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Characterization of complex rock masses by combined borehole GSI and sonic logging

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Reliable assessment of the strength and hydraulic properties of rock masses at depth is key to a number of geological, engineering and geohazard applications, including tunnelling, reservoir characterization and slope stability analysis. Rock mass investigations usually exploit direct geomechanical core logging and indirect geophysical techniques. A cost-effective and reliable characterisation of rock mass quality by direct investigation is often hampered by extremely variable lithological and structural conditions. On the other hand, available indirect methods correlating rock mass properties with geophysical investigation results apply to near-surface (upper few tens of meters in depth) and rely on rock mass descriptors poorly suitable for complex rocks (including deformed, weathered, or damaged rocks). Thus, there is a need to set up: 1) robust and versatile approaches to quantify (direct) rock mass descriptors suitable for complex geological conditions from drillcores; 2) statistically-sound relationships between such descriptors and rock mass properties obtained by (indirect) geophysical methods.
We focus on the analysis of relationships between sonic P-wave velocity and rock mass quality described by the Geological Strength Index (GSI), both quantified in deep boreholes. The GSI is a suitable descriptor of rock mass structure and weathering, suitable for application to nearly all kind of rock types and geological conditions. We used site investigation data gathered to design a 9.2 km long headrace tunnel in a crystalline core complex of the central italian Alps. We analysed three boreholes up to 400 m deep in gneiss and meta-sedimentary rocks (including gypsum-anhydrite, marbles, decomposed carbonates) from which high quality HQ drillcores were extracted, allowing high-resolution geological and geomechanical logging. In the same boreholes, geophysical logging was performed using a “full-wave” sonic tool (transmitter operating at 27 kHz, receivers recording up to 100 kHz, 1-1.25 m transmitter-receiver distances). Sonic logs were acquired for more than 600 m of borehole length with cm-scale acquisition interval. Wide range of recorded Vp (1700 to 5300 m/s) testify the extreme lithological variability and structural complexity of the investigated domain. The GSI logging along drillcore scanlines was performed using an original quantitative method, based on unique-condition combinations of standard rating of joint spacing and weathering. Candidate empirical correlation functions linking GSI and Vp values were derived and discussed by a two-step statistical analysis of the data population (>500 Vp-GSI data couples), including: 1) outlier identification and removal; 2) non-linear regression analysis. Our results allowed to identify empirical relationships integrating very different lithologies, weathering and rock mass damage conditions over a wide depth range, showing potential for practical applications in a variety of engineering settings.