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The effect of ground investigations on the civil engineering design for windfarms in Scotland

L'effet des enquêtes au sol sur la conception du génie civil des parcs éoliennes en Écosse

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ABSTRACT: Published guidance is intended to provide a robust technical approach to assessing the underlying ground conditions at proposed windfarm developments, with a large focus on the need for peat investigation and assessment of peat slide risk and disturbance. The civil engineering design process for windfarms takes into consideration all findings of ground investigations but, with exception of peat landslide issues, ground investigation design relies on the knowledge and experience of geotechnical engineers to ensure sufficient ground investigations take place to inform an economical, efficient civil design while, in turn, meet the varying parameters of turbine manufacturer's specifications. Extensive critical literature review revealed that there is an opportunity for establishing good practice guidance in ground investigation schemes for windfarms. Additionally, there is also a need to evaluate the effects of ground investigations on civil design process for windfarms. For this study we engaged with a range of industry professionals and reviewed relevant case studies to investigate the above needs. Based on the results of our research, we propose an innovative good practice framework that will promote effective ground investigation design for windfarms and a standardisation of civil design.

RÉSUMÉ: Les directives publiées visent à fournir une approche technique solide pour évaluer les conditions du sol sous-jacentes aux aménagements de parcs d'éoliennes proposés, en mettant l'accent sur la nécessité d'étudier la tourbe et d'évaluer les risques et les perturbations causés par les lames de tourbe. Le processus de conception du génie civil pour les parcs éoliens prend en compte tous les résultats des investigations au sol. Cependant, avec le guidage des glissements de tourbe, la conception des investigations au sol repose sur les connaissances et l'expérience des ingénieurs géotechniciens. conception tout en répondant aux différents paramètres des spécifications du fabricant de turbines. Une analyse critique approfondie de la littérature a révélé qu'il existe une possibilité d'établir des directives de bonne pratique dans les systèmes d'investigation au sol pour les parcs éoliens. En outre, il est également nécessaire d'évaluer les effets des enquêtes au sol sur le processus de conception civile des parcs d'éoliennes. Pour cette étude, nous avons collaboré avec divers professionnels du secteur et examiné des études de cas pertinentes pour étudier les besoins ci-dessus. Sur la base des résultats de nos recherches, nous proposons un cadre innovant de bonnes pratiques qui favorisera une conception efficace des investigations au sol pour les parcs d'éoliennes et une normalisation du design civil.

Keywords: ground investigations, wind farm, peat, design, framework.

1 INTRODUCTION

Windfarm design is fundamental in supporting a successful planning application and construction in the short term as well as operation, maintenance and decommissioning in the long term. The design of windfarms should respond to the environmental sensitivities and constraints identified during the baseline surveys, as well as technical and economic considerations for the construction and operation of the development.

Minimisation of civil infrastructure-related costs for wind energy projects, including turbine foundations and access roads, can be achieved through a redistribution of the geotechnical exploration effort (Griffiths, 2013). However, currently there are no published civil design guidelines specifically in relation to windfarms. Many of the design parameters are dependent on the wind turbine supplier's provision of specifications, which will not typically be available until sometime after the initial design, meaning that the specimen design by the developer would generally result in the most conservative requirements. This would typically include the track specifications, maximum vertical and horizontal curves, required clearance widths and other infrastructure requirements such as crane hardstanding parameters in accordance with geotechnical standards (BSI, 2004a, BSI, 2004b).

Windfarm developments are often fast-paced projects that cover large areas of varying terrains (Griffiths, 2013). Such conditions inevitably lead to higher geotechnical risks, which require specific geotechnical ground investigations and analysis, designed to manage risks. Ground investigation forms part of the design process throughout different phases of the project: from less intrusive preliminary investigation to more intrusive ground investigations after planning consent. The purpose of the initial ground investigations is to obtain knowledge of topography, the geology of the site, previous land uses and climatic factors such as flooding, ascertain the quality and quantity of on-site construction materials and understand foundation design purposes.

The presence of peat is a main consideration in windfarm design from both an environmental and geotechnical perspective. While the environmental effects of windfarm construction continue to be examined, there is always a need to advance ground investigations to obtain the suitable information to provide a practical and viable civil engineering design. Peat is influenced significantly by climatic conditions and topography and its strength and stability are of paramount importance for civil design on grounds where it occurs. Due to the challenging geotechnical parameters of peat (Long 2005), careful consideration is required during the design and construction of windfarms because it is well documented that 80% of peat failures from across the world occur in the British Isles (Dykes and Kirk 2006). The assessment of peat parameters is key to the engineering design of turbine foundations, windfarm tracks, and turbine locations and, therefore, it is important to understand the extent and nature of peat on a proposed windfarm site as this is a main driver behind turbine location and foundation solutions. Many argue that the siting of windfarms should entirely avoid peat disturbance and associated carbon loss, and sensitive upland peats should remain unaffected (Nayak et al, 2008). However, to the best of our knowledge, there is no standardised best practice beyond existing peat investigation guidance that would steer the civil engineer through further investigation and assessment of the ground conditions where peat occurs and windfarms are to be constructed.

The aim of this study was to understand the objective of ground investigations at windfarms and its effects on the overall civil engineering design. Furthermore, this study aims at outlining the benefits of a good practice ground investigation and design framework for the industry, developers, consultants and contractors alike.

2 METHODOLOGY

To achieve the aim and objectives of this study, a comprehensive critical literature review was carried out, followed by a broad questionnaire survey and interviews with stakeholders engaged in civil engineering design for windfarms.

The primary data was obtained by distribution of questionnaires to industry professionals including contractors, consultants and developers involved in windfarm design and consisted of questions aimed at: (i) gaining knowledge on the level of ground investigations carried out at wind farms and satisfaction with it within the industry in Scotland; (ii) understanding the advantages and disadvantages of engaging early with contractors and (iii) gain understanding on the economic implications of civil design changes.

The information derived from the questionnaires formed the basis for further discussion in form of semi-structured, focussed interviews (Fellows and Liu, 2008) in order to illicit stakeholders opinions on specific areas of the study such as typical problems in civil design for windfarms stemming from the encountered ground conditions, as well as potential ways of enhancing the design practice.

For the purposes of this study, a case study design was undertaken to examine the types of ground investigation noted in the survey and interviews and their effects on civil design at a typical windfarm development. Throughout the case study design, the pre- and post-consent ground investigation results (preliminary and second-phase peat probing and trial pitting at crane hardstanding and access track locations, as well as boreholes sunk at proposed turbine locations) were analysed and used to develop a civil design using Autodesk Civil 3D software. This study allowed the understanding of how different ground condition aspects can be considered to develop and outline civil design.

3 RESULTS AND ANALYSIS

3.1 Questionnaire survey

The questionnaire survey enabled wide coverage of information quickly, although this type of research usually yields low response rates and has to be expanded through interviews (Robson, 2007).

Although all of the respondents agreed that desk-based findings generally are confirmed by the intrusive GI, half of them also noted that unexpected ground conditions were encountered at least once on their project, especially in connection to turbine foundation excavations, which had significant cost implications. 65% of the respondents claimed that these conditions occur due to the limited breadth of pre-consent GI which usually comprise only peat probing limited to the locations of the proposed access tracks, turbine bases, construction compounds, water crossings, and borrow pits. Respondents agreed that peat samples are not usually taken for analysis at this stage but potentially later in the design process when zones of high risk to stability would be identified on the development site and the peat properties would be needed to satisfy stability (e.g. type, water content, strength) and environmental (e.g. habitat, carbon losses, CO_2 payback) requirements.

The respondents were unanimous in suggesting that the findings of the GI usually contribute to minor changes in the civils design, most frequently micro-siting (minor realignment of access tracks and change construction methods). Similarly, all respondents agreed that the standard foundation solution is piling when peat is recorded as consistently thick on site. In this respect, several respondents suggested that GI are necessary in order to record and model the peat extent and thickness so the designer can avoid siting over or near the areas of thick peat. Such models would also provide insight into the risk of peat slides.

In terms of potential enhancements of the GI, the respondents were divided in to groups: one advocating intrusive GI to prove, map, and characterise rockhead for foundation design, and the other suggesting more CBR tests for access track design would lower the overall costs of construction of the windfarm. Both issues raised here reflect the main turbine supplier requirements which were further explored in the interview sessions.

3.2 Interviews

The interviewees agreed that good practice guidance exists for a wide range of technical subjects in the renewables industry, with a primary focus on the environmental conditions. This includes the GI on peat and management of disturbed peat which, the interviewees felt, was due to the planning process being biased towards the environment. Contrary to this, the interviewees noted a lack of guidance directly relating to geotechnical aspects of investigations at windfarms, presenting an opportunity for an enhancement to the existing good practice guidance list.

The interviewees stressed the importance of the various phases of peat probing, stating that peat investigations (DCP or window sampling) were the most important investigations in any windfarm development because they are usually sited in the rural uplands of Scotland (Fig.1).

Figure 1. Peat hagging and failure at a highland windfarm - (Source: Arcus Consultancy, 2017)

The interviewees agreed that the turbine manufacturer‘s requirements can be achieved in most design situations, especially if peat extent is limited on the site. This differed from the questionnaire responses where the majority of respondents reported on several types of issues when trying to achieve manufacturer’s requirements, specifically meeting the compaction and elastic moduli levels associated with crane hardstand design. The interviewees also confirmed that, in their opinion, the need for peat investigations was due to the risk of peat disturbance directly from the construction of windfarms and indirectly through creation of possible instability and slide risk (Scottish Government, 2017) and these should be assessed based on site specific GI rather than designing for compliance with supplier‘s requirements.

3.3 Case study

The case study design was driven by the available ground investigation information, the presence of peat, and the parameters of a selected turbine manufacturer’s specification – predominant issues identified in our survey and interviews.

The development of the outline windfarm design followed a framework we developed based on the literature review and findings of the survey and interviews. Initially, the existing/available ground investigation information was reviewed. In absence of historic GI on the site, this included preliminary and detailed peat probing, as well as trial pitting information, which were then correlated to the published geology of the site. The next step was to examine the topography of the site in order to identify potential locations for the access tracks and hardstanding areas. A peat depth interpolation model was then prepared to identify zones of high risk of peat failure and slides, as well as to avoid the necessity of excavating in peat. After these, the turbine supplier specifications were accessed to set out the requirements and constraints for the design. Considering that only one other constraint from the developer was then needed (i.e. achieve optimal cut-fill balance), three dimensional design of windfarm using Civil 3D software was finally undertaken.

The output of the case study was a Civil 3D windfarm design illustrated through plan and profile, including the development of tracks, crane hardstanding and other windfarm infrastructure while indicating the ground investigation locations, peat thicknesses and other pertinent information. A peat interpolation map was also collated as the main consideration in the design layout. The access tracks were divided into 4 discreet alignment sections (Fig 2) including crane hardstanding. The track gradients did not exceed 12% throughout the design process, in line with the turbine manufacturer's specification. Level areas with a maximum gradient of 0.25% were developed over a length of 120 m centred on each turbine to provide a facility for safe movement / offloading. The topography was optimally utilised through the design, allowing for suitable entry and exit gradients from the 1% graded hardstand areas, again in line with the manufacturer's specifications.

Out with the crane hardstanding areas, the outline design was developed to minimise the impact relative to existing ground levels whilst complying with the turbine Abnormal Load Vehicle (ALV) access requirements. The modelled platforms have gradient of ≤1% in any direction. The crane hardstand platforms were designed with a preferable level considering the track alignments and optimal cut and fill balance (cut volume 7,709 m^3; fill volume 12,535 m^3). The main reason for the excessive fill was that track sections over deep peat required to be in fill areas and therefore the design was tailored to cope with this issue. Based on an assumption that the CBR values may only achieve between 2.5% and 5% the typical expected aggregate thicknesses would be 450 mm for track construction and 600 mm for crane hardstanding.

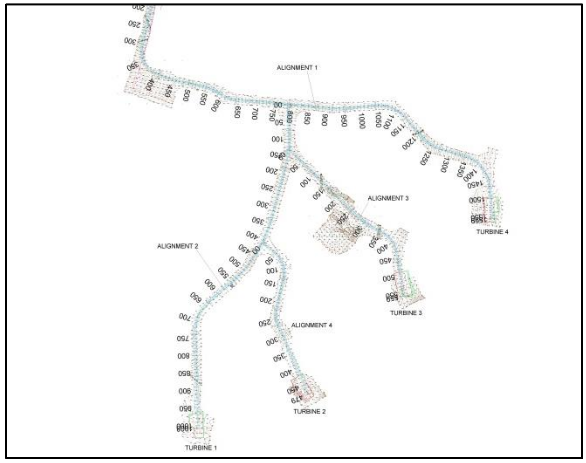

Figure 2. Outline civil design for the case study site

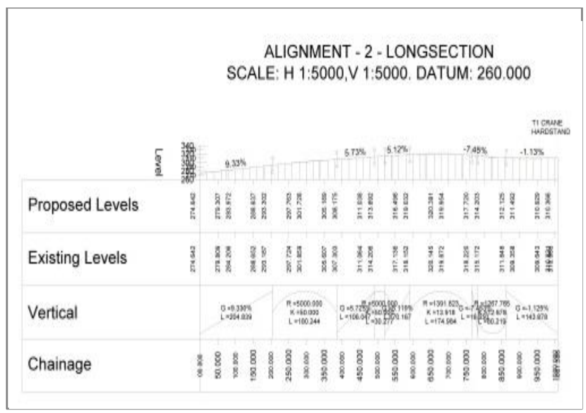

Figure 3. Example alignment for the case study site

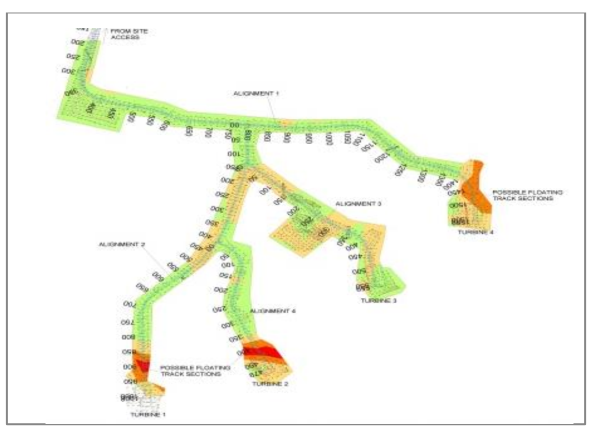

Figure 4 Peat interpolation for the case study site

4 DISCUSSION AND CONCLUSIONS

The results of our survey and interviews showed that although there is an abundance of guidelines for GI-based design for many infrastructure projects, there is currently little guidance on designing windfarms. Based on this, we developed a high level framework (Fig. 5), and used it to develop an outline civil engineering design for a windfarm in Scotland.

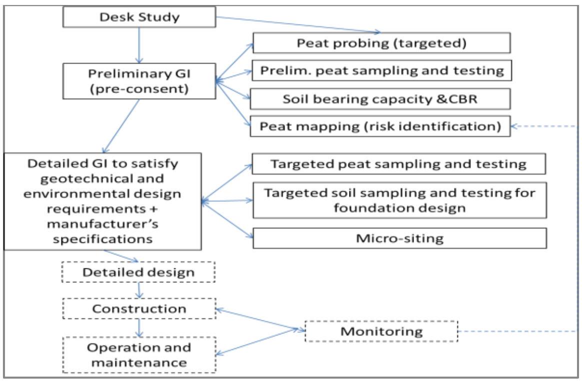

Figure 5 Proposed framework

We believe that this framework can be used as a basis for undertaking a cost-effective ground investigation exercise to inform the design as early as possible in the design process (at a pre-consent stage). This could lead to the adoption of fewer assumptions and more confidence in ground conditions for the 'Balance of Plant' contractor to take to detailed design and onto construction. Encompassing the views recorded in our survey, this framework could reduce the planning risks and provide investors with more certainty of the project from an earlier stage. An ideal scenario for design would be increased density of site investigations, however, naturally, there is a cost element attached to this approach. Additional issue may be the fact that, as one of our respondents suggested, persuading developers of the importance of obtaining ground investigation information at an early stage is often difficult and frequently challenging.

The main positive aspect of the best practice framework is that it might well allow a wider knowledge of the types of ground investigations and the associated geotechnical testing needs at windfarms to be shared. This framework acknowledges the pressures from the manufacturers on design parameters and ground conditions to be realised by the developers and contractors. Guidance on ground investigations would aim to inform the next steps beyond the peat probing phases of pre-consent works, and begin to introduce the basis of civil design elements.

The available GI information suitably informed our outline GI design. In this respect, the case study showed that, due to presence of peat, more detailed peat information is needed even for an outline design. The principle objectives behind the initial phase of peat investigations were reduction in ground condition uncertainties, identification of the existing ground conditions and provision of information for engineering design to avoid or reduce peat landslide hazard. However, more detailed peat probing information allowed detailed 3D mapping to inform the design which was vindicated by the opinions expressed from contractors in our survey - detailed probing perpendicularly as well as linear along proposed tracks would be advantageous to allow for re-routing in the form of micro-siting.

Contrariwise, detailed GI information was not available for design of the access tracks and hardstanding because the GI specification did not include this requirement. Hence, the design had to rely on assumptions and, as such, may not be optimal. If in situ and lab testing for bearing capacity and CBR were carried out pre-consent, design refinements would have been possible which would have probably led to further savings in the overall project costs. Similarly, as the results from the interviews showed, a more sophisticated testing for derivation of relevant stiffness parameters would assist with optimisation of turbine base design.

The outline design of the case study and the experience of the surveyed and interviewed stakeholders showed the importance of manufacturer's specs in completing the design of a windfarm. Bearing in mind the variation of these specifications from one manufacturer to other, we believe that a generic framework such as the one proposed should be used to at least cover the main design elements and their design requirements in terms of ground investigation requirements, aiming at risk reduction and design optimisation.

Along similar lines, the GI findings will have varying effect on the civil design of windfarms depending on the designer and approach. However, early involvement of a Geotechnical Engineer and effective specification, reporting and communication between them and the rest of the project team would appear to be of paramount importance.

Clients and contractors should be made aware of the importance of relevant and accurate ground investigations at different project stages and professional organisations should adopt standardised approach for windfarm design like other areas of civil engineering (e.g. water, transportation etc.) or, supporting the opinions expressed in our study, there should be a very formal structure to designing the windfarm, from desk-based researches, initial planning and strategy, and revisiting planning and strategy phases to determine project and cost benefit of additional ground investigation.

In order to be effective in terms of reducing risk and identifying opportunities, geotechnical risks should be identified as early as possible in the project process. While the proposed framework focuses on peat-related risks, DMRB guidance (HD 22/08, 2009) and Eurocode 7 (BSI, 2004b) guidance can be included to assist with decision making and risk reduction in the form of geotechnical consideration checklist (Geotechnical Risk Register; Orr, 2014).

Ground investigations and design at windfarms are generally at the discretion of the developer and appointed design team, therefore developers would need to want to place more stringent rules on their design works and all parties involved in windfarm design would need to engage. If all parties involved in windfarm construction adopt this approach, it is extremely likely that the industry would get a better product. Introduction of a good practice framework would mean rolling out investigation and design standards which are on the conservative side of design, and consequently, could lead to a potential economic restriction for smaller developers. It may be a more attractive prospect for a large developer with a large portfolio of projects and established funding, such as a utility company, that everything be designed to the same high standards, naturally lowering operations and maintenance costs.

Based on the results of our research, there is reason to believe that an innovative good practice framework promoting effective ground investigation design for windfarms would improve the industry practices while providing a better standardisation of civils parameters to achieve effective designs. The best practice should emphasise the importance of employing geotechnical expertise from an early stage to assess the risks of the site, and collation of a geotechnical risk from a preliminary stage.

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6 REFERENCES

British Standard Institute (BSI). 2004. BS EN ISO 1997-1 *Eurocode 7, Geotechnical Design. General rules.* BSI, London.

British Standard Institute (BSI). 2004. BS EN ISO 1997-2. *Eurocode 7, Geotechnical Design Eurocode 7, Geotechnical design. Ground investigation and testing.* BSI, London.

Dykes, A.P., Kirk, K.J. 2006. *Slope instability and mass movements in peat deposits*. In: I.P. Martini, A. Martínez Cortizas, W. Chesworth (eds) Peatlands: evolution and records of environmental and climate changes. Elsevier, Amsterdam, pp 377–406.

Fellows, R. and Liu, A. 2008. *Research methods for construction* (3rd ed.). Oxford, UK: Wiley-Blackwell.

Griffiths, D.V. 2013. *Geotechnical Exploration for Wind Energy Projects*, The Americas, pp. 2319–2322.

Highways England, Transport Scotland, Welsh Government the Department for Regional Development Northern Ireland. 2008. *Design Manual for Roads and Bridges, Volume 4, Part 2 HD 22/08 Managing Geotechnical Risk*.

Long, M. 2005. *Review of peat strength, peat characterization and constitutive modelling of peat with reference to landslides*. Studia Geotechnica et Mechanica, 27: 67-90.

Nayak, D.R., Miller, D., Nolan, A., Smith, P. and Smith, J.U. 2008. *Calculating carbon savings from wind farms on Scottish peat lands - A new approach*. Final Report. RERAD UAB-016-07 .

Orr, T. L. L. 2014. How geotechnical risk, uncertainty and decision making are addressed in Eurocode 7. In: Vulnerability, Uncertainty, and Risk: Quantification, Mitigation, and Management, M. Beer and E. Patelli (eds), Liverpool, July 2014, American Society of Civil Engineers, 2014, pp2419 – 2428.

Robson, C. 2007. How to Do a Research Project: A Guide for Undergraduate Students. Wiley-Blackwell, London, 172pp.

Scottish Government. 2017. Peat Landslide Hazard and Risk Assessments, Best Practice Guide for Proposed Electricity Generation Developments. ISBN 0 7559 6378 4.