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Estimating the geomechanical quality of complex and damaged rock masses by borehole sonic logging

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A reliable assessment of the strength, deformability and hydraulic properties of rock masses at depth is crucial for a number of applications, including geological and structural investigations, deep tunnels and underground openings. Nevertheless, when dealing with complex geological conditions (lithologically/structurally complex or damaged rock masses), a cost-effective, reliable characterisation of rock mass conditions by direct investigation is often unfeasible due to extreme variability of lithology, fracturing, and damage state of rocks. In this context, geophysical investigation techniques can be particularly useful to establish correlations between the elastic properties of rock masses and suitable, quantitative albeit empirical descriptors of rock mass quality and performance commonly used in rock engineering. Nevertheless, most empirical relationships available in the literature apply to the near-surface (upper few tens of meters of earth's crust) and use rock mass descriptors (e.g. Barton "Q") poorly suitable for complex rock masses (including strongly deformed or folded metasediments or weathered fault rocks).
We analysed the relationships between sonic wave velocity measured in boreholes drilled up to 400 m in depth and rock mass quality described using the Geological Strength Index (GSI). This is a descriptor of rock mass structure and weathering, suitable to be applied to nearly all kind of rock types and structural conditions.
Data were gathered from a detailed geological investigation carried out for a 9.2 km long headrace tunnel in a crystalline core complex of the north-western italian Alps, composed of two gneiss units (i.e. Antigorio and Verampio units) interlayered with meta-sedimentary rocks. The meta-sedimentary sequence is composed by gypsum-anhydrite, fractured marbles and calcschists, and at least two layers of uniform sand derived by decomposed carbonates. Continuous, high quality coring (HQ diameter) was obtained in 300 to 400 meters deep boreholes by both conventional and wireline techniques. Geomechanical core logging allowed to perform a continuous, detailed description and characterisation of drill cores according to GSI.
600 m of geophysical logging were performed with a centimetre-scale acquisition pace using a "full-wave" sonic logger (transmitter operating at 27 kHz, receivers recording up to 100 kHz, transmitter-receiver distance 1 m). The dataset shows a wide range of Vp (1700 to 5300 m/s), testifying high lithological variability and structural complexity of the investigated domain.
We performed a statistical analysis of the collected data (>500 Vp-GSI couples), whose scattering required accurate outlier identification and removal. Non-linear regression analysis allowed to identify a best-fitting empirical relationship integrating different lithologies, weathering and rock mass damage conditions over a wide depth range.