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Characterization of Rock Fracturing for Vertical Boreability

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Abstract

Boreability can be defined as the ability of a bore to penetrate a rock mass. Understanding the factors influencing boreability is critical for enhanced project planning and reduce geotechnical risk in an offshore shaft boring environment. Large diameter drills are used for offshore shaft boring, which can be up to 7 m in diameter, and therefore more akin to tunnel boring machines due to the scale of the excavation and extent of ground interaction. With increases in bore diameter, there is a need to properly define and evaluate the effect of the degree of rock mass fracturing on machine performance for improved estimates of boreability. Discrete Fracture Network (DFN) simulation has been used as an innovative approach for stochastic realisation of rock mass fracturing by determination of the P_{32} volumetric fracture intensity in the context of boreability. P_{32} shows positive trend to specific penetration (SP), with maximum SP being achieved at moderate to high fracturing levels (20 - 25m^{-1}). However, in this case, P_{32} shows a similar positive trend to $P_{10,}$ but with peak SP appearing at higher intensity levels. Increased RQD values result in reduced SP, with peak SP reached at moderate fracturing levels, similar to P_{10}.

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1. Introduction

Boreability is defined as the ability of a machine to penetrate a rock mass [1], and is commonly associated with Tunnel Boring Machines (TBM). The development of offshore shafts, Large Diameter Drills (LDD) are utilized, which feature similar tools or technology to that of oil well drilling with reverse circulation system for muck removal. The size and scale of ground interaction can be up to seven meters, making these type of LDD's more akin to tunnel

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boring machines due to their scale. Little research has been undertaken on the performance or boreability of LDD's when compared to evaluation of TBM behavior. Given that the underlying excavation process and ground interaction tools differ between LDD and TBM machines, TBM performance can only therefore be used as a proxy rather than direct comparison.

Research at the Camborne School of Mines is currently evaluating existing empirical boreability models for LDD's, and how they can be used to inform and help minimize geotechnical risk for offshore shaft developments, such as offshore windfarm monopole sockets. This paper presents some initial findings of how three rock core-derived fracture metrics correlate with recorded machine penetration rates for a LDD, for future use within a full boreability model.

2. Degree of fracturing

Boreability, as a variable, is related to the properties of the rock mass and machine specification [1]. Various models, from simple to multi – parametric models, have been produced for TBM's. Farrokh et al. [2] provides a good overview of the models available. Common to all of these models are some measure of rock mass fracturing. Wanner and Aerberli [3] found that fractures from shearing influenced the productivity of borers. Howarth [4] found that moderately fractured rock improved machine performance. Zhao et al. [5] found that an increase in fracture spacing (reduction in fracture frequency) lead to a reduction in productivity, with maximum productivity attributed to a relative joint strike of 60 degrees to the tunnel axis. Macias et al. [6], however, found a negative correlation with the rock mass fracturing factor (k_s).

In view of limited rock exposure in an offshore drilling or boring environment prediction of machine performance is typically based on evaluation of rock core and geophysics data. This limits estimates of the degree of fracturing of the rock mass and is constrained to measures such as the Rock Quality Designation and Fracture Frequency.

Traditionally, RQD is used as the standard for classifying the degree of fracturing of the rock mass [8], and is a key parameter in most stability-centric rock mass classification schemes such as the Geomechanics Rock Mass Rating [7] and the NGI Tunneling Quality (Q) Index [8], as well as inputs into existing boreability or TBM-related models [9, 10]. RQD is a relatively simple measure to determine, but its simplicity may lead to some disadvantages. These include the apparent rapid change in RQD when sub-parallel fractures are spaced in a range close to the cut off threshold [11], as well as the non-additive properties of RQD for combined databases [12]. The later issue becomes apparent when the axis of the excavation is different to that of the site investigation, such as with the utilization of the QTBM model developed by Barton [9].

Fracture Frequency is a measure of Fracture intensity and is defined as the number of fractures within a given interval. There are three main forms of fracture intensity, which differ by sample and measurement dimensionality. These different forms have been concatenated into the P_{ij} system by Dershowitz and Herda [13]. Within this system, P means 'persistence', with the following subscripts denoting sample dimension and measurement dimension respectively, as shown in table 1. Note that 'fracture intensities' are highlighted in red within table 1.

Table 1. Summary of Fracture Intensity Measures [13].

	Measurement Dimension (j)			
Sample Dimension (i)	Count (0)	Length (1)	Area (2)	Volume (3)
1D (borehole)	**P_{10}**	P_{11}	-	-
2D (mapping)	P_{20}	**P_{21}**	P_{22}	-
3D (geophysics)	-	-	**P_{32}**	P_{33}

Given the form of data available for this study, only P_{10} and P_{32} are used in the subsequent analysis. Fracture intensity in its simplest form is defined as the number of fractures per meter, a one-dimensional measure, which is historically referred to as Fracture Frequency, or P_{10} under the P_{ij} system, and has the dimensions of: