS	ICP-AES					
Nb *	<6		mg/kg TS	ICP-AES					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, B, Sb, Se och S gäller: Analysprov har torkats vid 50°C och elementhalterna har TS-korrigerats till 105°C. Upplösning har skett i mikrovågsugn i slutna teflonbehållare med salpetersyra / vatten 1:1. För övriga grundämnen gäller : 0.125 g torkat prov smälts med 0.375 g $LiBO_2$ och upplöses i HNO_3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-MS).

U10136329-00: Co: Förhöjd rapporteringsgräns pga Ca-störning.

Parametrar märkta med * indikerar ej ackrediterade analyser.

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Signatur
Erik Burman
Kemist

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 9. Stabilised peat from borehole PS21 and PS22

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised peat samples

Peat from borehole PS21 and PS22

Samples mixed with Irish Cement
- 2004-04-01 for 150 kg/m^3.
- 2004-04-02 for 200 and 250 kg/m^3.

After mixing of natural peat samples were taken to determine natural water content of mixed peat

w_N^1 =	1104 %	Sample 1 on mixed natural peat
w_N^2 =	1093 %	Sample 2 on mixed natural peat
w_N^{mean} =	1098 %	Mean value of sample 1 and 2

After mixing (0.45 hours) samples stored under water with a 'surcharge' of 18 kPa at 20 degree C.

No	Quantity cement kg/m^3	Density$^{1)}$ t/m^3	$\varepsilon_{vertical}$ % 1 day	$\varepsilon_{vertical}$ % 3 days	Testing age days	$\varepsilon_{vertical}$ % final	Density$^{2)}$ t/m^3	$w_N$$^{2)}$ %	τ_{fu} kPa	E_{50} MPa
I1	150	1,12	14,8	15,7	28	15,7	1,13	291	58	11,4
I2	150	1,12	16,8	17,7	28	17,7	1,13	283	59	10,6
I3	150	1,10	16,0	16,5	90	16,5	1,13	273	79	13,3
I4	150	1,12	13,7	14,1	90	14,1	1,13	277	74	10,4
I9	200	1,15	14,8	14,8	6	14,8	1,17	238	88	14,8
I10	200	1,14	15,4	15,4	6	15,4	1,17	239	84	14,3
I11	200	1,15	15,0	15,5	14	15,5	1,16	227	125	19,1
I12	200	1,16	15,7	16,2	14	16,2	1,17	230	112	20,5
I13	200	1,16	15,4	15,4	28	15,4	1,16	229	126	15,4
I14	200	1,15	16,2	16,2	28	16,2	1,16	225	111	24,3
I15	200	1,15	15,9	15,9	90	15,9	1,16	222	126	24,3
I16	200	1,16	15,0	15,0	90	15,0	1,16	224	130	20,3
I5	250	1,18	12,2	12,7	28	12,7	1,19	200	108	25,1
I6	250	1,18	13,5	13,9	28	13,9	1,18	200	131	15,4
I7	250	1,18	12,5	12,5	90	12,5	1,19	197	161	22,3
I8	250	1,19	12,7	12,7	90	12,7	1,20	177	197	32,3

$^{1)}$ = directly after mixing and placement into sampling tube
$^{2)}$ = at testing day

SGI LABORATORIET

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory
SWEDAC ACKREDITERING 1148

KEMISKT STABILISERAD JORD
Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell 1(2)
Dnr 2-0403-0163
Datum 040707
Teknisk ledare

Datum för inblandning: 040401-040402
Provdiameter (mm): 68,6
Laboratorieundersökning Datum: 040406-040701 Utförd av: O.A

Bland-ning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
Bl. 1								1098[1]			
Prov 1	150	100			28	ca+20	1,13	291		58	Fritt vatten
Prov 2	150	100			28	ca+20	1,13	283		59	Fritt vatten
Prov 3	150	100			90	ca+20	1,13	273		79	Fritt vatten
Prov 4	150	100			90	ca+20	1,13	277		74	Fritt vatten
Bl. 2								1098[1]			
Prov 9	200	100			6	ca+20	1,17	238		88	Fritt vatten
Prov 10	200	100			6	ca+20	1,17	239		84	Fritt vatten
Prov 11	200	100			14	ca+20	1,16	227		125	Fritt vatten
Prov 12	200	100			14	ca+20	1,17	230		112	Fritt vatten
								1098[1]			
Prov 13	200	100			28	ca+20	1,16	229		126	Fritt vatten
Prov 14	200	100			28	ca+20	1,16	225		111	Fritt vatten
Prov 15	200	100			90	ca+20	1,16	222		126	Fritt vatten
Prov 16	200	100			90	ca+20	1,16	224		130	Fritt vatten

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.
2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde framgår av SGI Kvalitetshandbok

Blandning: 1 Peat sample 21+22 Djup 0,75-2,60m Proverna har lagrats med last = 18 kPa

Blandning: 2 Peat sample 21+22 Djup 0,75-2,60m Proverna har lagrats med last = 18 kPa

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

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KEMISKT STABILISERAD JORD
Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Torlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell	2(2)
Dnr	2-043-0163
Datum	040707
Teknisk ledare	

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040402	68,6	040430-040701	O.A

Bland-ning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL 3								1098¹⁾			
Prov 5	250				28	ca+20	1,19	200		108	Fritt vatten
Prov 6	250				28	ca+20	1,18	200		131	Fritt vatten
Prov 7	250				90	ca+20	1,19	197		161	Fritt vatten
Prov 8	250				90	ca+20	1,20	177		197	Fritt vatten

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Måtosäkerhet och mätområde framgår av SGI Kvalitetshandbok

Blandning:3 Peat sample 21+22 Djup 0,75-2,60m Proverna har lagrats med last = 18 kPa

R7 2003-11-05

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 10. Stabilised peat from borehole PS23

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised peat samples

Peat from borehole PS23 depth 0.70 - 1.70 m

Samples mixed with Irish Cement 42.5 N
- 2004-05-26 for 50 and 100 kg/m³.
- 2004-05-27 for 150, 200 and 250 kg/m³.

After mixing of natural peat samples were taken to determine natural water content of mixed peat

w_N^1 =	893 %	Sample 1 on premixed natural peat
w_N^2 =	896 %	Sample 2 on premixed natural peat
w_N^{mean} =	894 %	Mean value of sample 1 and 2

After mixing (0.45 hours) samples stored under water with a 'surcharge' of 18 kPa at 20 degree C.

No	Quantity cement kg/m³	Density[1)] t/m³	$\varepsilon_{vertical}$ % After	$\varepsilon_{vertical}$ % After	Testing age days	$\varepsilon_{vertical}$ % final	Density[2)] t/m³	w_N[2)] %	τ_{fu} kPa	E_{50} MPa
			1 day	6 days						
I17	50		12,9	20,7	28	21,7	1,05	432	13	2,4
I18	50		15,1	22,6	28	23,6	1,06	451	18	2,7
I19	50		14,3	21,2	90					
I20	50		14,7	20,6	90					
			1 day	6 days						
I21	100		12,5	13,4	28	13,9	1,09	351	40	8,1
I22	100		14,4	15,7	28	16,2	1,10	342	45	7,6
I23	100		12,1	13,0	90					
I24	100		12,2	13,5	90					
			1 day	5 days						
I25	150		12,1	12,1	28	12,1	1,12	274	85	13,2
I26	150		11,5	11,5	28	11,5	1,1[illegible]	284	77	12,5
I27	150		12,0	12,0	90					
I28	150		12,6	12,6	90					
			1 day	5 days						
I29	200		10,6	10,6	28	10,6	1,15	229	102	13,6
I30	200		10,6	10,6	28	10,6	1,17	225	103	17,0
I31	200		9,8	9,8	90					
I32	200		9,5	9,5	90					
			1 day	5 days						
I33	250		9,0	9,0	28	9,0	1,19	188	153	23,3
I34	250		9,1	9,1	28	9,1	1,18	199	120	26,4

PS23 Page 2 (2)

I35	250	10,2	10,2	90
I36	250	9,8	9,8	90

1) = directly after mixing and placement into sampling tube (not determined)
2) = at testing day

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KEMISKT STABILISERAD JORD
Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell	
Dnr	2-0403-0163
Datum	040625
Teknisk ledare	

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040526-040527	68,6	040623	O.A

Bland-ning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL.4								894[1]			
Prov 17	50	100			28	ca+20	1,05	432		13	
Prov 18	50	100			28	ca+20	1,06	451		18	
Prov 19	50	100			90	ca+20					
Prov 20	50	100			90	ca+20					
BL.5								894[1]			
Prov 21	100	100			28	ca+20	1,09	351		40	
Prov 22	100	100			28	ca+20	1,10	342		45	
Prov 23	100	100			90	ca+20					
Prov 24	100	100			90	ca+20					
BL.6								894[1]			
Prov 25	150	100			28	ca+20	1,12	274		85	
Prov 26	150	100			28	ca+20	1,13	284		77	
Prov 27	150	100			90	ca+20					
Prov 28	150	100			90	ca+20					

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovisas på vår hemsida, www.swedgeo.se

Blandning: 4 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa
Blandning: 5 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa
Blandning: 6 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

R7 2004-04-22

AN BORD PLEANÁLA
TIME ______ BY ______
31 AUG 2004
LTR-DATED ______ FROM ______
PL ______

SGI LABORATORIET

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KEMISKT STABILISERAD JORD

Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal			Tabell
			Dnr 2-0403-0163
Datum för inblandning: 040527	Provdiameter (mm): 68,6	Laboratorieundersökning Datum: 040624, Utförd av: O.A	Datum 040625
			Teknisk ledare

Bland-ning	Tillsatsmedel Mängd stab.-medel kg/m³	Proportioner Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL 7								894¹			
Prov 29	200	100			28	ca+20	1,15	229		102	
Prov 30	200	100			28	ca+20	1,17	225		103	
Prov 31	200	100			90	ca+20					
Prov 32	200	100			90	ca+20					
BL 8								894¹			
Prov 33	250	100			28	ca+20	1,19	188		153	
Prov 34	250	100			28	ca+20	1,18	199		120	
Prov 35	250	100			90	ca+20					
Prov 36	250	100			90	ca+20					

1) Blandningens vattenkvot före inbladning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovias på vår hemsida, www.swedgeo.se

Blandning: 7 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

Blandning: 8 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

AN BORD PLEANÁLA
TIME ____ BY ____
31 AUG 2004
LTR-DATED ____ FROM ____
PL ____

R7 2004-04-22

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 11. Stabilised peat from borehole PS35 at depth 2.10-3.10 m

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised peat samples

Peat from borehole PS35 depth 2.10 - 3.10 m

Samples mixed with Irish Cement 42.5 N
- 2004-05-28 for 150, 200 and 250 kg/m^3.

After mixing of natural peat samples were taken to determine natural water content of mixed peat

w_N^1 =	1028 %	Sample 1 on mixed natural peat
w_N^2 =	1010 %	Sample 2 on mixed natural peat
w_N^{mean} =	1019 %	Mean value of sample 1 and 2

After mixing (0.45 hours) samples stored under water with a 'surcharge' of 18 kPa at 20 degree C.

No	Quantity cement kg/m^3	Density[1)] t/m^3	$\varepsilon_{vertical}$ % After	$\varepsilon_{vertical}$ % After	Testing age days	$\varepsilon_{vertical}$ % final	Density[2)] t/m^3	w_N[2)] %	τ_{fu} kPa	E_{50} MPa
			0.27 days	4 days						
I37	150		14,0	15,0	7	15,0	1,12	278	55	13,4
I38	150		13,3	14,2	7	14,2	1,12	281	50	5,6
I39	150		14,2	15,5	14	15,5	1,12	270	49	8,0
I40	150		14,8	15,7	14	15,7	1,13	259	59	8,8
I41	150		13,5	13,9	28	14,8	1,11	278	80	17,0
I42	150		14,0	14,0	28	14,9	1,12	266	78	14,8
I43	150		13,1	13,6	90					
I44	150		13,3	13,8	90					
			0.24 days	4 days						
I45	200		12,9	13,8	7	13,8	1,17	227	80	7,3
I46	200		12,3	13,2	7	13,2	1,16	220	67	8,2
I47	200		11,9	12,8	14	13,2	1,15	235	103	17,1
I48	200		10,7	12,0	14	12,0	1,15	226	111	16,3
I49	200		12,7	13,5	28	14,4	1,17	224	135	26,2
I50	200		12,8	13,7	28	14,1	1,15	218	91	15,7
I51	200		12,1	12,5	90					
I52	200		12,2	13,1	90					
			0.18 days	4 days						
I53	250		11,2	12,9	28	12,9	1,21	187	210	35,2
I54	250		11,0	11,4	28	11,8	1,19	184	157	33,3
I55	250		11,3	12,2	90					
I56	250		11,9	13,2	90					

1) = directly after mixing and placement into sampling tube (not determined)
2) = at testing day

SGI LABORATORIET

RAPPORT
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1148

KEMISKT STABILISERAD JORD
Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell

Dnr 2-0403-0163

Datum 040625

Teknisk ledare

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040528	68,6	040604-040625	IMK

Bland-ning	Tillsatsmedel Mängd stab.-medel kg/m³	Proportioner Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL 10								1019¹			
Prov 45	200	100			7	ca+20	1,17	227		80	
Prov 46	200	100			7	ca+20	1,16	220		67	
Prov 47	200	100			14	ca+20	1,15	235		103	
Prov 48	200	100			14	ca+20	1,15	226		111	
Prov 49	200	100			28	ca+20	1,17	224		135	
Prov 50	200	100			28	ca+20	1,15	218		91	
Prov 51	200	100			90	ca+20					
Prov 50	200	100			90	ca+20					
BL 11								1019¹			
Prov 53	250	100			28	ca+20	1,21	187		210	
Prov 54	250	100			28	ca+20	1,19	184		157	
Prov 55	250	100			90	ca+20					
Prov 56	250	100			90	ca+20					

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovias på vår hemsida, www.swedgeo.se

Blandning: 10 PS 35 Djup 2,1-3,1m Provema har lagrats med last = 18 kPa

Blandning: 11 PS 35 Djup 2,1-3,1m Provema har lagrats med last = 18 kPa

R7 2004-04-22

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
utfärdad av ackrediterat laboratorium
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KEMISKT STABILISERAD JORD

Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell

Dnr 2-0403-0163

Datum 040625

Teknisk ledare

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040528	68,6	040604-040625	IMK O.A

Blandning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inblandning dygn	Lagringstemperatur °C	2) Densitet ρ t/m³	3) Vattenkvot w %	4) Konflytgräns w_L %	5) Skjuvhållfasthet Enaxliga tryckförsök τ_{fu} kPa	Anmärkning
BL 9								1019¹			
Prov 37	150	100			7	ca+20	1,12	278		55	
Prov 38	150	100			7	ca+20	1,12	281		50	
Prov 39	150	100			14	ca+20	1,12	270		49	
Prov 40	150	100			14	ca+20	1,13	259		59	
Prov 41	150	100			28	ca+20	1,11	278		80	
Prov 42	150	100			28	ca+20	1,12	266		78	
Prov 43	150	100			90	ca+20					
Prov 44	150	100			90	ca+20					

AN BORD PLEANÁLA
TIME ____ BY ____
31 AUG 2004
LTR-DATED ____ FROM ____
PL

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovias på vår hemsida, www.swedgeo.se

Blandning: 9 PS 35 Djup 2,1-3,1m Proverna har lagrats med last = 18 kPa

R7 2004-04-22

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 12. Stabilised peat from borehole PS35 at depth 1.10-2.10 m

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised peat samples

Peat from borehole PS35 depth 1.10 - 2.10 m

Samples mixed with Irish Sand 100 kg/m³ and Irish Cement 42.5 N
- 2004-06-08 for 50, 100 and 150 kg/m³ of cement.

After premixing of natural peat samples were taken to determine natural water content of mixed peat

w_N^1 =	1147 %	Sample 1 on premixed natural peat
w_N^2 =	1144 %	Sample 2 on premixed natural peat
w_N^{mean} =	1145 %	Mean value of sample 1 and 2

After mixing (0.45 hours) samples stored under water with a 'surcharge' of 18 kPa at 20 degree C.

No	Quantity cement kg/m³	Density[1)] t/m³	$\varepsilon_{vertical}$ % After 1 day	$\varepsilon_{vertical}$ % After 3 days	Testing age days	$\varepsilon_{vertical}$ % final	Density[2)] t/m³	w_N[2)] %	τ_{fu} kPa	E_{50} MPa
I59	50	1,10	27,9	30,1	28	31,5	1,13	253	26	3,9
I60	50	1,10	26,5	28,8	28	29,7	1,12	263	24	4,3
I61	50	1,11	26,8	28,6	90					
I62	50	1,10	28,1	29,0	90					
I63	100	1,12	22,8	23,7	28	23,7	1,16	223	46	7,3
I64	100	1,13	22,3	22,7	28	22,7	1,17	221	55	8,8
I65	100	1,13	22,1	22,5	90					
I66	100	1,13	21,7	22,1	90					
I67	150	1,17	19,0	19,5	28	19,5	1,20	203	92	15,7
I68	150	1,15	19,0	19,4	28	19,4	1,20	200	105	17,5
I69	150	1,16	18,8	19,3	90					
I70	150	1,16	19,6	19,6	90					

1) = directly after mixing and placement into sampling tube
2) = at testing day

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

KEMISKT STABILISERAD JORD
Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Grund Engineering Consultants Limited

Corrib Gas Terminal

Tabell
Dnr 2-0403-0163
Datum 040708
Teknisk ledare

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040609	68,6	040707	O.A

Bland-ning	Tillsatsmedel Mängd stab.-medel kg/m³	Proportioner Cement Irish Cement %	Sand kg/m³		Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL 14								1145[1]			
Prov 59	50	100	100		28	ca+20	1,13	253		26	Fritt vatten
Prov 60	50	100	100		28	ca+20	1,12	263		24	Fritt vatten
Prov 61	50	100	100		90	ca+20					
Prov 62	50	100	100		90	ca+20					
BL 15								1145[1]			
Prov 63	100	100	100		28	ca+20	1,16	223		46	Fritt vatten
Prov 64	100	100	100		28	ca+20	1,17	221		55	Fritt vatten
Prov 65	100	100	100		90	ca+20					
Prov 66	100	100	100		90	ca+20					
BL 16								1145[1]			
Prov 67	150	100	100		28	ca+20	1,20	203		92	Fritt vatten
Prov 68	150	100	100		28	ca+20	1,20	200		105	Fritt vatten
Prov 69	150	100	100		90	ca+20					
Prov 70	150	100	100		90	ca+20					

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovias på vår hemsida, www.swedgeo.se

Blandning: 14 PS 35 Djup 1,10-2,10m Proverna har lagrats med = 18 kPa

Blandning:15 PS 35 Djup 1,10-2,10m Proverna har lagrats med = 18 kPa

Blandning:16 PS 35 Djup 1,10-2,10m Proverna har lagrats med = 18 kPa

R7 2004-04-22

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 13. Stabilised mineral soil samples from borehole TPS-23A and TP-PS35.

ANNEX 13:1 Summary of results TPS-23A depth 1.70-1.80 m
ANNEX 13:2 Summary of results TPS-23A depth 1.80-2.10 m
ANNEX 13:3 Summary of results TP-PS35 depth 3.10-3.35 m
ANNEX 13:4 SGI Reporting on results.

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised soil samples

Soil from borehole TPS-23A depth 1.70 - 1.80 m

Samples mixed with Irish Cement 42.5 N
- 2004-06-09 for 200 kg/m^3.

After premixing of natural soil samples were taken to determine natural water content of mixed soil

w_N^1 =	54,8 %	Sample 1 on premixed natural soil
w_N^2 =	52,0 %	Sample 2 on premixed natural soil
w_N^{mean} =	53,4 %	Mean value of sample 1 and 2

Sample diameter = 50 mm

After mixing the samples are stored at 20 degree C.

No	Quantity cement kg/m^3	Testing age days	Density[1)] t/m^3	w_N[1)] %	τ_{fu} kPa	E_{50} MPa
I71	200	28	1,71	41	141	11,0
I72	200	28	1,70	40	134	12,0

[1)] = at testing day

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised soil samples

Soil from borehole TPS-23A depth 1.80 - 2.10 m

Samples mixed with Irish Cement 42.5 N
- 2004-06-09 for 100 kg/m^3.

After premixing of natural soil samples were taken to determine natural water content of mixed soil

w_N^1 =	27,5 %	Sample 1 on premixed natural soil
w_N^2 =	29,9 %	Sample 2 on premixed natural soil
w_N^{mean} =	28,7 %	Mean value of sample 1 and 2

Sample diameter = 50 mm

After mixing the samples are stored at 20 degree C.

No	Quantity cement kg/m^3	Testing age days	Density[1)] t/m^3	w_N[1)] %	τ_{fu} kPa	E_{50} MPa
I73	100	28	1,94	25	83	6,0
I74	100	28	1,89	25	68	8,9
I75	100	90				
I76	100	90				

[1)] = at testing day

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised soil samples

Soil from borehole PS35 depth 3.10 - 3.35 m

Samples mixed with Irish Cement 42.5 N
- 2004-06-09 for 200 kg/m^3.

After premixing of natural soil samples were taken to determine natural water content of mixed soil

w_N^1 =	222 %	Sample 1 on premixed natural soil
w_N^2 =	218 %	Sample 2 on premixed natural soil
w_N^{mean} =	220 %	Mean value of sample 1 and 2

Sample diameter = 50 mm

After mixing (0.45 hours) samples stored under water with a 'surcharge' of 18 kPa at 20 degree C.

No	Quantity cement kg/m^3	Density[1)] t/m^3	$\varepsilon_{vertical}$ % After 1 day	$\varepsilon_{vertical}$ % After 3 days	Testing age days	$\varepsilon_{vertical}$ % final	Density[2)] t/m^3	w_N[2)] %	τ_{fu} kPa	E_{50} MPa
177	200	1,34	7,7	7,7	7	7,7	1,35	110	45	9,5
178	200	1,33	8,3	7,7	7	7,7	1,36	108	45	6,1
179	200	1,36	9,2	8,5	28	8,5	1,39	110	51	5,5
180	200	1,33	9,0	9,0	28	9,0	1,38	110	53	5,0

[1)] = directly after mixing and placement into sampling tube
[2)] = at testing day

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

KEMISKT STABILISERAD JORD

Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Grund Engineering Consultants Limited

Corrib Gas Terminal

Tabell	
Dnr	2-0403-0163
Datum	040708
Teknisk ledare	

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040609	50	040616-040707	O.A

Blandning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inblandning dygn	Lagringstemperatur °C	2) Densitet ρ t/m³	3) Vattenkvot w %	4) Konflytgräns w_L %	5) Skjuvhållfasthet Enaxliga tryckförsök τ_{fu} kPa	Anmärkning
BL 17								53[1]			
Prov 71	200	100			28	ca+20	1,71	41		141	
Prov 72	200	100			28	ca+20	1,70	40		134	
BL 18								29[1]			
Prov 73	100	100			28	ca+20	1,94	25		83	
Prov 74	100	100			28	ca+20	1,89	25		68	
Prov 75	100	100			90	ca+20					
Prov 76	100	100			90	ca+20					
BL 19								220[1]			
Prov 77	200	100			7	ca+20	1,35	110		45	
Prov 78	200	100			7	ca+20	1,36	108		45	
Prov 79	200	100			28	ca+20	1,39	110		51	
Prov 80	200	100			28	ca+20	1,38	110		53	

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet [illegible] redovisas på vår hemsida, www.swedgeo.se

Blandning: 17 TPS 23A Djup 1,70-1,80m

Blandning: 18 TPS 23A Djup 1,80-2,10m

Blandning: 19 TP PS35 Djup 3,10-3,35m Proverna har lagrats med last = 18 kPa

R7 2004-04-22

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Laboratory testing of natural and stabilised peat and mineral soil.

ANNEX 14. Oedometer tests on stabilised peat samples from borehole PS23 at depth 1.0-1.2 m and from borehole PS35 at depth 2.6-2.8 m.

Summary of stress condition for oedometer tests on samples from borehole PS23 depth 1.0-1.2 m and PS35 depth 2.6-2.8 m.

PS23 @ 1.0-1.2 m. Sample I-57A.

After placement in oedometer-cell the vertical stress is
- 18 kPa for 1 day
- 50 kPa for 1 day
- 100 kPa for 1 day
- 150 kPa for 1 day
- 250 kPa for 1 day
- 400 kPa for 30 days

The oedometer test in ongoing (2004-07-20) with the vertical stress 400 kPa .

PS23 @ 2.6-2.8 m. Sample I-58A.

After placement in oedometer-cell the vertical stress is
- 18 kPa for 1 day
- 50 kPa for 1 day
- 100 kPa for 1 day
- 150 kPa for 1 day
- 250 kPa for 1 day
- 400 kPa for 1 day
- Unloading to 250 kPa for 1 day
- Unloading to 150 kPa for 1 day

The oedometer test has been finished.

PS23 @ 2.6-2.8 m. Sample I-58B.

After placement in oedometer-cell the vertical stress is
- 18 kPa for 1 day
- 50 kPa for 1 day
- 100 kPa for 30 days

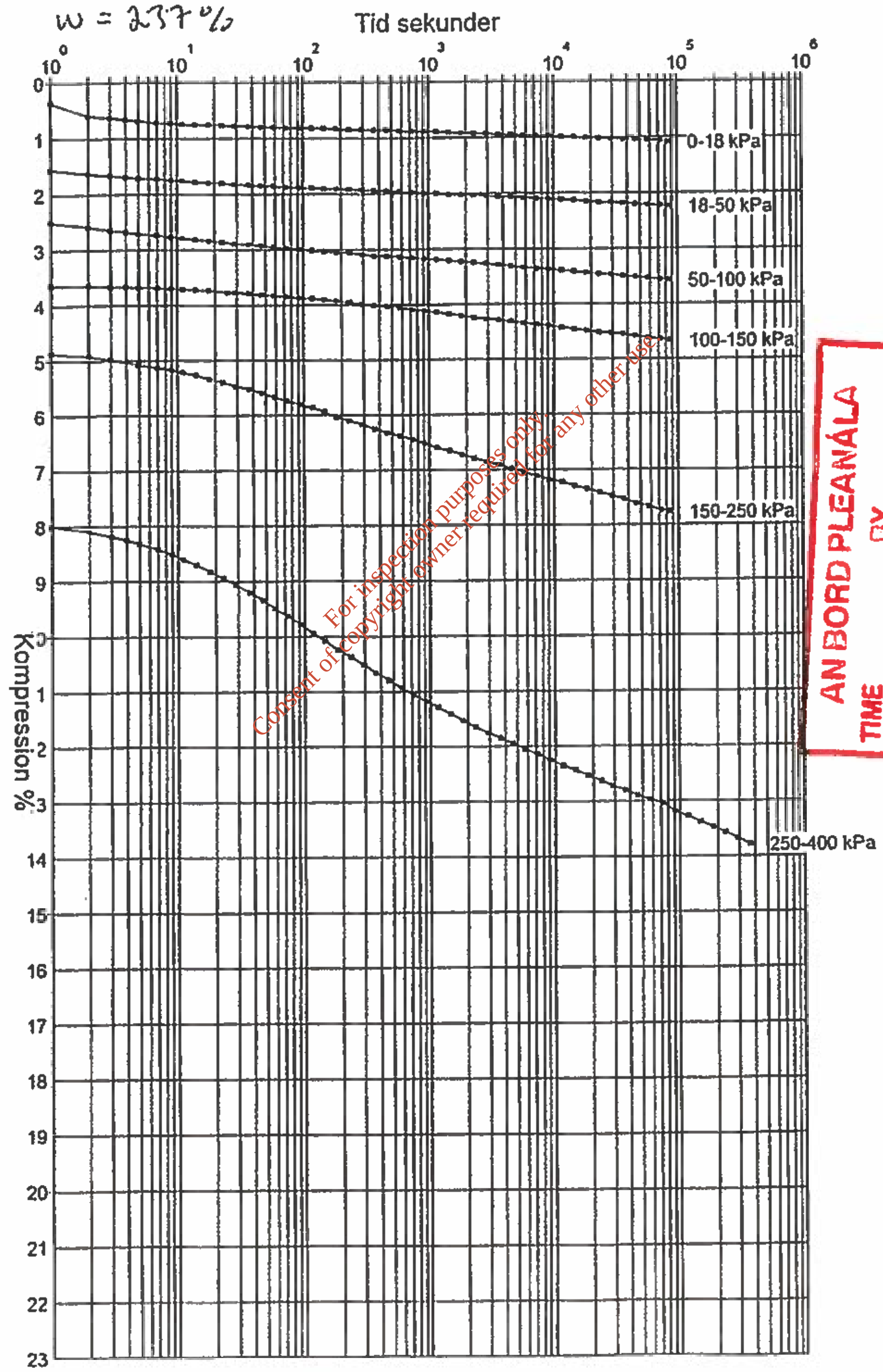
The oedometer test is on-going 2004-07-20 with the vertical stress 100 kPa.

SGI Ödometerförsök

Projektnummer: 2-0403-163
Borrhål: TPS23, Bl.12
Djup : 1,0-1,2 Prov I57A
Jordart: Stab.torv
ρ = 1,21 t/m³
w = 237 %

Provhöjd : 51 mm
Provdiameter: 100 mm
Provets vikt : 483,38 gram
Ödometer nr : 9

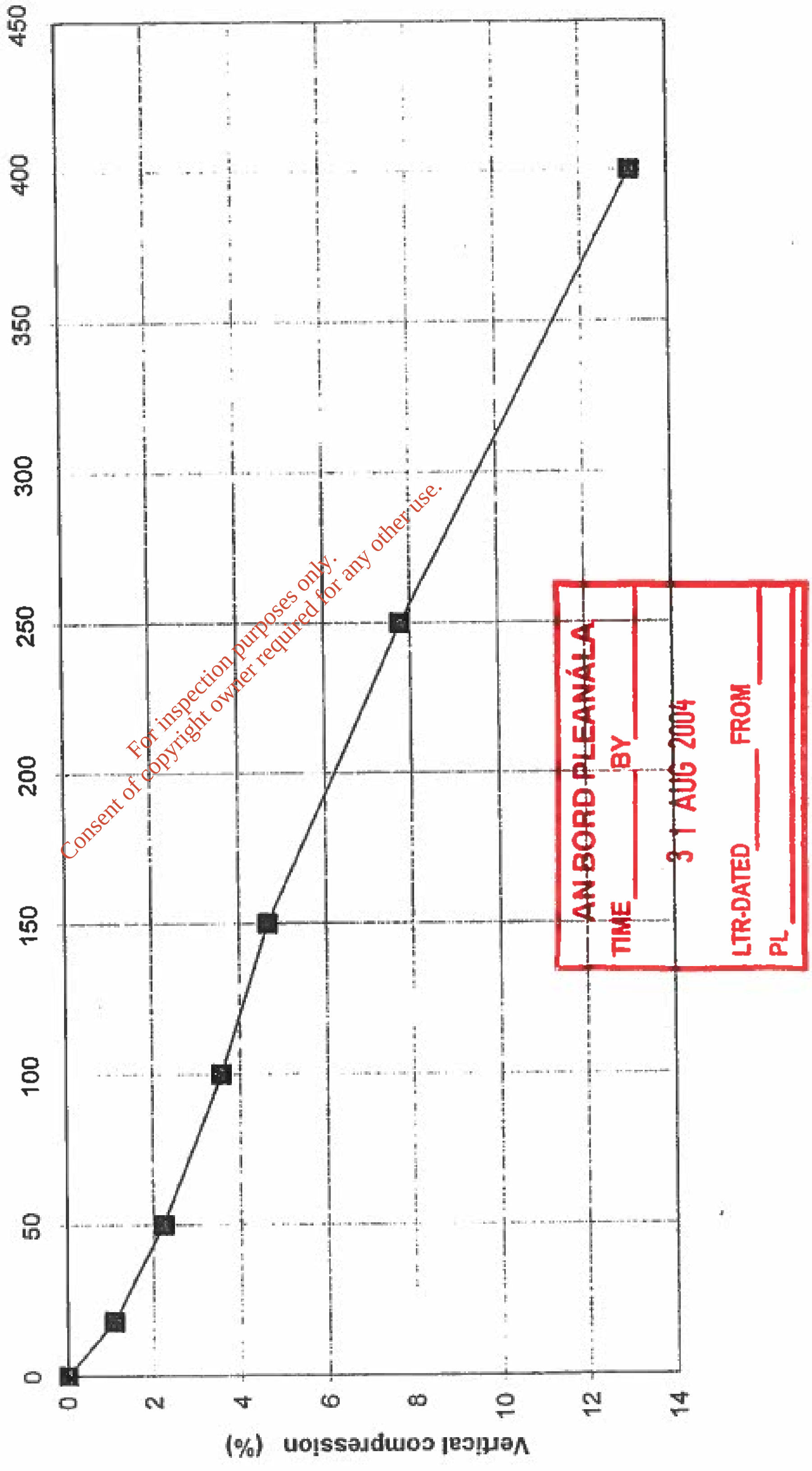
Filnamn : 0407\040706AC
Datum : 20040706-20040711
Sign :
Utrustningens egendeformation är beaktad



Dnr 2-0403-163
2004-07-19
IMK

Ödometer nr 9

Oedometer test on stabilised peat
I-57A - TPS23 depth 1.0-1.2 m

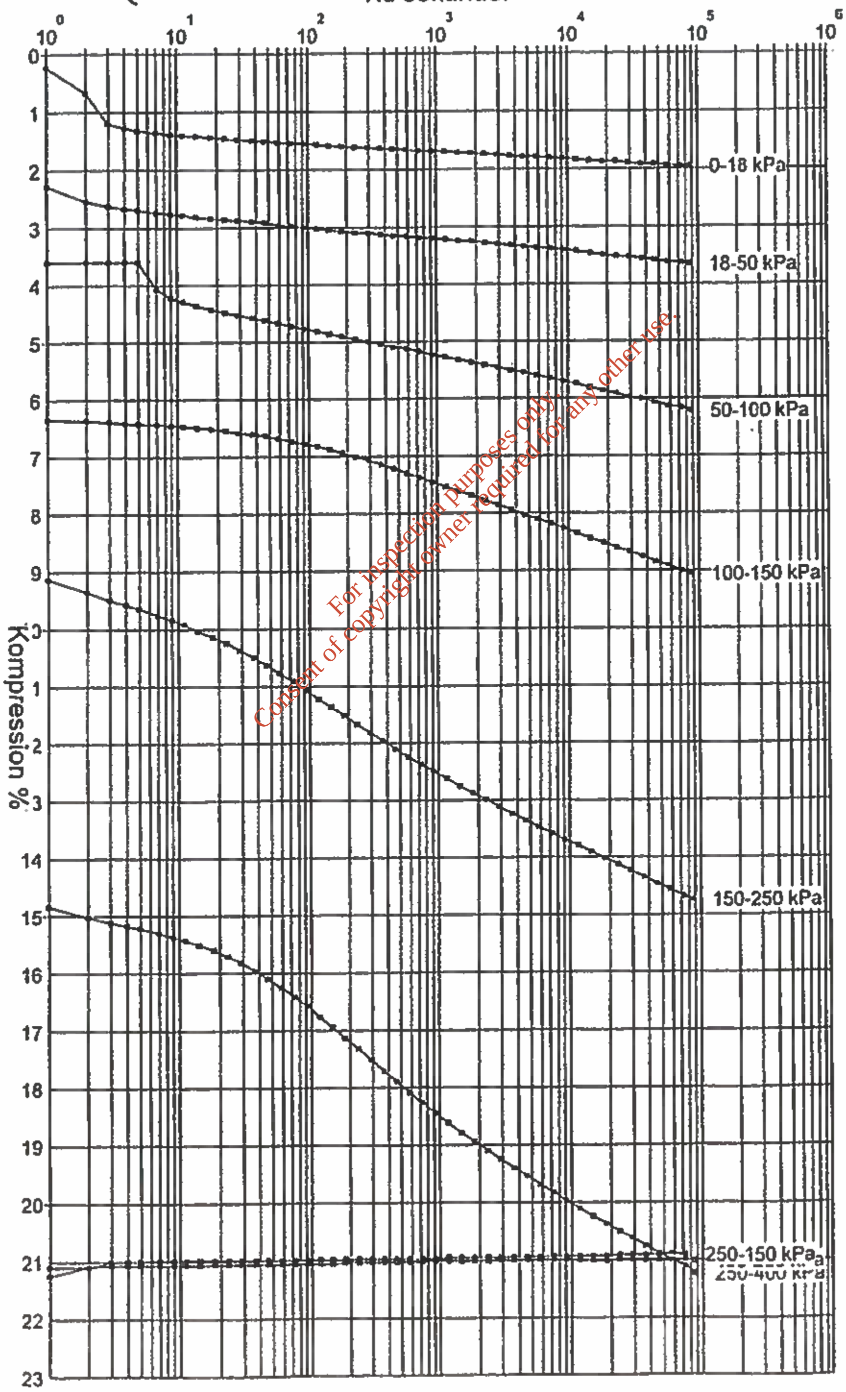


SGI Ödometerförsök

Projektnummer: 2-0403-163
Borrhål: PS35, Bl.13
Djup : 2,6-2,8 Prov I58A
Jordart: Stab.torv
ρ = 1,21 t/m³
w = (204%)

Provhöjd : 49,23 mm
Provdiameter: 100 mm
Provets vikt : 469,04 gram
Ödometer nr : 7

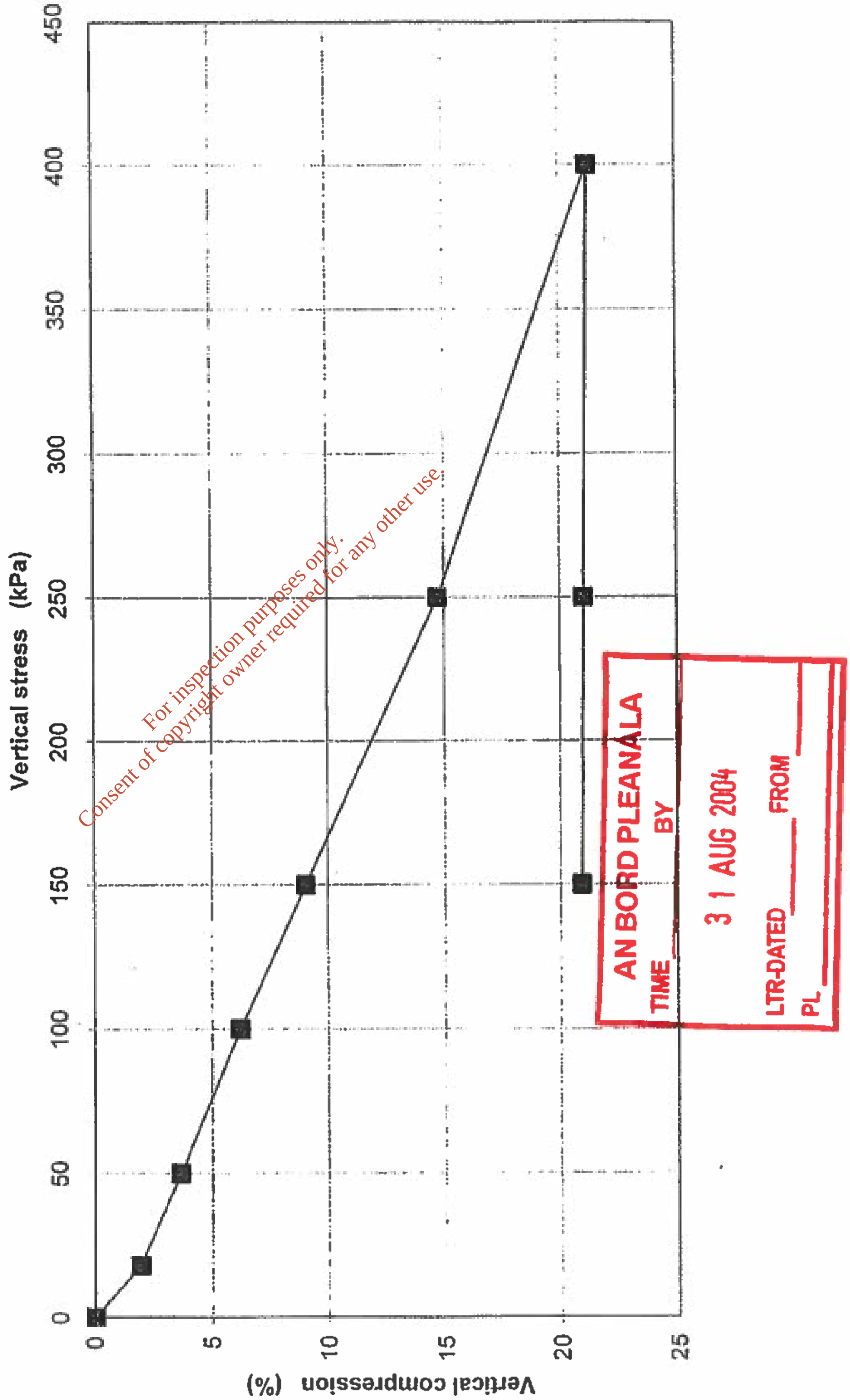
Filnamn : 0407\040706AB
Datum : 20040706-20040713
Sign :
Utrustningens egendeformation är beaktad



Dnr 2-0403-163
2004-07-19
IMK

Ödometer nr 7

Oedoemeter test on stabilised peat
I-58A - PS35 depth 2.6-2.8 m

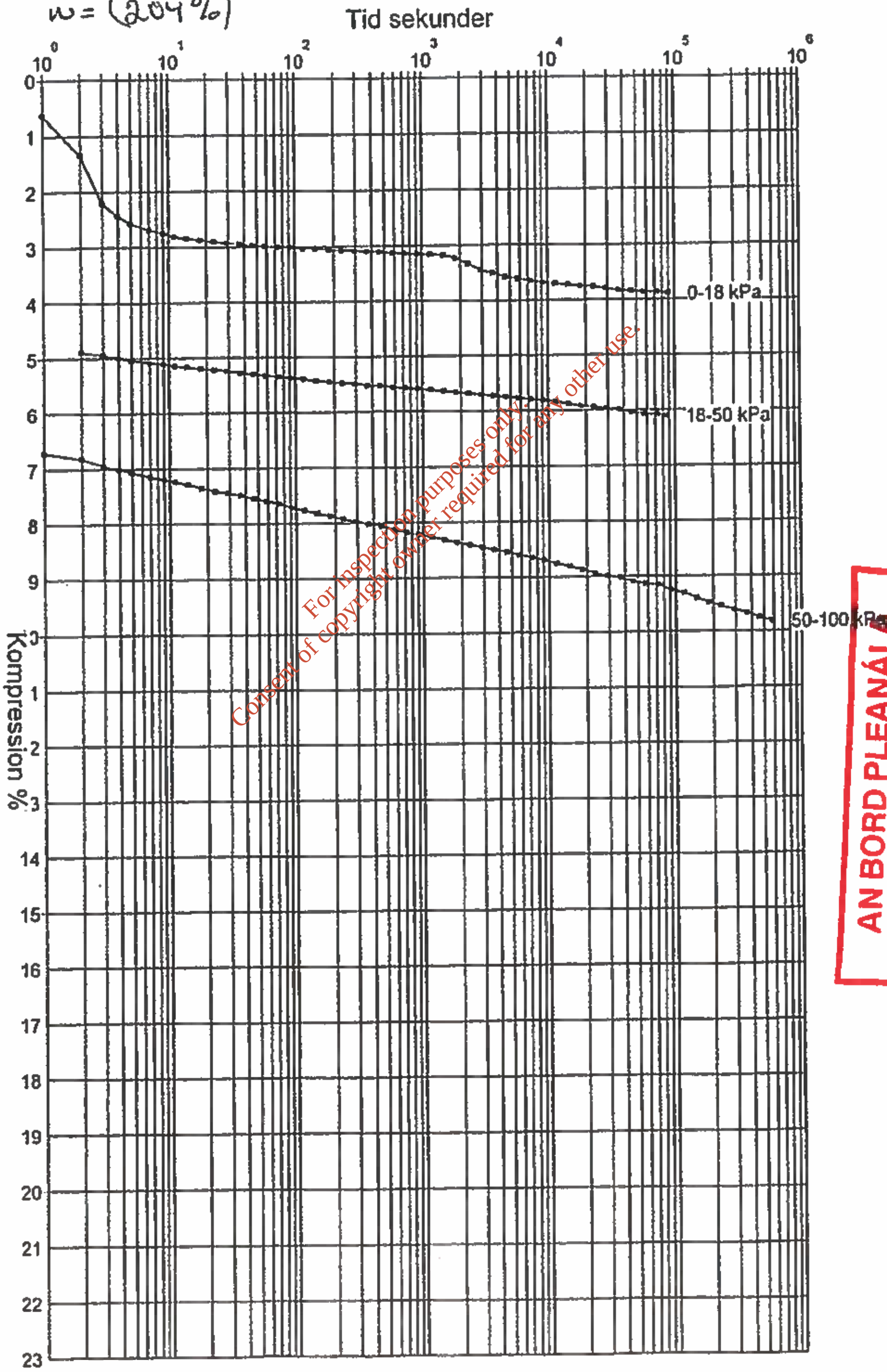


SGI Ödometerförsök

Projektnummer: 2-0403-163
Borrhål: PS 35, Bl.13
Djup : 2,6-2,8 Prov I58B
Jordart: Stab. torv
ρ = 1,20 t/m³
w = (204%)

Provhöjd : 48,7 mm
Provdiameter: 100 mm
Provets vikt : 459,2 gram
Ödometer nr : 8

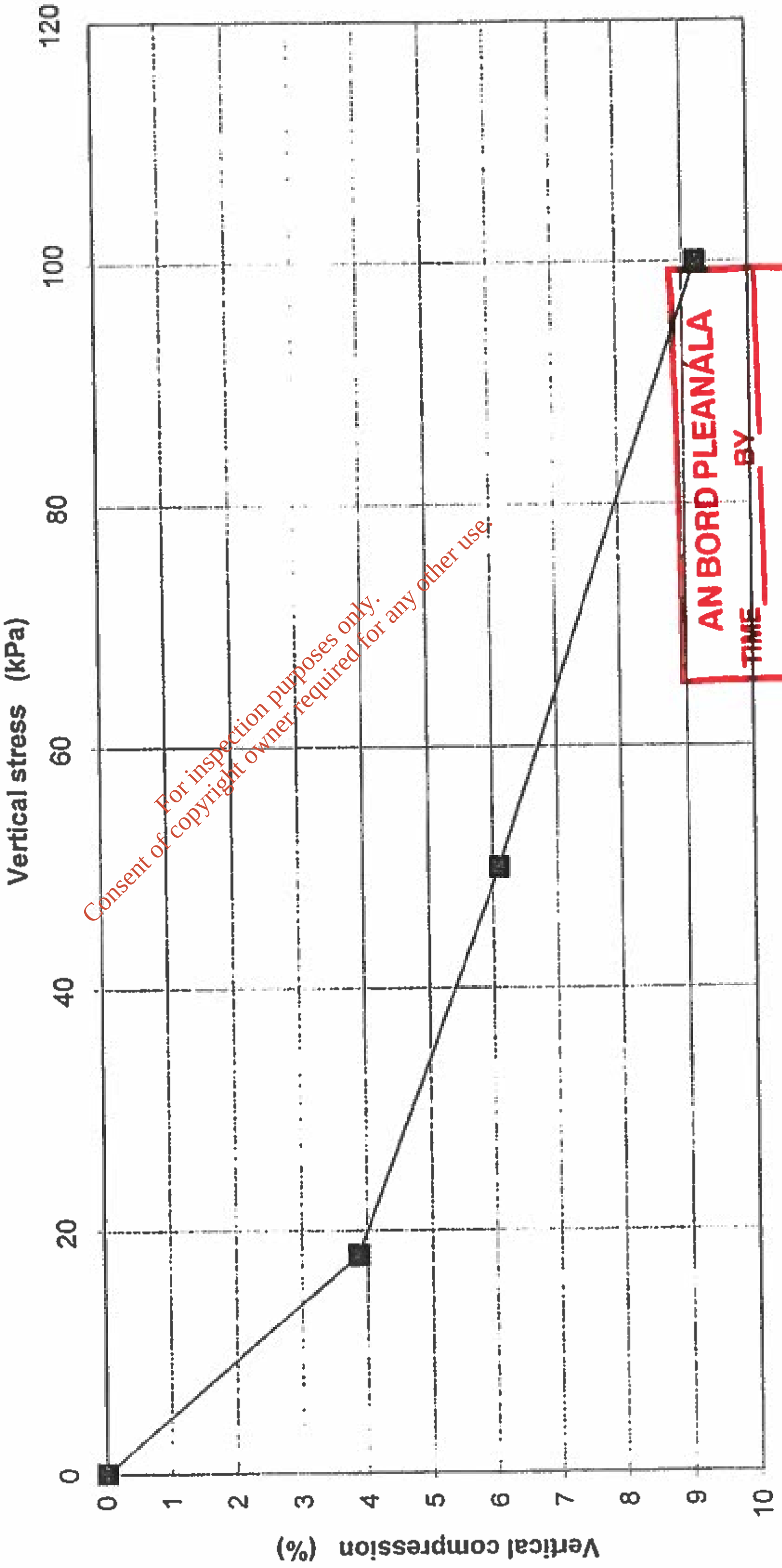
Filnamn : 0407\040706AA
Datum : 20040706-20040708
Sign :
Utrustningens egendeformation är beaktad



Dnr 2-0403-163
2004-07-19
IMK

Ödometer nr 8

Oedometer test on stabilised peat
I-58B - PS35 depth 2.6-2.8 m



Appendix 3b

SGI Test update 27th August 2004

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised peat samples

Peat from borehole PS23 depth 0.70 - 1.70 m

Samples mixed with Irish Cement 42.5 N
- 2004-05-26 for 50 and 100 kg/m^3.
- 2004-05-27 for 150, 200 and 250 kg/m^3.

After mixing of natural peat samples were taken to determine natural water content of mixed peat

w_N^1 =	893 %	Sample 1 on premixed natural peat
w_N^2 =	896 %	Sample 2 on premixed natural peat
w_N^{mean} =	894 %	Mean value of sample 1 and 2

After mixing (0.45 hours) samples stored under water with a 'surcharge' of 18 kPa at 20 degree C.

No	Quantity cement kg/m^3	Density$^{1)}$ t/m^3	$\varepsilon_{vertical}$ % After	$\varepsilon_{vertical}$ % After	Testing age days	$\varepsilon_{vertical}$ % final	Density$^{2)}$ t/m^3	$w_N$$^{2)}$ %	τ_{fu} kPa	E_{50} MPa
			1 day	6 days						
I17	50		12.9	20.7	28	21.7	1.05	432	13	2.4
I18	50		15.1	22.6	28	23.6	1.06	451	18	2.7
I19	50		14.3	21.2	90	22.6	1.05	446	18	2.3
I20	50		14.7	20.6	90	23.4	1.06	421	20	2.7
			1 day	6 days						
I21	100		12.5	13.4	28	13.9	1.09	351	40	8.1
I22	100		14.4	15.7	28	16.2	1.10	342	45	7.6
I23	100		12.1	13.0	90	13.5	1.09	345	39	6.8
I24	100		12.2	13.5	90	14.0	1.08	348	40	6.4
			1 day	5 days						
I25	150		12.1	12.1	28	12.1	1.12	274	85	13.2
I26	150		11.5	11.5	28	11.5	1.13	284	77	12.5
I27	150		12.0	12.0	90	12.5	1.12	278	75	7.4
I28	150		12.6	12.6	90	13.1	1.13	275	98	10.8
			1 day	5 days						
I29	200		10.6	10.6	28	10.6	1.15	229	102	13.6
I30	200		10.6	10.6	28	10.6	1.17	225	103	17.0
I31	200		9.8	9.8	90	10.2	1.14	223	122	16.2
I32	200		9.5	9.5	90	9.9	1.14	225	118	13.5
			1 day	5 days						
I33	250		9.0	9.0	28	9.0	1.19	188	153	23.3
I34	250		9.1	9.1	28	9.1	1.18	199	120	26.4

I35	250	10.2	10.2	90	10.6	1.18	194	171	25.6
I36	250	9.8	9.8	90	9.8	1.18	193	164	27.5

1) = directly after mixing and placement into sampling tube (not determined)
2) = at testing day

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

KEMISKT STABILISERAD JORD
Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell	
Dnr	2-0403-0163
Datum	040827
Teknisk ledare	

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040526-040527	68,6	040623-040825	O.A

Blandning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inblandning dygn	Lagringstemperatur °C	2) Densitet ρ t/m³	3) Vattenkvot w %	4) Konflytgräns w_L %	5) Skjuvhållfasthet Enaxliga tryckförsök τ_{fu} kPa	Anmärkning
BL 4								894[1]			
Prov 17	50	100			28	ca+20	1,05	432		13	
Prov 18	50	100			28	ca+20	1,06	451		18	
Prov 19	50	100			90	ca+20	1,05	446		18	
Prov 20	50	100			90	ca+20	1,06	421		20	
BL 5								894[1]			
Prov 21	100	100			28	ca+20	1,09	351		40	
Prov 22	100	100			28	ca+20	1,10	342		45	
Prov 23	100	100			90	ca+20	1,09	345		39	
Prov 24	100	100			90	ca+20	1,08	348		40	
BL 6								894[1]			
Prov 25	150	100			28	ca+20	1,12	274		85	
Prov 26	150	100			28	ca+20	1,13	284		77	
Prov 27	150	100			90	ca+20	1,12	278		75	
Prov 28	150	100			90	ca+20	1,13	275		98	

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovisas på vår hemsida, www.swedgeo.se

Blandning: 4 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

Blandning: 5 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

Blandning: 6 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

R7 2004-04-22

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag. Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17025. Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat. Resultaten gäller enbart för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

KEMISKT STABILISERAD JORD

Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell

Dnr 2-0403-0163

Datum 040827

Teknisk ledare

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040527	68,6	040624-040825	O.A

Bland-ning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL 7								894[1]			
Prov 29	200	100			28	ca+20	1,15	229		102	
Prov 30	200	100			28	ca+20	1,17	225		103	
Prov 31	200	100			90	ca+20	1,14	223		122	
Prov 32	200	100			90	ca+20	1,14	225		118	
BL 8								894[1]			
Prov 33	250	100			28	ca+20	1,19	188		153	
Prov 34	250	100			28	ca+20	1,18	199		120	
Prov 35	250	100			90	ca+20	1,18	194		171	
Prov 36	250	100			90	ca+20	1,18	193		164	

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovias på vår hemsida, www.swedgeo.se

Blandning: 7 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

Blandning: 8 PS TPS 23 Djup 0,7-1,7m Proverna har lagrats med last = 18 kPa

R7 2004-04-22

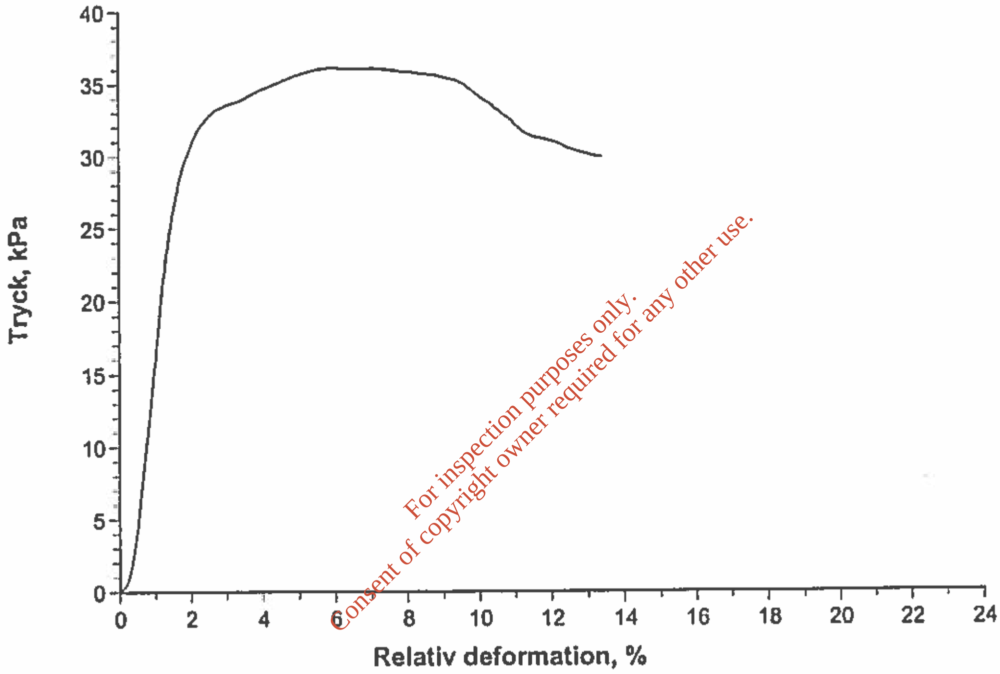
SGI

SWEDAC ACKREDITERING 1148

Objekt		Corrib Gas Terminal	
Provningsdatum	2004-08-24	Diagram	
Provhöjd	13,80 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 4
Area	36,96 cm^2	Djup/Nivå/Prov nr	19
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1120		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
18	0,142 vid 5,9% def	2291	1,6		

Anmärkning ____

Godkänd av ____ Linköping den ____

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

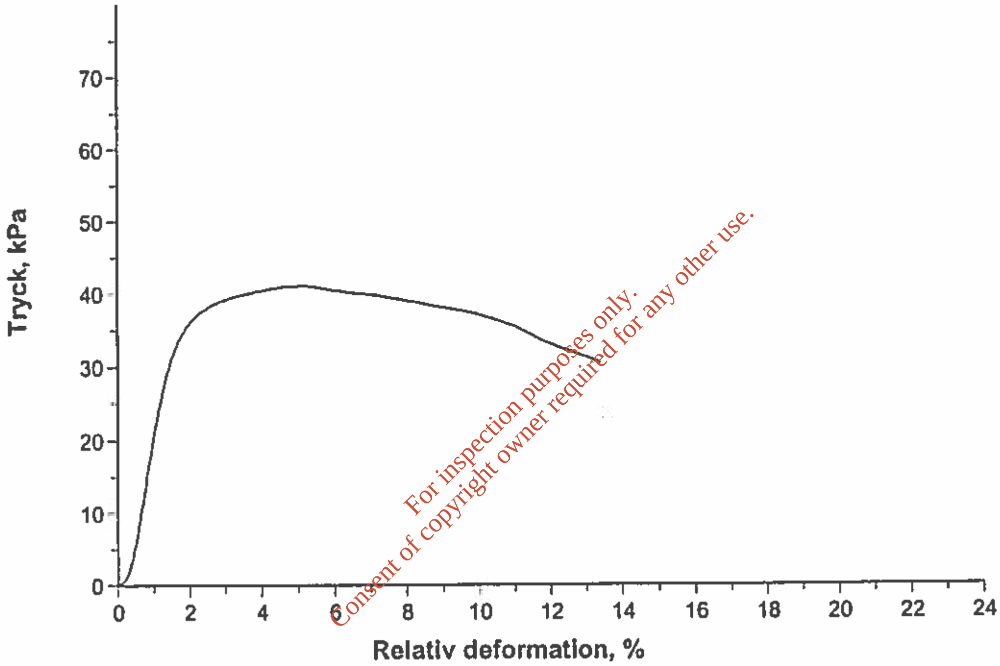
SGI

SWEDAC ACKREDITERING 1148

Objekt		Corrib Gas Terminal	
Provningsdatum	2004-08-24	Diagram	
Provhöjd	13,90 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 4
Area	36,96 cm^2	Djup/Nivå/Prov nr	20
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1121		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
20	0,159 vid 5,0% def	2701	1,6		

Anmärkning ______

Godkänd av ______ Linköping den ______

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025.

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

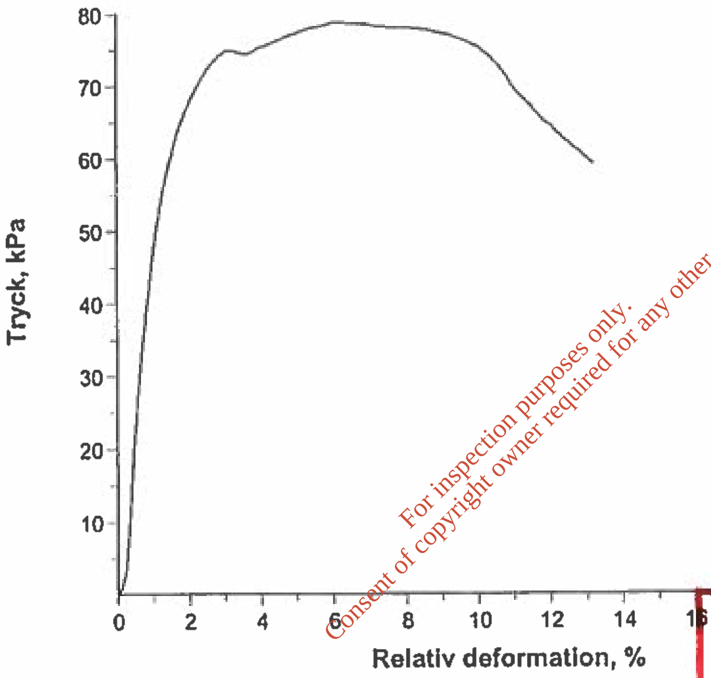
SGI

SWEDAC ACKREDITERING 1148

Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-24	Diagram	
Provhöjd	13,80 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 5
Area	36,96 cm²	Djup/Nivå/Prov nr	23
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1124		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Be... korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
39	0,310 vid 6,2% def	6848	1,6		

Anmärkning ____________________

Godkänd av ____________________ Linköping den ____________________

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag. Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

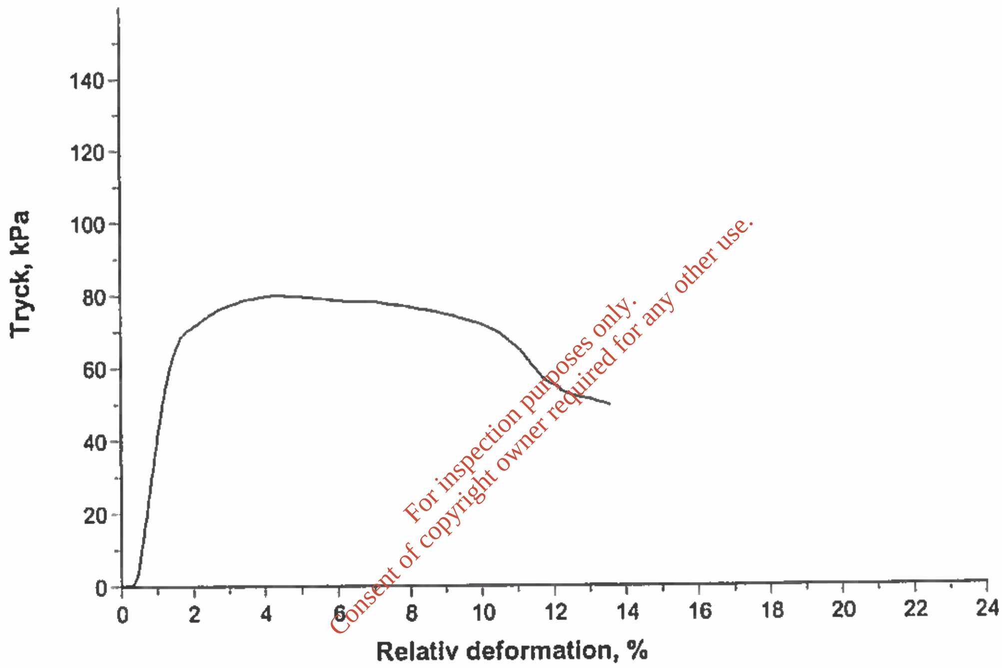
Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-24	Diagram	
Provhöjd	13,90 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 5
Area	36,96 cm^2	Djup/Nivå/Prov nr	24
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1125		
Tid efter inbl.	90 dygn		

SGI

SWEDAC ACKREDITERING 1148

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
40	0,310 vid 4,4% def	6398	1,6		

Anmärkning ______________________________

Godkänd av ______________________ Linköping den ______________________

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

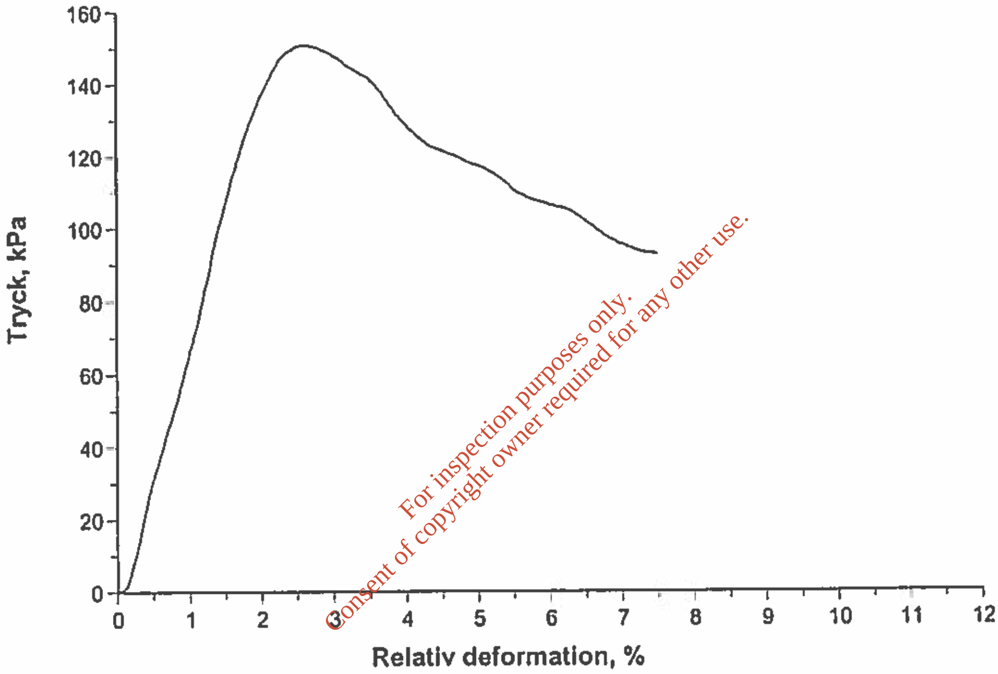
Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

Objekt			Corrib Gas Terminal
Provningsdatum	2004-08-25	Diagram	
Provhöjd	13,80 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 6
Area	36,96 cm²	Djup/Nivå/Prov nr	27
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1128		
Tid efter inbl.	90 dygn		

SGI
SWEDAC ACKREDITERING 1148

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
75	0,572 vid 2,6% def	7427	1,6		

Anmärkning ____________________

Godkänd av ____________________ Linköping den ____________________

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025.

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

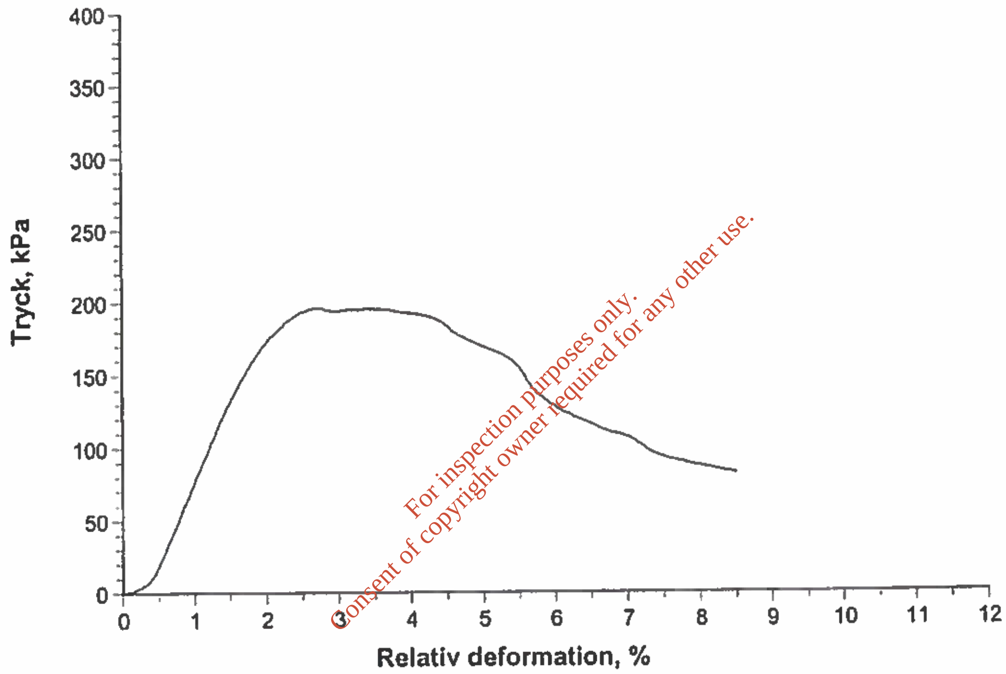
Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-25	Diagram	
Provhöjd	13,80 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 6
Area	36,96 cm²	Djup/Nivå/Prov nr	28
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1129		
Tid efter inbl.	90 dygn		

SWEDAC ACKREDITERING 1148

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
98	0,749 vid 2,7% def	10807	1,6		

Anmärkning

Godkänd av Linköping den

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

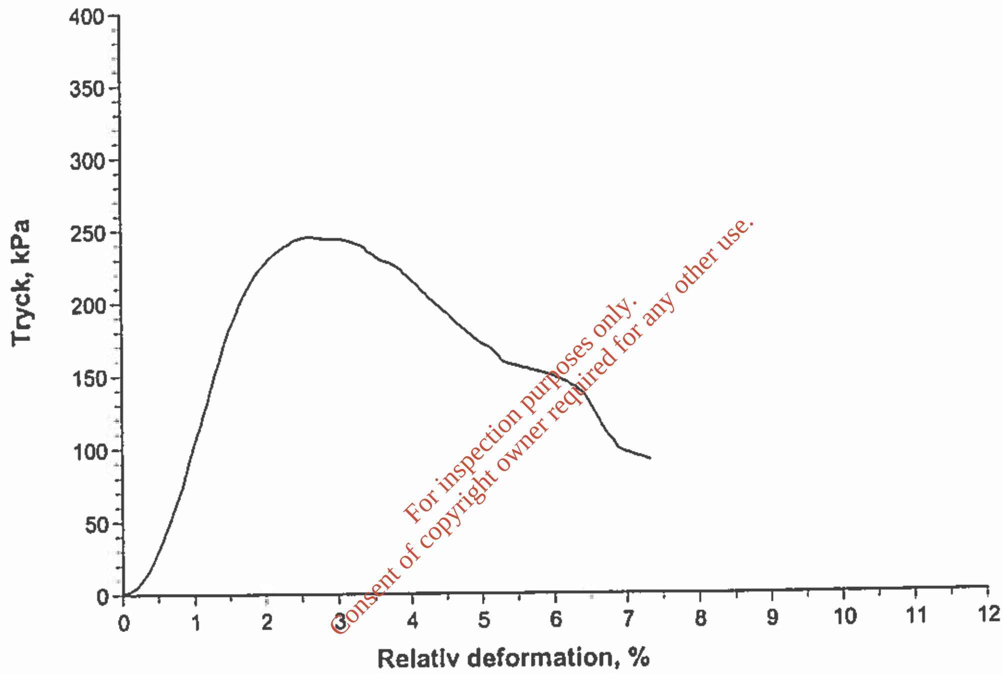
SGI

SWEDAC ACKREDITERING 1148

Objekt			Corrib Gas Terminal
Provningsdatum	2004-08-25	Diagram	
Provhöjd	13,60 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 7
Area	36,96 cm²	Djup/Nivå/Prov nr	31
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1132		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
122	0,935 vid 2,6% def	16215	1,6		

Anmärkning

Godkänd av Linköping den

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025.

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

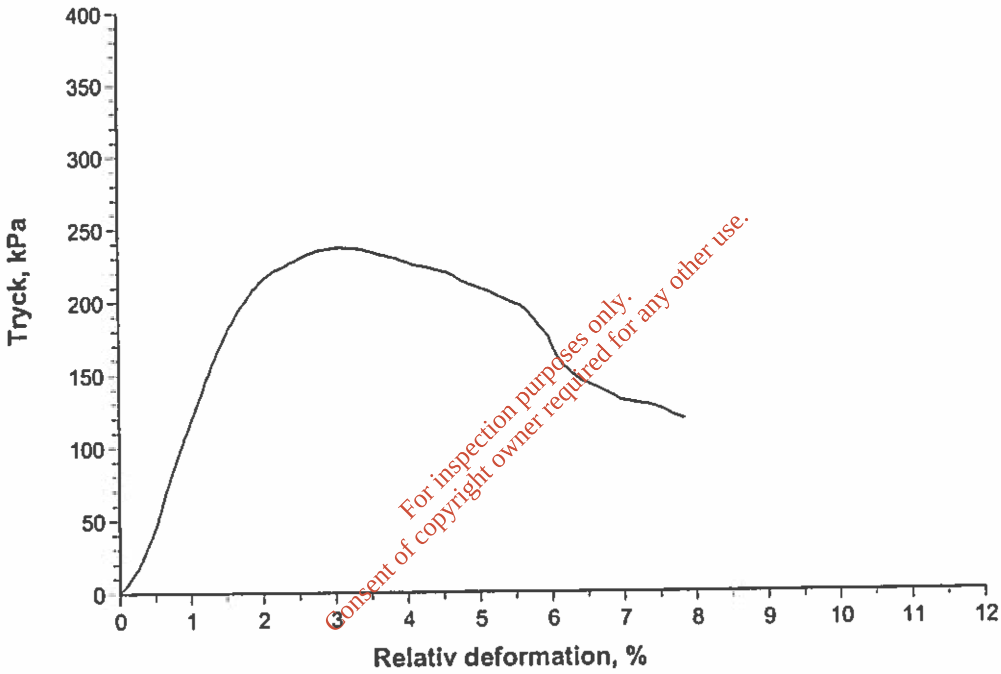
SGI

SWEDAC ACKREDITERING 1148

Objekt		Corrib Gas Terminal	
Provningsdatum	2004-08-25	Diagram	
Provhöjd	13,40 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 7
Area	36,96 cm^2	Djup/Nivå/Prov nr	32
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1133		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
118	0,907 vid 3,0% def	13514	1,5		

Anmärkning ____

Godkänd av ______________________ Linköping den ______________

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

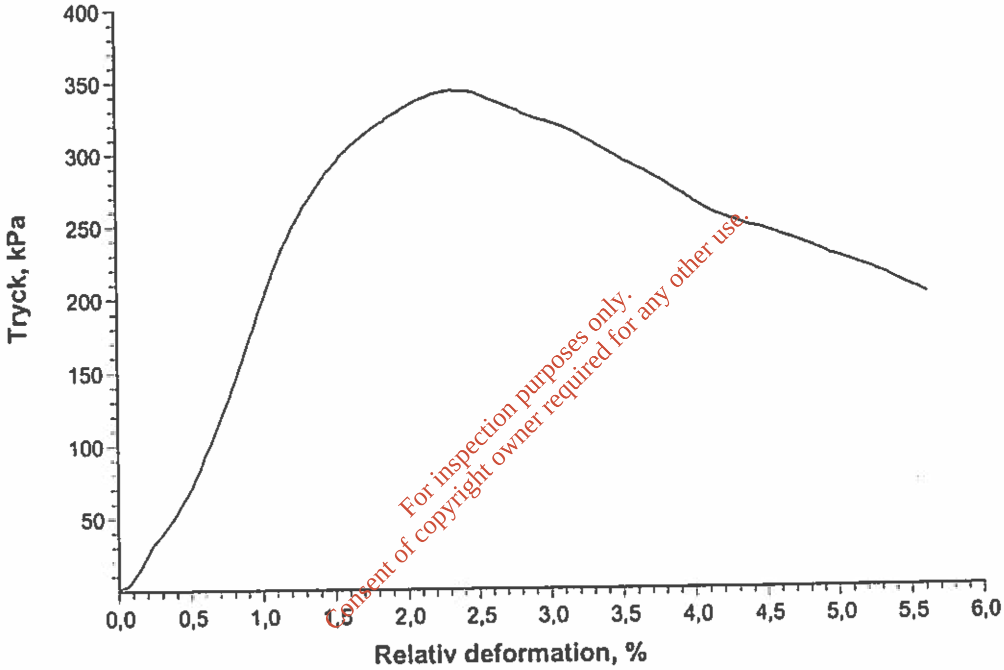
SGI

SWEDAC ACKREDITERING 1148

Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-25	Diagram	
Provhöjd	13,80 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 8
Area	36,96 cm²	Djup/Nivå/Prov nr	35
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1136		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min
171	1,308 vid 2,3% def	25590	1,6

Anmärkning ______

Godkänd av ______ Linköping den

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

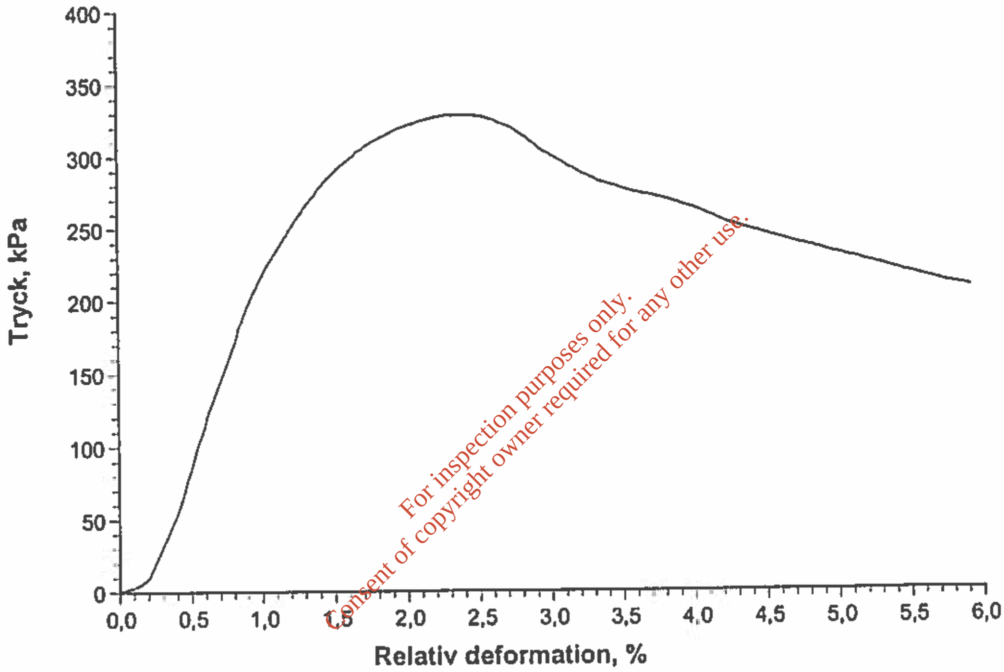
SGI

SWEDAC ACKREDITERING 1148

Objekt		Corrib Gas Terminal	
Provningsdatum	2004-08-25	Diagram	
Provhöjd	13,80 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 8
Area	36,96 cm^2	Djup/Nivå/Prov nr	36
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1137		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
164	1,254 vid 2,3% def	27489	1,6		

Anmärkning ____________________

Godkänd av ____________________ Linköping den ____________________

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025.

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

AGEC Ltd, Ireland

Corrib Gas Terminal

Laboratory test at SGI on stabilised peat samples

Peat from borehole PS35 depth 2.10 - 3.10 m

Samples mixed with Irish Cement 42.5 N
- 2004-05-28 for 150, 200 and 250 kg/m³.

After mixing of natural peat samples were taken to determine natural water content of mixed peat

w_N^1 =	1028 %	Sample 1 on mixed natural peat
w_N^2 =	1010 %	Sample 2 on mixed natural peat
w_N^{mean} =	1019 %	Mean value of sample 1 and 2

After mixing (0.45 hours) samples stored under water with a 'surcharge' of 18 kPa at 20 degree C.

No	Quantity cement kg/m³	Density[1)] t/m³	$\varepsilon_{vertical}$ % After	$\varepsilon_{vertical}$ % After	Testing age days	$\varepsilon_{vertical}$ % final	Density[2)] t/m³	w_N[2)] %	τ_{fu} kPa	E_{50} MPa
			0.27 days	4 days						
I37	150		14.0	15.0	7	15.0	1.12	278	55	13.4
I38	150		13.3	14.2	7	14.2	1.12	281	50	5.6
I39	150		14.2	15.5	14	15.5	1.12	270	49	8.0
I40	150		14.8	15.7	14	15.7	1.13	259	59	8.8
I41	150		13.5	13.9	28	14.8	1.11	278	80	17.0
I42	150		14.0	14.0	28	14.9	1.12	266	78	14.8
I43	150		13.1	13.6	90	14.5	1.12	264	84	13.5
I44	150		13.3	13.8	90	14.2	1.13	265	79	13.2
			0.24 days	4 days						
I45	200		12.9	13.8	7	13.8	1.17	227	80	7.3
I46	200		12.3	13.2	7	13.2	1.16	220	67	8.2
I47	200		11.9	12.8	14	13.2	1.15	235	103	17.1
I48	200		10.7	12.0	14	12.0	1.15	226	111	16.3
I49	200		12.7	13.5	28	14.4	1.17	224	135	26.2
I50	200		12.8	13.7	28	14.1	1.15	218	91	15.7
I51	200		12.1	12.5	90	13.4	1.17	228	125	22.4
I52	200		12.2	13.1	90	14.0	1.15	223	117	25.5
			0.18 days	4 days						
I53	250		11.2	12.9	28	12.9	1.21	187	210	35.2
I54	250		11.0	11.4	28	11.8	1.19	184	157	33.3
I55	250		11.3	12.2	90	13.1	1.21	180	185	31.5
I56	250		11.9	13.2	90	13.2	1.21	182	226	43.3

1) = directly after mixing and placement into sampling tube (not determined)
2) = at testing day

SGI LABORATORIET

SWEDAC ACKREDITERING 1148

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

KEMISKT STABILISERAD JORD
Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell

Dnr 2-0403-0163

Datum 040827

Teknisk ledare

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040528	68,6	040604-040826	IMK O.A

Bland-ning	Tillsatsmedel Mängd stab.-medel kg/m³	Proportioner Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL 9								1019[1]			
Prov 37	150	100			7	ca+20	1,12	278		55	
Prov 38	150	100			7	ca+20	1,12	281		50	
Prov 39	150	100			14	ca+20	1,12	270		49	
Prov 40	150	100			14	ca+20	1,13	259		59	
Prov 41	150	100			28	ca+20	1,10	278		80	
Prov 42	150	100			28	ca+20	1,12	266		78	
Prov 43	150	100			90	ca+20	1,12	264		84	
Prov 44	150	100			90	ca+20	1,13	265		79	

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovias på vår hemsida, www.swedgeo.se

Blandning: 9 PS 35 Djup 2,1-3,1m Proverna har lagrats med last = 18 kPa

R7 2004-04-22

SGI LABORATORIET

RAPPORT
utfärdad av ackrediterat laboratorium
REPORT is issued by an Accredited Laboratory

SWEDAC ACKREDITERING 1148

KEMISKT STABILISERAD JORD

Referens: SGI, egna anvisningar. Dokument nr 29

Beställare: Turlough Johnston Applied Ground Engineering Consultants Limited

Corrib Gas Terminal

Tabell	
Dnr	2-0403-0163
Datum	040827
Teknisk ledare	

Datum för inblandning	Provdiameter (mm)	Laboratorieundersökning Datum	Utförd av
040528	68,6	040604-040826	IMK

Bland-ning	Tillsatsmedel: Mängd stab.-medel kg/m³	Proportioner: Cement Irish Cement %			Tid efter inbland-ning dygn	Lag-rings-tempe-ratur °C	2) Densitet ρ t/m³	3) Vatten-kvot w %	4) Kon-flyt-gräns w_L %	5) Skjuvhållfasthet Enaxliga tryck-försök τ_{fu} kPa	Anmärkning
BL 10								1019[1]			
Prov 45	200	100			7	ca+20	1,17	227		80	
Prov 46	200	100			7	ca+20	1,16	220		67	
Prov 47	200	100			14	ca+20	1,15	235		103	
Prov 48	200	100			14	ca+20	1,15	226		111	
Prov 49	200	100			28	ca+20	1,15	224		135	
Prov 50	200	100			28	ca+20	1,15	218		91	
Prov 51	200	100			90	ca+20	1,17	228		125	
Prov 50	200	100			90	ca+20	1,15	223		117	
BL 11								1019[1]			
Prov 53	250	100			28	ca+20	1,21	187		210	
Prov 54	250	100			28	ca+20	1,19	184		157	
Prov 55	250	100			90	ca+20	1,21	180		185	
Prov 56	250	100			90	ca+20	1,21	182		226	

1) Blandningens vattenkvot före inblandning av stabiliseringsmedel.

2) Skrymdensitet, SS 027114, utgåva 2
3) Vattenkvot, SS 027116, utgåva 3
4) Konflytgräns, SS 027120, utgåva 2
5) Enaxliga tryckförsök, SS 027128, utgåva 1
Mätosäkerhet och mätområde för våra metoder redovias på vår hemsida, www.swedgeo.se

Blandning: 10 PS 35 Djup 2,1-3,1m Proverna har lagrats med last = 18 kPa

Blandning: 11 PS 35 Djup 2,1-3,1m Proverna har lagrats med last = 18 kPa

R7 2004-04-22

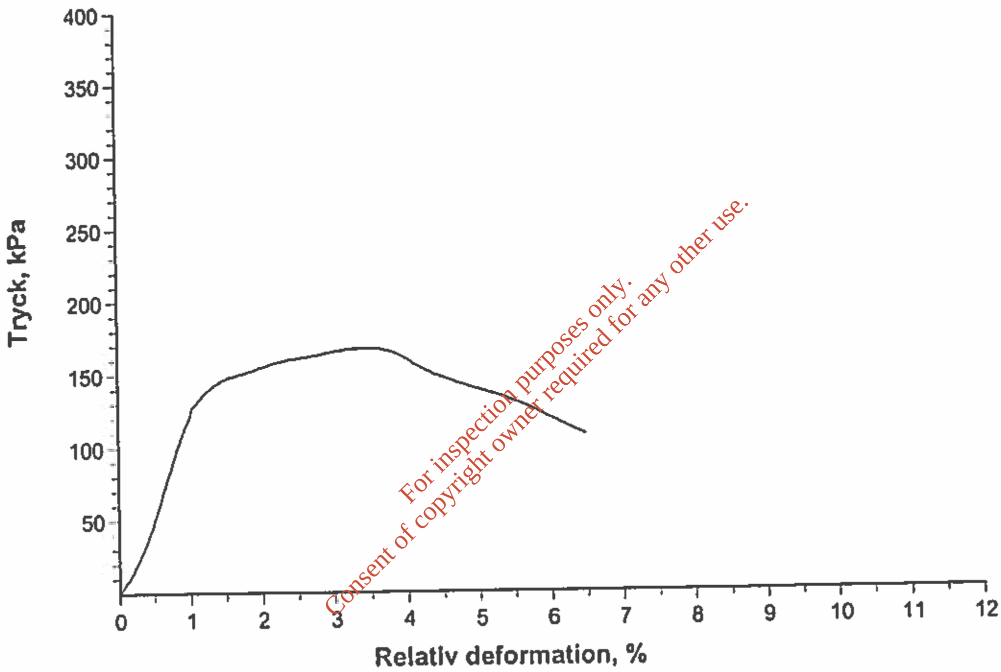
Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, telefax 013-20 19 14

Objekt		Corrib Gas Terminal	
Provningsdatum	2004-08-26	Diagram	
Provhöjd	13,60 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 9
Area	36,96 cm²	Djup/Nivå/Prov nr	43
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1144		
Tid efter inbl.	90 dygn		

SWEDAC ACKREDITERING 1148

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
84	0,644 vid 3,5% def	13547	1,5		

Anmärkning ______

Godkänd av ______ Linköping den ______

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag. Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

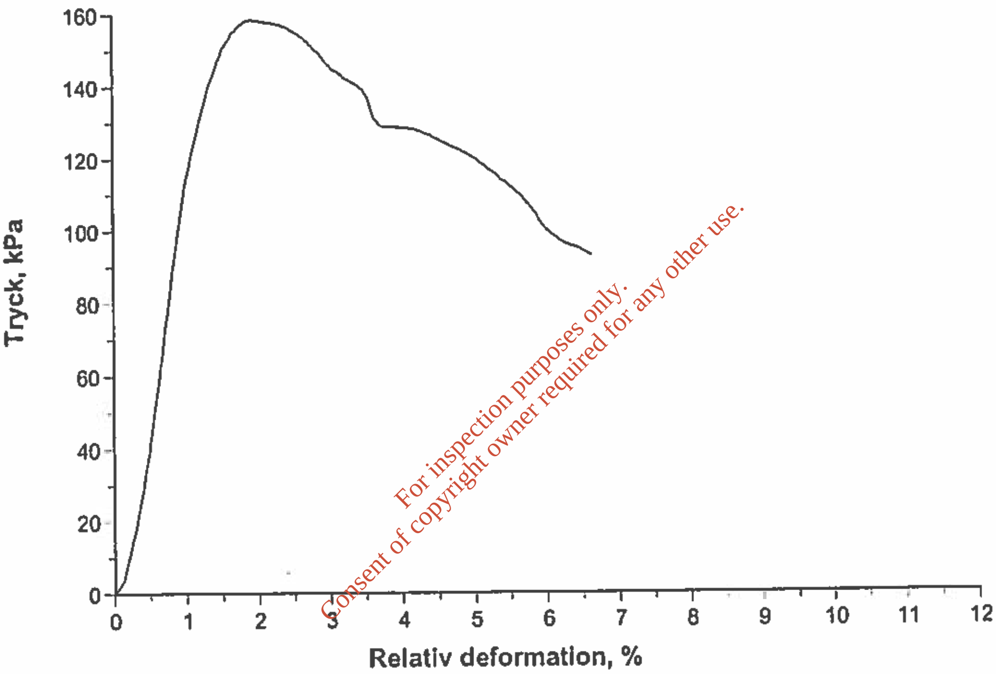
Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-26	Diagram	
Provhöjd	13,60 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 9
Area	36,96 cm²	Djup/Nivå/Prov nr	44
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1145		
Tid efter inbl.	90 dygn		

SGI

SWEDAC ACKREDITERING 1148

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
79	0,598 vid 1,9% def	13239	1,6		

Anmärkning ______

Godkänd av ______ Linköping den ______

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

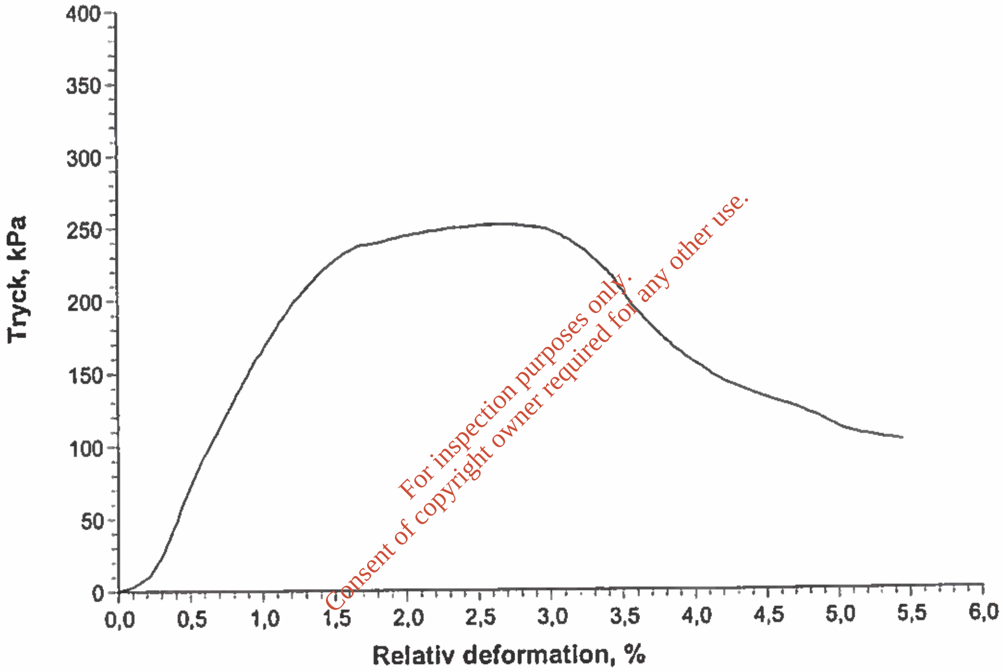
Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

Objekt		Corrib Gas Terminal	
Provningsdatum	2004-08-26	Diagram	
Provhöjd	13,70 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 10
Area	36,96 cm²	Djup/Nivå/Prov nr	51
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1152		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
125	0,957 vid 2,6% def	22395	1,6		

Anmärkning

Godkänd av ______________________ Linköping den ______

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025.

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm ocx
Version: 1.0.0.39

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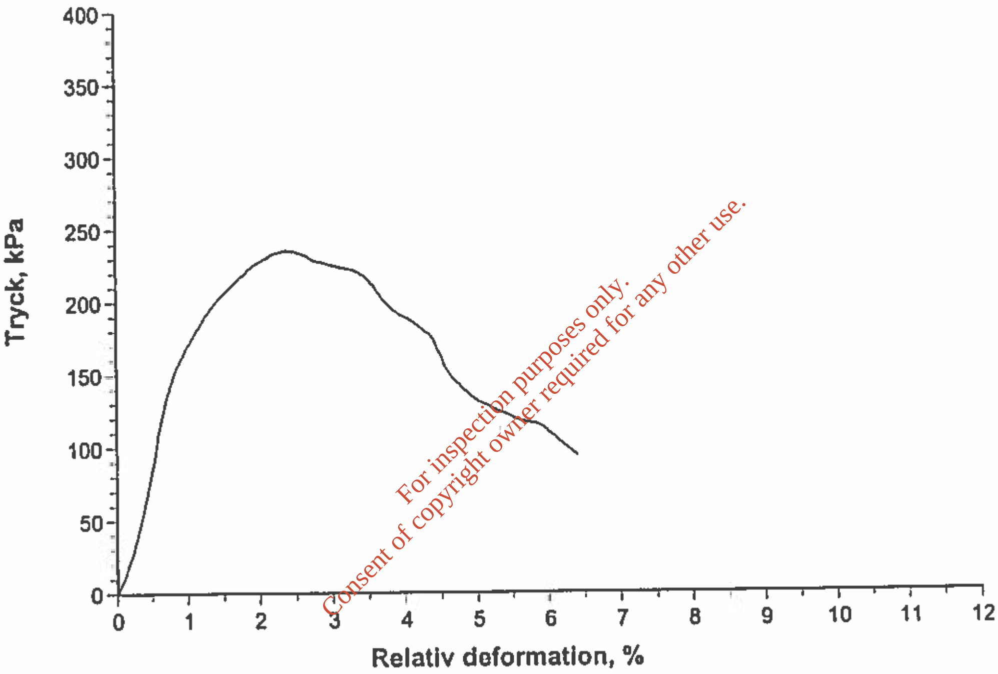
SWEDAC ACKREDITERING 1148

Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-26	Diagram	
Provhöjd	14,00 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 10
Area	36,96 cm^2	Djup/Nivå/Prov nr	52
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1153		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
117	0,897 vid 2,3% def	25475	1,6		

Anmärkning ______________________________

Godkänd av ______________________ Linköping den ______________________

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag. Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkännt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

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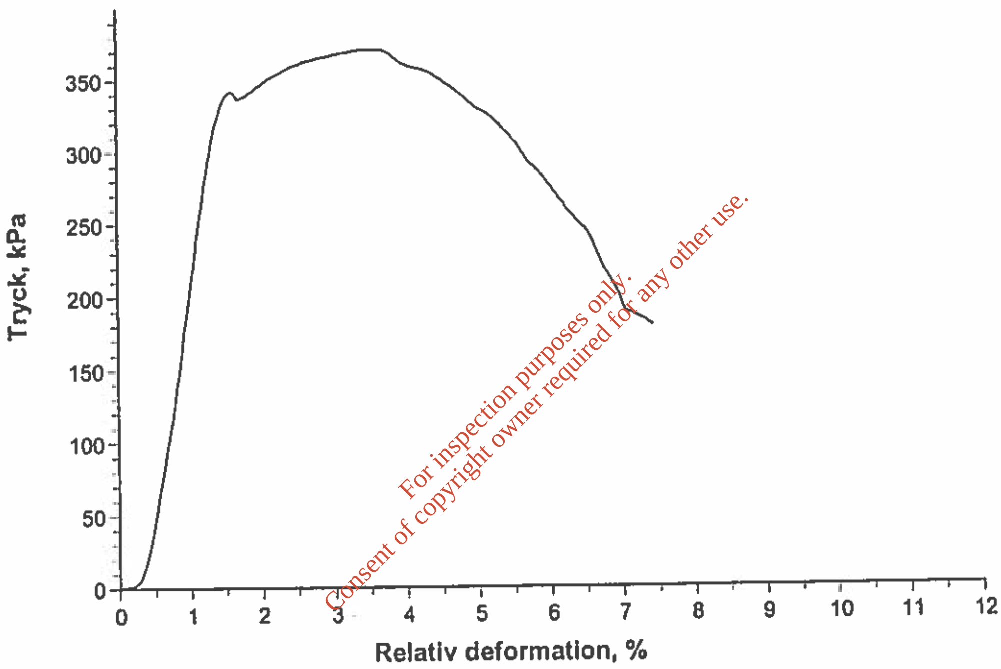
SWEDAC ACKREDITERING 1148

Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-26	Diagram	
Provhöjd	13,95 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 11
Area	36,96 cm²	Djup/Nivå/Prov nr	55
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1156		
Tid efter inbl.	90 dygn		

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
185	1,426 vid 3,5% def	31543	1,6		

Anmärkning ______________________________

Godkänd av ______________________ Linköping den ______________________

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm ocx
Version: 1.0.0.39

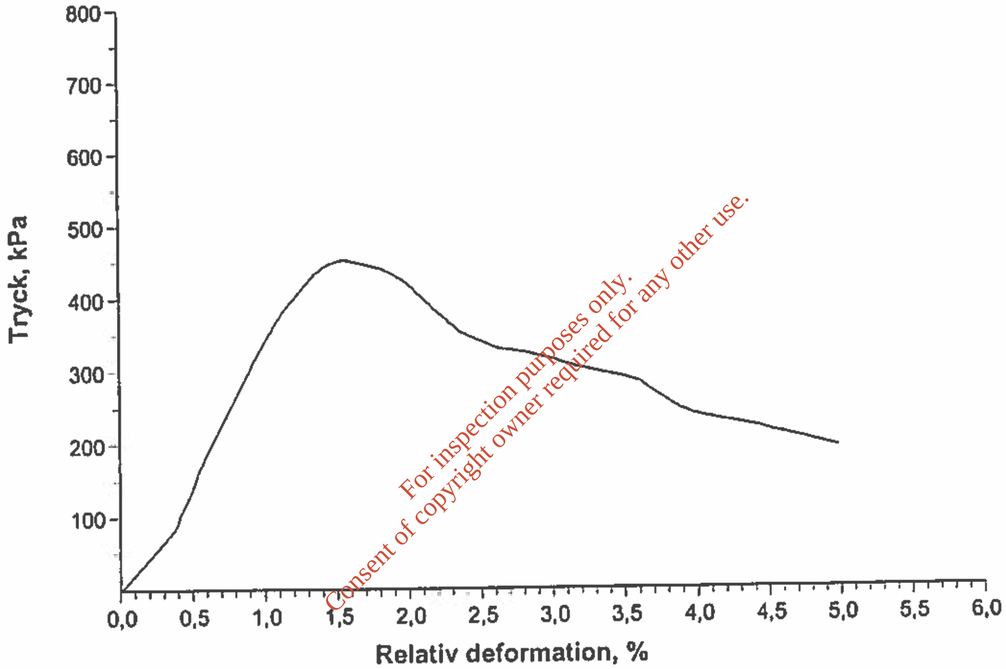
Objekt	Corrib Gas Terminal		
Provningsdatum	2004-08-26	Diagram	
Provhöjd	13,90 cm	Diarie nr	2-0403-0163
Provdiameter	6,9 cm	Sektion/borrhål/blandning	BL 11
Area	36,96 cm²	Djup/Nivå/Prov nr	56
Tryckpress	Lilla Pressen		
Utfört av	O.A		
Försök nr	1157		
Tid efter inbl.	90 dygn		

SGI

SWEDAC ACKREDITERING 1148

Redovisning av enaxligt tryckförsök

Prov efter försök



Försöket är utfört och utvärderat enligt Svensk Standard SS 027128. Beräknat tryck är korrigerat enligt Svensk Standard.

τ_{fu}, kPa	P_f, kN	E_{50}-modul, kPa	Def-hast mm/min		
226	1,707 vid 1,5% def	43257	1,6		

Anmärkning

Godkänd av ______________________ Linköping den

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag.
Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 17 025

Denna rapport får endast återges i sin helhet, om inte SWEDAC och utfärdande laboratorium i förväg skriftligen godkänt annat. Resultaten gäller för de provade materialen.

Statens geotekniska institut
581 93 Linköping, telefon 013-20 18 00, fax 013-20 19 14

Program: EnaxligtTryckUtvRedoForm.ocx
Version: 1.0.0.39

Appendix 4

Letter from Swedish Geotechnical Institute

SGI

Date
August 27, 2004

Your date

Registration number
2-0403-163

Your reference

Our reference
Per-Evert Bengtsson

AGEC Ltd
Att. Turlough Johnston
5 Kilcarrig Street
Bagenalstown
Co. Carlow
Ireland

Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland

Answers to two questions from the planning authority, An Bord Pleanála.

On commission by AGEC Ltd, Bagenalstown, Ireland, the Swedish Geotechnical Institute (SGI), www.swedgeo.se, is currently performing laboratory testing on soil samples from the site at Bellanaboy Bridge Gas Terminal, Co. Mayo, Ireland.

The Swedish Geotechnical Institute is a government agency dealing with geotechnical research, information and consultancy. The purpose of the Institute is to achieve better techniques, safety and economy by the correct application of geotechnical knowledge in the building process.

For the past 30 years SGI has been involved in R&D and practical applications of deep mixing (stabilisation) on a large number of projects.

The aim of the laboratory testing currently being carried out by SGI is to give advice on choice of type of binder and quantity of binder for stabilisation of the peat and the mineral soil just below the peat. Field trials will serve as the basis for the final choice of binder type and binder quantity.

Mass stabilisation of peat with different kinds of binders is a technique that has been used successfully for about 10 years in Finland and Sweden but as of yet not in Ireland.

We understand that the planning authorities have some questions about the technique and its application on the Bellanaboy site.

Question No 2.
The methodology used in this case is laboratory testing performed by SGI to find the type of binder and binder quantity to be used for stabilisation of peat and mineral soil just below the peat. In this case cement and/or sand and cement combination is proposed to be used as binder.

The results from the laboratory testing and earlier experience will finally lead to a proposal for binder quantity to be used in field trials. The field trials in turn will serve as a basis for the decision on the binder quantity to be used for the planned construction. Control testing and monitoring will be performed before and during the final construction to ascertain that expected results are achieved.

The mixing and curing conditions in the laboratory are normally more favourable than the in-situ mixing so the field trials are a necessary part in the final choice of binder quantities.

The results so far from the on-going laboratory testing at SGI have been presented in an interim report by SGI dated July 20, 2004. About 80 stabilised samples have been produced and tested. The natural peat has a shear strength of less than 10 kPa. For stabilised peat results from the laboratory tests show typically a shear strength of 100 kPa or more for a curing time of 90 days (with a binder quantity of 200 kg cement per m^3 of peat).

The results so far indicate that the expected strength of the stabilised soil is going to be achieved.

Question No 3.
Use of cement in the ground does not usually raise environmental concerns and SGI have few examples of earlier experience with measurements of the actual environmental impact by deep mixing (stabilisation) on the ground water. Our experience indicates that we should expect no harmful environmental impact caused by the deep mixing (stabilisation). Earlier experience from measurements in leaching from stabilised soil (Holma Bog, Sweden (EuroSoilStab-project)) is that at a short distance of about 1 m from the stabilised soil it is not possible to detect any leaching. It should also be noted that the method is commonly used to encapsulate contaminated soil.

The possible environmental impacts being considered in this case by laboratory testing include total content tests, availability tests and batch tests on natural soil, cement and stabilised soil. The total content test gives total amount of metals and trace elements. The availability test gives information about possible leachate after a long time and batch test after a short time.

These tests are on going and results are expected in less than one month.

SGI understand that for the Corrib project the environmental impact on the ground water is planned to be monitored by a number of control wells.

Swedish Geotechnical Institute
Dept. of Geotechnical Design

Per-Evert Bengtsson
Project Manager

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Appendix 5

Item3 – Potential leaching from stabilised soil

Appendix 5 Potential leaching from stabilised soil

Introduction

In order to stabilise peat on the terminal site, it is proposed to mix cement into the peat in order to increase the strength of the ground. The introduction of cement into the ground was identified as possibly having deleterious effects upon groundwater and surface water, both in the short, medium and long term. An assessment of the chemistry of cement and the local ground conditions was carried out in order to identify the likely effects and their magnitude, both spatially and temporally.

1 Approach

The assessment has been divided into two broad areas, one concerned with the effects of cement injected below ground and the second on the effects of cement above ground. The assessment of the below ground injection of cement looked at the possible effects on hydro-geochemistry along with changes in chemistry with time. The above ground assessment investigated the effects of run-off and possible effects on hydro-geochemistry.

1.1 Potential Effects of Cement on Below Ground Chemistry

The introduction of cement below ground will introduce a mixture of chemicals into the ground that will undergo reactions once wet. The products of these reactions and the interaction with the surrounding geological materials are important in assessing any impact on the environment. The additional influence of local geology and hydrogeology also affects the potential environmental impacts

1.2 Short Term (less than 7 days) changes in Hydrochemistry

The effects of emplacement of cement on hydrochemistry have been examined principally in terms of time after emplacement and changes through time. Short term changes in hydrochemistry are expected to occur during the first 24 hours following emplacement as stated in Response to Request for Further Information by Mayo County Council dated 17/02/04 section 4.3.1.

The chemical reactions occurring during this period have an important bearing on short-term changes in hydrochemistry, and this phase of assessment is probably the most important in terms of environmental impact to the subsurface as the chemical reactions responsible for producing potentially deleterious conditions occur during this period.

Brief Overview of Chemical Reactions During Cement Setting

After cement has been hydrated, reactions occur between calcium silicate minerals and the water, resulting in the growth of new hydrated minerals that act to bind the cement and materials it is in contact with. As these reactions progress, a bi-product of this is the release of lime (Ca $(OH)_2$).

The near field pore water chemistry will be dominated by the dissolution of lime, and at equilibrium pore water will have a pH of approximately 12.1. Dissolution of lime into pore water itself releases Ca_2+ and OH- (hydroxide) ions with the hydroxide ions responsible for raising pH. In addition, lime is often added to cement and is a bi-product of the manufacturing process, resulting is relatively large amounts of lime within the total cement.

Effects of high pH porewater on Hydrochemistry

It has been shown elsewhere (MCCRFI 2004 section 3.3), that heavy metals do not tend to leach out from cement. This is broadly due to two main reasons. Firstly, the nature of the feedstock materials (mostly limestone and clay) into cement are low in heavy metals and secondly, high pH conditions tend to result in relatively low levels of metals leaching. However, it is known that chromium will occur as the chromate complex ion at high pH. The chromate complex ion has a bulk negative charge and will tend to be relatively mobile. However, (MCCRFI 2004 section 3.3) have shown that concentrations in leachate are generally low.

1.3 Medium to Long-term (7 days to end of design life) changes in Hydrogeochemistry

Medium to long-term changes in local hydrogeochemistry are those that might occur after approximately the first week following emplacement of the cement and continue beyond the end of the design life of the Terminal.

As the cement sets, porewater will have effectively become trapped within the mass of the body of material into which the cement was added. Longer-term reactions that may become important during this time would be the interaction with the material into which the cement was added. In addition, the porewaters generated during the setting of the cement may migrate away from the main area of cement emplacement, and interaction between peat porewater and groundwater and the waters from the cement mix are considered in assessing the medium to long-term interaction and effects on the environment. The impacts will depend upon the permeability of the concrete, the peat and the mineral soils into which the cement has been injected. As far as the concrete is concerned it will be effectively impermeable when set and hence porewater migration will not be a significant issue. In the case of old concrete that may begin to deteriorate, the research undertaken by the German Cement Institute on crushed concrete shows that the concrete constituents remain fixed in the solidified mass and the quantities released are extremely small.

Reactions with Peat Porewater

Cement will be emplaced within a peat matrix at the site. Peat is mostly composed of plant materials, which are undergoing slow degradation. The degradation processes result in the production of organic acids and a small amount of alkalinity in the pore and groundwaters of the peat, with porewater generally being slightly acidic in nature.

As shown above, porewater associated with cement will be highly alkaline (up to pH 12.1), and therefore mixing of cement and peat water will result in chemical reactions occurring which will change the chemistry of the porewater.

As the majority of porewater in terms of volume will be the slightly acidic porewater of the peat, the most important reaction will be the ability of the peat porewater to neutralise the highly alkaline porewater from the cement. In addition, highly alkaline ground water will only effectively be produced for up a maximum of a to a week before the processes of cement hydration and hardening produce a mass of sand, cement and natural materials which will become effectively impermeable and hydraulically isolated from the surrounding groundwater. There is therefore is a finite source of cement porewater, and its ability to migrate is governed by the permeability of the peat and mineral soils which is low (see section 8.3.5 Volume 1 of the Environmental Impact Statement for the proposed Bellanaboy Bridge Gas Terminal)

Effects On Alkalinity

Alkalinity in peat groundwater will be generated by the dissolution of carbon dioxide produced by the aerobic breakdown of organic material by bacteria. In slightly acidic water the carbonate system will be dominated by the bicarbonate ion (HCO_3^-). When the water mixes with the high pH water associated with the cement, this results in the carbonate chemistry being dominated by the carbonate ion (CO_3^{2-}), with H^+ ions released.

The consequence of the mixing of water will be that calcium carbonate ($CaCO_3$) may become precipitated, as the porewater will contain considerable quantities of Ca^{2+}, from the dissolution of lime, and carbonate due to the carbonate system equilibrium reacting to high pH conditions.

Effect on pH

The result of mixing between high pH and relatively low pH porewaters will result in changes in pH. An additional complication is the potential for the buffering of acidity by dissolution of minerals within the geological matrix.

Mixing of peat porewater and cement porewater will result in the pH of the cement porewater decreasing. Cement porewater is expected to have become isolated from further sources of calcium hydroxide because the cement has set (7days +). Up to this point there is the possibility that as the porewaters interact, and pH decrease, more calcium hydroxide could dissolve and buffer the pH at approximately 12.1. Once the cement has set, no further calcium hydroxide will dissolve, and therefore the buffering action of calcium hydroxide on groundwater pH will no longer be available. This will result in pH decreasing as the larger buffering capacity of the peat and organic acid (and carbonic acid, resulting from carbon dioxide dissolution) will eventually decrease the pH.

1.4 Summary, short and medium to long term

High pH porewaters will be produced for a relatively short period of time, diminishing exponentially after the first 24 hours up to 7 days as the cement sets. This produces a finite source of high pH water, which will react with the surrounding, effectively infinite source of slightly acid water in the peat. Organic and carbonic acids will decrease the pH to eventually remove the excess alkalinity produced by the dissolution of lime. Beyond the first 7 days the cemente has become fully hardened (although not yet achieving full structural strength necessary) and no further leaching takes place.

2 Potential Effects of Cement on Above Ground Chemistry

Where the sand and cement are at or close to ground level, there is the potential for dust and run-off to result in cement being transported away from the area of emplacement, and effect the environment.

Following hydration, the reactions detailed above will result in the release of lime, and will result in relatively high pH conditions until the reactions have completed. In terms of potential effect on the environment above ground, transport of highly alkaline waters will be important.

2.1 Potential Effects of Run-Off

The chemical reactions involved in the setting of cement are detailed in the sections above. This reaction is relatively short lived and cement effectively becomes set after approximately 24 hours.

Therefore, approximately 24 hours after emplacement the potential to produce high pH run-off waters will have stopped. However, until that has occurred the release of high pH water is possible due to run-off. If run-off is generated then the flow path the run-off takes and the location of any sensitive receptors, such as surface water or habitats, will dominate the potential for this to effect the environment.

If run-off enters surface waters, then similar chemical processes will occur as in groundwater. An additional effect will be greater dilution from stream flow; however, this will also have the effect of transporting the run-off over a wider area. The high pH will be buffered by organic and carbonic acids in surface water as well as being diluted by stream flow.

Over time it might be anticipated that the cement stabilised peat will begin to deteriorate and there may be the potential for some lime availability. This is considered likely to have a very low potential for environmental impact by comparison to the initial installation process.