



Drilling Parameters in the Evaluation of Rock Mass Quality

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Abstract

The production of a geotechnical model-based on-site investigation and surface mapping is particularly challenging for tunnels due to the depth at which the excavation is performed. Besides the lithology and the weathering grade, the main factors influencing the underground excavation are related to the rock mass structure, namely joints and major faults. The knowledge in advance of the conditions to be found during the excavation usually saves time and money and increases safety. In the present work, the excavation of two large tunnels was studied, aiming to obtain correlations between the rock mass properties and the parameters obtained by the drilling machine ahead of the excavation front. The study included the geological mapping of the excavation surfaces, the determination of the intact rock strength and the record of the drilling parameters, namely the penetration rate, feeder pressure, pressure in the hammer, rotation pressure and strike pressure. The variability of the results was analysed and the Pearson coefficient $|r|$ established for each parameter in order to find the most accurate correlations. It was concluded that, for deep structures, monitoring these parameters constitutes an essential complement to the previous geotechnical site investigation, contributing to a better definition of immediate support measures to apply along the excavation works.

Keywords

Measurement while drilling • Rock support • Rock mass characterisation • Tunneling • Drilling parameters

1 Introduction

The excavation of tunnels demands previous detailed site investigation and application of exploration techniques, namely core drilling, to define the geological model and produce the geotechnical zonation. The data obtained are applied in the most common geomechanical rock mass classifications—the Rock Mass Rating (RMR) and the Q-system—which suggest adequate measures of support depending on the span and the stand-up time. The uncertainty of the rock mass properties between consecutive drilling sites leads to the interpretation by the engineering geologist of large volumes of rock mass, which might sometimes not be confirmed during the construction phase. The properties of the rock mass are defined by the lithology but also depend on the weathering grade (W1–W5, ISRM 2007), the fracture spacing (F1–F5, ISRM 2007), the rock strength and the presence of major faults (Howarth and Rowlands 1987; Hoseinie et al. 2007). Furthermore, the anisotropy of the rock, the orientation of the discontinuities with the direction of drilling, the porosity, the mineralogy and the unconfined compressive strength of the intact rock influence the drilling parameters and the stability of the excavation (e.g. Yue et al. 2004; Reiffsteck et al. 2018; Vezhapparambu et al. 2018; Khorzoughi et al. 2018; van Eldert et al. 2020). The surface geological mapping performed in the early stages of the site investigation must be confirmed, detailed and complemented by the engineering geological mapping of the excavated surfaces, just the following blasting, to adapt the support design to the real behaviour of the rock mass. The drill rigs automatically collect the drilling parameters by measurements while

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drilling (MWD), which are recognised in the construction industry to correlate with the characteristics of the rock mass (e.g. Reiffsteck et al. 2018). In this concern, drill hole depth (distance), penetration rate (distance/time), thrust (feed pressure in kN), torque pressure (bar), percussive pressure (bar) and rotation speed (RPM) (Schunnesson 1997) can assist in forecasting the behaviour of the rock mass ahead of the tunnel face contributing to save time and money in the definition of the adequate rock support. Although drill monitoring has been used for decades, it is not a standard technic in excavation works.

The present work summarises the results obtained by MWD in excavating two large tunnels in a granitic rock mass in the North of Portugal. Charts were prepared to correlate the features measured with each of the rock mass properties, namely W, F, the properties of joints, and the presence of faults. The study demonstrated the capability of the data acquisition while drilling to forecast the rock mass properties and to detect zones of weakness, such as major faults or strongly weathered rock mass which may occur unexpectedly during the excavation (Kovári and Fechtig 2000), therefore contributing to the decision processes needed during the tunnel construction.

2 Methodology

Two tunnels excavated in syn-tectonic Hercynian granitic rock mass were studied: Tunnel 1 with 740 m in length, inverted U-profile, 48 m² cross-section and dipping 11%; Tunnel 2 with 814,5 m in length, a circular profile of 113 m² cross-section and dipping 13.8%. The rock mass is a medium- to coarse-grained porphyric two-mica granite of the Galicia-Trás-os-Montes Zone, Iberian Massif.

The number of measurements recorded is 214 for Tunnel 1 and 134 for Tunnel 2. The parameters recorded by the drilling machine were correlated with the geotechnical map of the tunnel face and closest walls. The drilling of the rock mass was carried out using a three-armed drilling rig, with continuous recording of the drilling parameters. The drilling proceeded by percussion and rotation, with bits of 3 inches in diameter. The depth of each drilling hole was defined according to the geomechanical classifications obtained in the previous drilling depth.

The Jumbo was equipped with Robodrill's Drill-Analyser software, registering the main drilling parameters: penetration rate (m/min), feeder pressure (thrust), rebound hammer pressure, rotation pressure and strike pressure (all in bar). The hammer pressure, or rebound pressure, is the energy applied in the opposite direction to the direction of the forward force. The feeder pressure is the force that pushes the drill bit against the rock mass. The rotation pressure results from the pressure exerted to perform the maneuver of the

stick rotation. Finally, the strike pressure is the pressure applied for the execution of the blow exerted by the hammer. The values of these parameters are conditioned by the characteristics of the material to be drilled, which combination influences the drilling penetration rate.

For each excavation advance, the mapping of the geological and geotechnical conditions was carried out, which included the recording of the lithology, the grade of fracturing (F) and weathering (W), in accordance with the ISRM (2007) recommendations. The set of joints was defined, including orientation, spacing, roughness and infilling. The Rock Quality Designation (RQD) was calculated following Palmström (1985), using the factor of fracture frequency (Jv). The values of uniaxial compressive strength (UCS), estimated at the excavation face aiming at the application of geomechanical classification, were obtained by point load tests carried out every 10–20 m. The major faults were recorded in what concerns orientation, the thickness of the fault gauge, the composition of the gauge and water presence.

3 Results

Tunnel 1 and Tunnel 2 were excavated in a granitic rock mass mainly composed of sound (W1) to slightly weathered (W2), in particular in the vicinity of faults, with wide to moderate spacing of discontinuities (F2–F3). However, in Tunnel 1 there were also very wide spacing discontinuities (F1). The data from geotechnical characterisation show that the rock mass in Tunnel 1 is slightly more weathered and fractured (RQD 81%) than in Tunnel 2 (RQD 91%). The drilling parameters are also different for both tunnels. On average, the impact pressure and the pressure forward are higher in Tunnel 1 than in Tunnel 2, while the torque pressure is 1.5 times lower. Table 1 summarises the values of each parameter. However, the penetration rate shows similar values, and therefore, the analysis was focused on the relationship between the penetration rate and the different geotechnical properties of the rock mass.

It was verified that the major faults and the more intense fracturing of the rock mass in their vicinity have a large influence on the results of the drilling parameters, as shown in Fig. 1. The charts also stress that the weakness zones have a large impact on the penetration rate, and, in Tunnel 2, the range of values in the head pressure is increased. On the contrary, in Tunnel 1, the main variation is obtained for the strike pressure.

The Pearson correlation coefficient $|r|$ (Franzblau 1958) was calculated between the penetration rate and the various rock mass characteristics, as presented in Table 2. It shows that there is (negative) robust correlation (>0.80) with the weathering (W) and fracturing (F) grades, with the decrease

Table 1 The average, median and standard deviation of the perforation parameters for Tunnel 1 (T1) and Tunnel 2 (T2)

	Penetration rate (m/min)		Rotation pressure (bar)		Strike pressure (bar)		Feeder pressure (bar)	
	T1	T2	T1	T2	T1	T2	T1	T2
Average	1.69	1.45	86.57	128.16	147.05	33.65	98.01	89.35
Median	1.60	1.40	86.00	128.00	152.00	34.00	98.00	85.00
Standard deviation	0.25	0.26	4.85	4.23	12.13	3.03	4.40	17.56

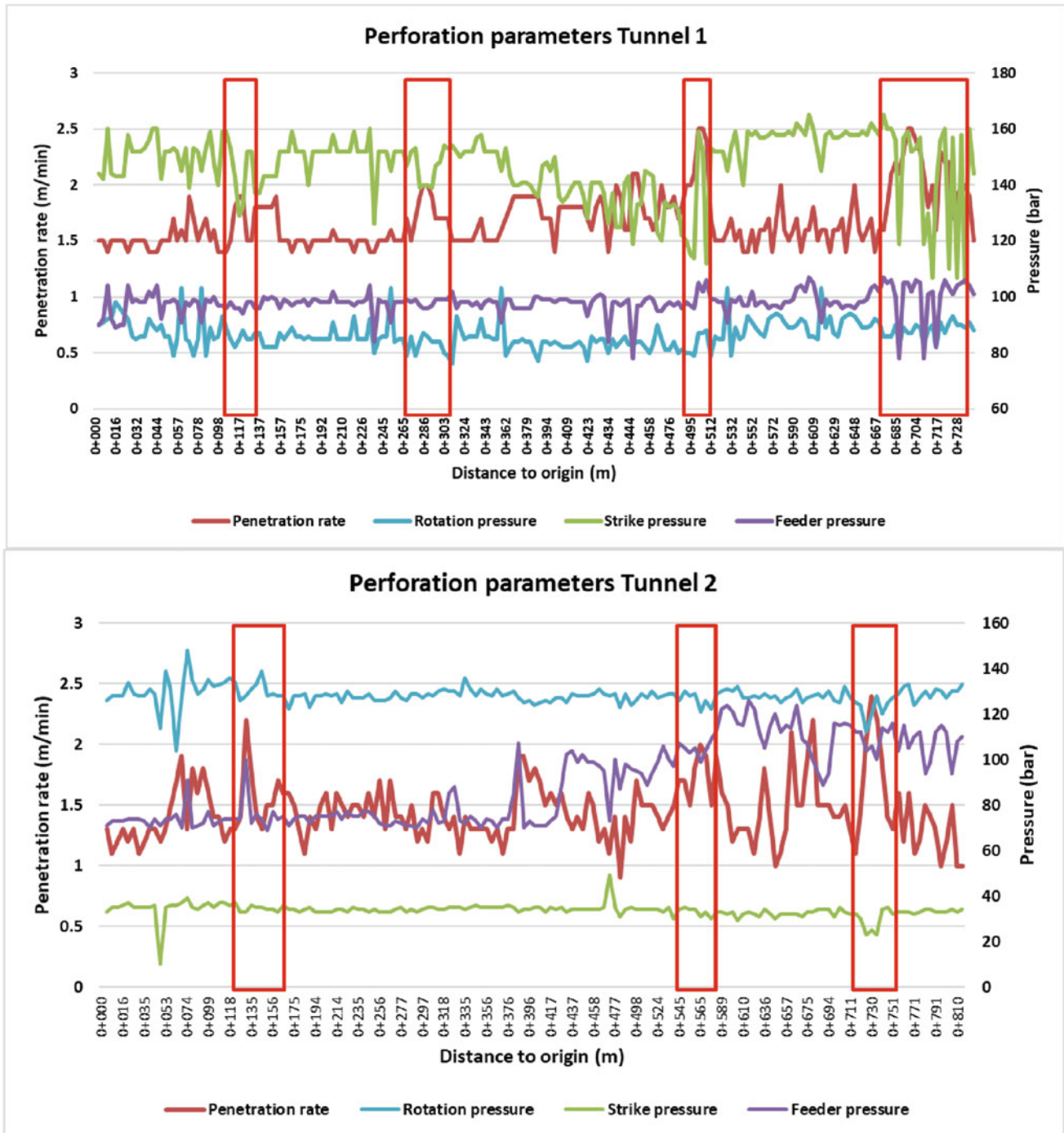


Fig. 1 Evolution of the perforation parameters along the length of both tunnels. The width of the red rectangles represents the length of intersection of the weakness zones and major faults for both tunnels (adapted from Pereira 2013)

Table 2 Pearson correlation coefficient between drilling penetration rate and the parameters (adapted from Pereira 2013)

	Tunnel 1 r	Tunnel 2 r
RQD	0.73	0.67
UCS	0.70	0.63
W	0.85	0.95
F	0.90	0.96
Joint properties	0.58	0.62

of the penetration rate as the quality of the rock mass increases. Also, there are (negative) strong correlations (0.60–0.80) with the unconfined compression strength and RQD and moderate (0.40–0.60) to strong correlation with the joint properties, namely persistence, aperture, roughness and infilling, for Tunnel 1 and Tunnel 2, respectively.

4 Concluding Remarks

Two tunnels with a total of more than 1500 m in length were studied, aiming to obtain correlations between the Measurement While Drilling (MWD) parameters and the geotechnical characteristics of the rock mass. The excavation was performed in granitic rock masses with different weathering and fracturing grades intersecting some major faults. The penetration rate shows a good correlation with the geotechnical properties and is highly affected by weak areas associated with major faults. The results obtained are intended to optimise future excavations in similar rock masses, using MDW to estimate the rock mass quality in advance of the excavation. Nevertheless, more data collected at the different geological environments must be analysed to create consistent correlations based on historical information, which must also consider the variability that might result from using different equipment.

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