Remote Analysis of Rock Slopes with Terrestrial Laser Scanning for Engineering Geological Tasks in Reservoir Planning

34

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Abstract

Building the lower basin of a pumped-storage hydropower plant in an active limestone quarry without any sealing is a challenging project. A proper site investigation is crucial to increase the overall efficiency of planning as well as realisation by anticipating potential problems and sticking points. The local geology comprises a complex system of reef structures and bedded sequences that is intersected by faults. Sets of faults can be identified on different scales and the fracturing patterns vary vertically and horizontally. Both the ongoing quarrying as well the sheer size and steepness of the outcrop prevent any extensive data acquisition using traditional methods. Therefore, terrestrial laser scanning (TLS) was used to map the quarry and to create a high resolution digital elevation model (HRDEM). The HRDEM allows to perform spatial analysis with respect to the distribution of geohydraulic and geotechnical properties of the rock mass in the quarry. The major advantages of this approach are the increased level of detail, a substantial improvement of documentation and synergetic effects that arise from the multiple different applications of scan data e.g. for analysis, interpretation, planning and solving geohydraulic and geotechnical issues. It has shown in practice that this multi-facetted usage of the collected data outweighs the initial efforts of data collection and processing by far.

Keywords

Pumped-storage hydropower • Rock mass characterization • Terrestrial laser scanning • Blautal

34.1 Introduction

For the planning approval of the pumped-storage hydropower plant (PSH) Blautal, commissioned by the municipal utilities Ulm (SWU) and EDUARD MERKLE GMBH & CO. KG, extensive geohydraulic and geotechnical site investigations are mandatory. Located about 4 km of the spring Blautopf in the karst landscape of the Swabian Jura's southern edge in Southern Germany, the PSH shall have an installed capacity of 60 MW by a built-in reservoir of 1.1 million m^3 and a height difference of 170 m. Initial planning has stipulated an unsealed lower basin situated on a mountainside inside the quarry as the preferred option of construction. The absence of any sealing means that the basin will be incorporated within the natural groundwater. Due to the subsequent use, the mine plan provides that the limestone will be quarried to 10 m below the groundwater table, creating a steep, 95 m high rock slope next to the eastern bank of the basin. As there are environmentally sensitive biotopes nearby, the anticipated impact on natural groundwater conditions must be limited in space. Therefore, two major aims have been defined for the site-investigation: To specify the potential influence on the groundwater during excavation, PSH construction and operation time on the one hand. On the other hand first estimations of the expected dynamic

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Fig. 34.1 Tripod mounted instrument, scanning a 65 m height slope. *Light-colored lime*—and marlstone, complex geological features and different rock face conditions due to ongoing quarrying complicate the rock classification

stress changes within the rock are to be given, since pore water pressure can significantly reduce slope stability (Köhler et al. 2013). To meet these goals, a detailed geohydraulic and geotechnical rock mass description is essential. The obtained information serves as input data for a detailed geohydraulic rock mass model with special emphasis on the location and spatial distribution of discontinuities as well as their degree of karstification. This will allow a hydraulic characterization of the rock mass and the identification of potential failure mechanisms due to increased buoyancy or sliding wedge formation. The local geology comprises a complex system of reef structures and bedded sequences that is intersected by faults. Sets of faults can be identified on different scales and the fracturing patterns vary vertically and horizontally. Both the ongoing quarrying as well the sheer size and steepness of the outcrop prevent any extensive data acquisition using traditional methods (Fig. 34.1). In the presented study area, traditional manual recording would be very laborious and time-consuming and therefore economically not feasible, as outlined above. Thus, remote sensing by terrestrial laser scanning (TLS) was used to map the quarry and subsequently used to create a high resolution digital elevation model (HRDEM).

34.2 Methodology

Terrestrial laser scanning utilizes reflected laser pulses emitted from a tripod-mounted scanning instrument (Fig. 34.1) to determine distances to targets of interest. The scanned surfaces are recorded as point data with accuracy ranging from 4 to 3 cm. Thus, TLS data provide the possibility to measure and visualize topographic relief down to centimeter resolution for close-up digital inspection. Provided that the exact scanner position is known, each point can be georeferenced and used to compute a digital elevation model (DEM). The newly generated DEM in turn can be registered with color photographs and serve as the basis for engineering geological rock mapping. The entire quarry has been time-efficiently scanned from different positions by a terrestrial laser scanner with average point spacing from 10 to 15 cm, including additional scans of selected slopes with 2 cm point spacing. Each scanner position has been determined by the use of Real Time Kinematic (RTK) satellite navigation. In addition, a photographic mapping has been applied to assist data analysis and interpretation. Applying the data preparation and processing after (Nguyen et al. 2011), a DEM of the quarry in 1 m resolution and HRDEMs of different slope exposures in 2 cm are used to create up to date topographic maps, cross-sections and virtual outcrop models. Thus, different—otherwise laborious—tasks can be completed in a `virtual lab', even for inaccessible areas.

34.3 Applications: A Spatial Analysis Approach

The following descriptions focuses on how to transform structural information from a HRDEM of a jointed rock mass into an organized discontinuity-network. For this purpose, the characterization of a rock mass has been exemplarily executed on a virtual outcrop model of the steep eastern slope of the investigation site. Due to low coloring diversity and the complex geological structure with its multiple reef formations and interconnected bedding, an interactive data interpretation is required for the rock mass characterization. In the beginning, an orthogonal projection of the HRDEM allows to precisely visualize the morphology

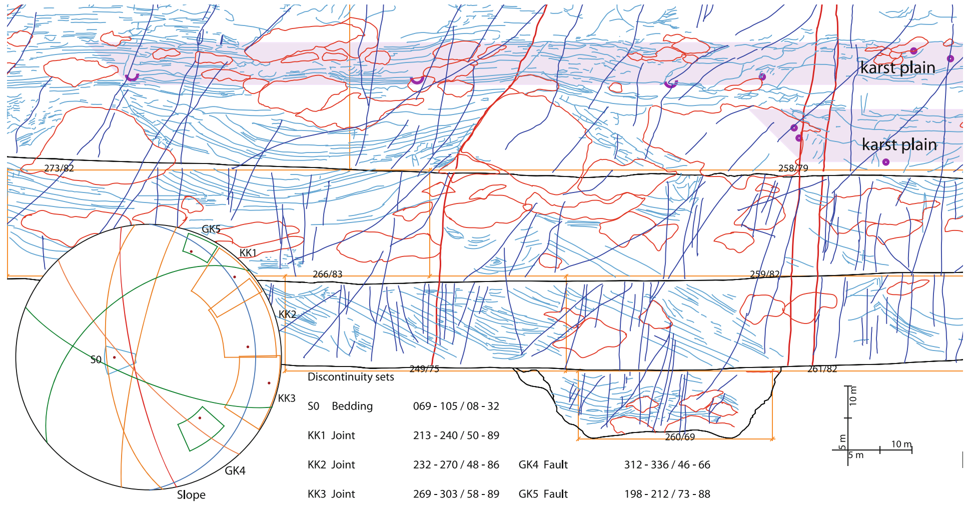

Fig. 34.2 Manual rock map by using the HRDEM. It forms the basis to locate geological features and to determine their attitude

of vertical and overhanging rock faces with an adaptable map scale for an adequate display. This enables different applications, e.g. the traditional mapping by simply tracing geological structures, the measuring of geometric features and the estimated localization of karst plains and shafts (Fig. 34.2). Identified features are from top to bottom: thin calcareous marlstone layers with underlying massive and clustered biohermal limestone interlocked with reworked framework elements and stratified limestone in the intermediate basins. All these structures are bound together by secondary encrustation or cementation. Apart from the bedding-planes, the fracture network consists of two conjugate sets of steep closely spaced joints and two conjugate sets of widely spaced faults with normal down-dip displacement. At different levels of elevation, karst features are exposed. However, it was difficult to clearly separate different lithological units during manual pre-allocation: As the joint patterns of the examined outcrop are complex and intersecting, tracing certain discontinuities often became unclear and ambiguous. Thus, analyzing the HRDEM in a virtual lab has to be repeated under different display conditions (angle of view, angle of light, color shade, photographic overlays). In a later stage, an adjustment by secondary data, e.g. calculated or estimated discontinuity frequency, has proved to be very helpful. To this extent, the framework of a discontinuity-network has been established by a heuristic description, encompassing the discontinuities in a rock mass. For the next step, using the orientation of each computed vertex or face of the HRDEM, a TLS data set can be automatically compiled into local dip and strike direction. This enables the researcher to map the populations of structural slope facets, to carry out a stereographic analysis and then ultimately identify discontinuity sets. For a time-efficient approach, the HRDEM has been divided into several partitions prior to structural analysis in order to decrease the noise generated from the spatial variability of identical fracture patterns over the entire outcrop. In order to identify individual sets, overpopulated steep west inclined facets resulting from manmade slope expositions have to be removed before transforming the orientation data into density patterns. By using the frequency distribution of spatial orientations, several present discontinuities can be characterized from the density pattern by successively decimating dominant sets to emphasize subdominant orientations (Köhler 2013). With the possibility to color and visualize identified sets within the HRDEM, it shows that the analyzed orientation data can be related to flat-angled east dipping bedding surfaces, to steep NNW-SSE and WSW-ENE striking conjugate joints and to subdominant steep WNW-ESE striking faults and a few NE-SW striking faults (Fig. 34.2).

Application continued with extracting traces of geological features by using an algorithm which sets closely spaced scanlines onto the partitions of the HRDEM and utilizes a moving search window for corner detection. By computing the intersection points between the scanlines and traces, resulting discontinuity frequency and their spatial pattern can be visualized into a grid, suitable for designating homogeneous areas (Fig. 34.3a). Here, discontinuity spacing showed distinguishable areas of closely to widely spaced joints. Again, a cross validation with manual pre-allocation is necessary, as scan resolution and rock faces determine the quality of traceable features and spacing data (Fig. 34.3b). However, as the HRDEM depicts the in situ condition of the slope, blasting of ongoing mining operations significantly increases the joint density, creating a disordered network that strongly differs from the original, tectonically induced, system of fractures. These areas were treated separately for evaluating the discontinuity connectivity in the rock mass (Fig. 34.3b). By displaying those features with other surface characteristics in engineering geological plans and other visual methods of displaying field data like cross-sections or

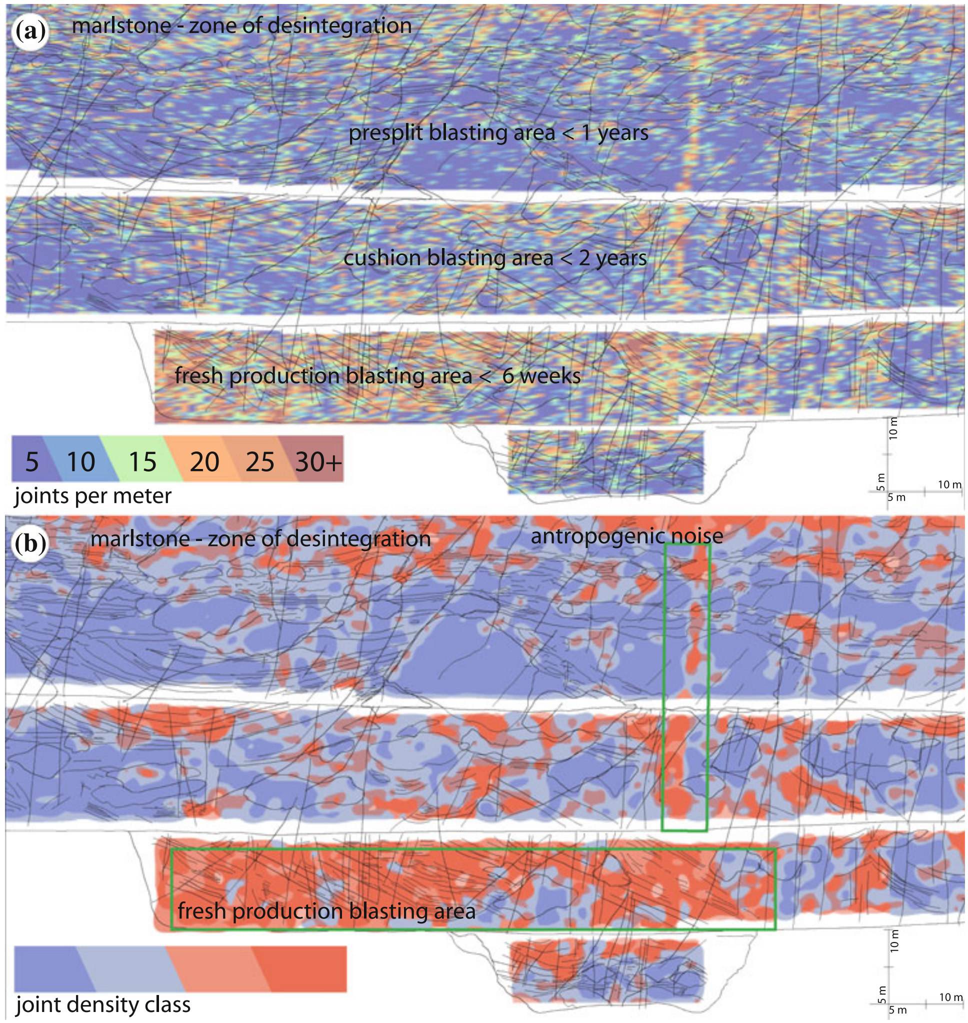

Fig. 34.3 **a** Narrow spaced scanlines shows spatially different joint density, separating massive reef bodies and thinly bedded marlstone layers. At the time of the recording, different blasting techniques altered traceable joint densities. **b** Translated into density classes for a practical use. As low resolution areas, fresh blasting works and anthropogenic features influence the classification, the results has to be field-validated

3D models, a high horizontal and vertical precision of the different information locations was secured. Based on this data and in combination with the results from prior applications, a discontinuity network can finally be organized as sets of discontinuities with identified spacing, persistence and attitudes. The major advantage of this procedure is the generation of detailed multiple-layered thematic 3D maps which provided a substantial improvement of data, knowledge representation and documentation, which in turn can be used as a template for ongoing applications as rock slope stability analysis.

34.4 Conclusion

The use of remote sensing with TLS shows that maps and cross sections generated from TLS data serve as a record of the spatial location of actual data and are suitable tools for characterizing discontinuities in a rock mass in detail over a large area. Operational experiences prove that primer higher efforts for data collection and processing will be compensated by far due to multi-use of data and flexibility in data supply, in terms of quantity and quality. The key advantage is that according to the investigation process and demand, data can be extracted and aggregated at varying levels of detail to respond quickly and economically to changing project requirements.

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