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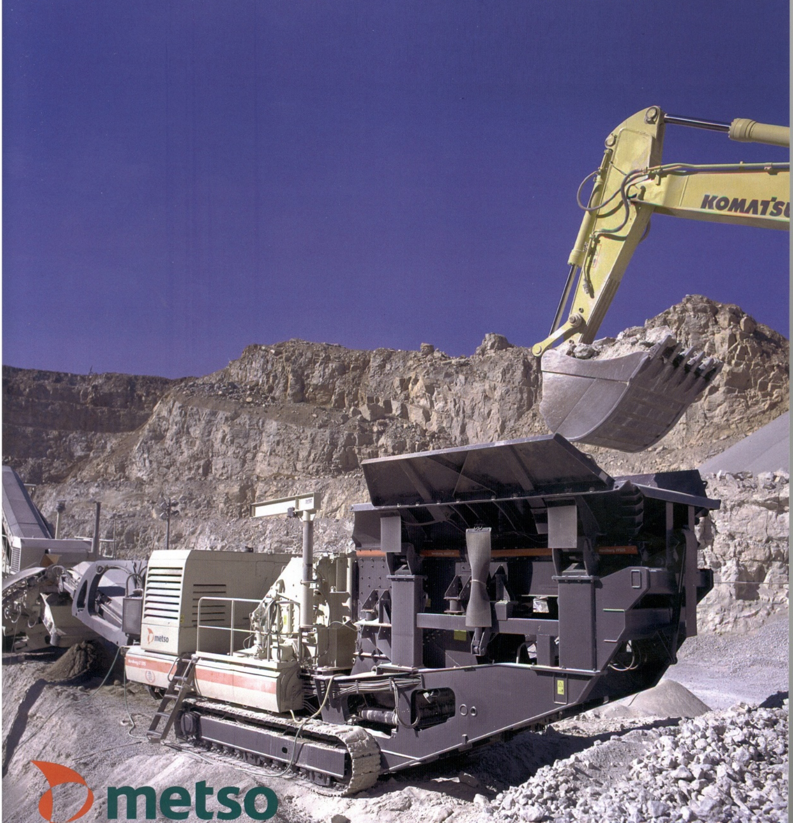

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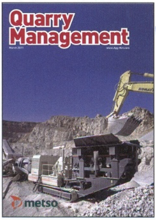

This month's cover
The new Lokotrack LT1315 mobile crushing plant, part of the Metso heavy-duty quarry range of Lokotracks.

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A 'Hands-off' Approach

Geological and geotechnical mapping and analysis using long-range high-density LiDAR surveying equipment

By A.P. Wilkinson, QuarryDesign Ltd

The Quarry Regulations 1999 state that all excavations and tips should be designed, appraised and, if significant hazards are identified, subjected to a geotechnical assessment (Regulations 30, 32 and 33). The contents of a geotechnical assessment are set out in Schedule 1 of the Quarries Regulations ACoP, of which the following are pertinent to this paper:

1. Site survey
2. Site investigation
6. Findings of analysis
8. Requirements during and after construction

Until recently, geological and geotechnical data were difficult to obtain safely and thus, in some situations, the analysis and subsequent design criteria could be flawed.

This paper outlines an integrated approach to geotechnical data collection using long-range, high-definition LiDAR (light-detection and ranging) surveying equipment and uniquely specialized geotechnical analysis software to acquire and interpret rock-mass data from a 'safe' distance from the quarry faces. Indeed, in some cases the analyses can be undertaken from as far away as the quarry periphery.

The approach outlined in this paper not only provides for remote geotechnical data collection, but also allows a significantly more detailed 'survey' of the faces to be obtained. It also provides a permanent record of the condition of the quarry faces on the day of the assessment, which can be referenced at a later date if stability issues arise.

Site survey

Traditionally, a quarry survey would be created using either dGPS (differential Global Positioning System) or by total-station surveying instruments. The resultant survey would comprise a series of break-line data (top of face, bottom of face etc) and spot levels upon which the ground contours would be derived. For the purposes of providing a topographical survey for quarry plan production, setting out or producing a reserve calculation, this methodology is perfectly adequate.

In situations where greater detail is required upon a quarry face (eg changes in geology, fault planes, back scars from rockfalls, or simply more data points for a more accurate rockfall analysis), the surveyor may obtain a series of spot levels on the quarry face using direct-reflective (DR) techniques. These data are relatively slow to obtain as each spot level has to be aimed from the instrument.

LiDAR surveying has improved dramatically in recent years, and with faster acquisition speeds and ranges in the order of 3,000m, it is now possible to effectively scan quarry faces from outside the working area (eg from an observation platform or screening bund on the outer edge of the quarry). It should be noted that not all LiDAR scanning equipment is the same. Exceptionally high-resolution, short-range scanners are used in Formula 1 motor racing (to obtain 3D models of cars for computer wind-tunnel simulations), while medium-range scanners are used for internal building and factory surveys. Long-range scanners are often employed to undertake coastal erosion monitoring and landslide risk analyses for strategic infrastructure in mountainous areas. It is this latter approach, using Optech's ILRIS-3D ER scanner, that QuarryDesign Ltd have adopted for the quarrying industry.

LiDAR scanning produces a 'point cloud' (a series of very closely spaced points with either an RGB colour value (from a digital camera) or a greyscale 'intensity' value (from the amount of returned light being recorded back at the scanner), as shown in figures 1, 2 & 3.

Fig. 1. Scan of a coastal rock face where each point has an RGB (red green blue) value allocated to it from the associated digital photograph (note: figure 1 is not the photograph but an actual screen shot from the 3D model)

Fig. 2. Close-up of a section of figure 1 where each individual point can be seen (in this case with a point spacing of 25mm)

The resultant point cloud can be either processed on a 'local' co-ordinate system or geo-referenced to the national co-ordinate system in the same manner as traditional surveys. It can also be converted into a triangulated mesh or wireframe digital surface model (DSM), which may include vegetation and buildings, or a digital terrain model (DTM) where points above an interpolated ground surface are removed.

From these DSMs or DTMs the relevant data (break lines, cross-sections, meshes or xyz points) can be exported into other suites of software for the production of plans or for further geological and geotechnical investigations or analyses.

Site investigation

It is possible to extract both geological and geotechnical information regarding the rock mass from these point clouds, and thus the use of LiDAR scanning can contribute greatly to the site investigation element of the Regulation 33 Geotechnical Assessment.

In terms of geological mapping, it has been found that different strata return different quantities of the originally transmitted light (ie they have different recorded 'intensity' values). For example, clays, shales and vegetation exhibit low-intensity values (with a greater amount of the light being absorbed than being reflected) and are initially processed as dark grey points, whereas granites exhibit high-intensity values (with more light being reflected than absorbed) and are initially processed as pale grey or white points.

In a similar manner, different grades of weathering of the same material can return different intensity values; with more-weathered material returning lower-intensity values than less-weathered material. 'Groups' of similar intensity points representing similar grades of weathering can be separated and coloured, making the visual analysis easier (fig. 4). The number of points within each group of similar coloured bands can also be summed and expressed as a relative percentage of the total number of points (in effect, producing a point-sampling method based upon the exposed surface of each grade of weathered material).

In addition to geological mapping of the strata, geotechnical data can be obtained from the LiDAR scans in the form of discontinuity data (dip, dip direction, spacing, persistence and roughness). Although these data are obtained from the processed scans back in the office, their creation does, in effect, still form part of the site investigation, as it

Fig. 3. Scan of Tarmac's Stancombe Quarry processing plant against a backdrop of heavily vegetated slopes and clean quarry faces. In this example greyscale 'intensity values' are shown

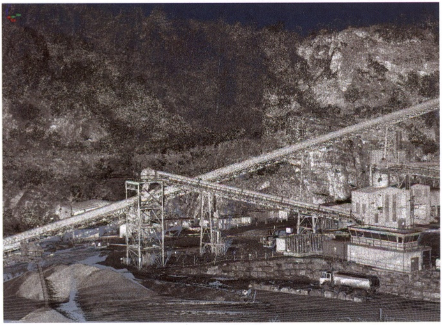


Fig. 4. Coloured groups of points representing points with similar intensity values corresponding to different grades of weathering (both along the orthogonal joints and as an exfoliation surface of a block of granite)

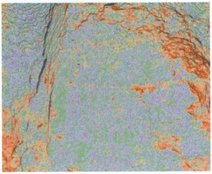


Fig. 5 A potentially unsafe and possibly redundant method of obtaining discontinuity data

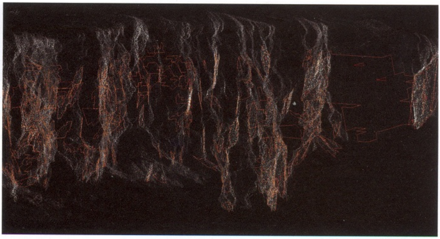


Fig. 7. Automated discontinuity data

replaces traditional methods of discontinuity data collection using a compass-clinometer (fig. 5).

Discontinuity data can be obtained by either manually digitizing each joint plane and recording its dip and dip direction (fig. 6) or by utilizing automated proprietary software specifically written to obtain geotechnical data from collected point clouds (figs 7 & 8). There are advantages and disadvantages to both methodologies and a sensible approach is to adopt an automated analysis reinforced by manual analysis.

With a manual point-cloud analysis, the engineer has the same control that he would have had in the field had he been collecting the data with a compass-clinometer, but with the added benefit that the readings will not be restricted to low 'safe' faces or to the height of the engineer.

However, this manual process can be slow to undertake and, as is human nature, can be influenced by what the engineer thinks are the joint sets (ie if he sees three sets he will preferentially record the dip and dip direction on the joints that match those sets).

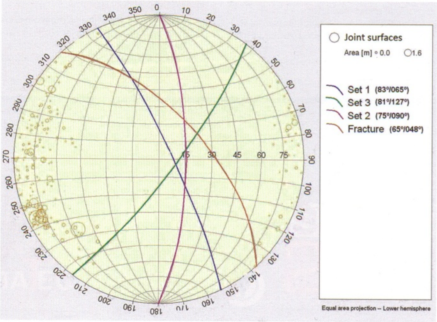
One of the many advantages of an automated method is that it produces far more data and can reduce the potential 'human' influence of the engineer. In figure 8, a 'shotgun scatter' of readings has been plotted on the stereonet for every visible joint plane recorded within a certain tolerance. This means that blast-induced joints are also recorded, which widens the distribution of the documented joint orientations. If these data were to be exported into DIPS (where each joint reading is equally weighted), the subsequent kinematic analysis would be difficult to undertake. However, the automated software also expresses the area of each measured joint, with larger circles representing larger exposed joints (as shown in fig. 8). In this example, a series of large joints forming Joint Set 1 can be observed dipping steeply at 83° towards 065° (East North-East). What is also apparent is that one of the joints in that region is very persistent and at a slightly different orientation (65°/048°); this actually represents a localized minor fault and is not part of the joint set.

Findings of analysis

As shown in the section above, data obtained by the LiDAR survey can be used to geologically map and geotechnically characterize quarry faces. The collected data can then be used to determine the potential

Fig. 6. Manual digitizing of discontinuity data

Fig. 8. Stereographic interpretation of automated discontinuity data



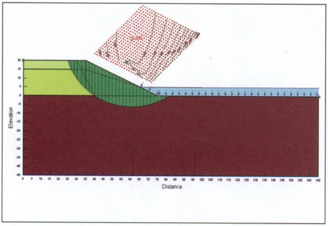


Fig. 9. Slope stability analysis

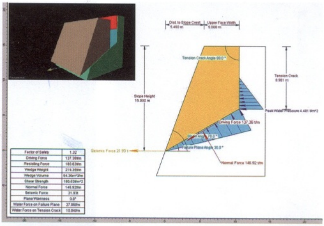


Fig. 10. Planar failure analysis

modes of failure (kinematical analysis) and, moreover, to calculate 'factors of safety' and/or 'probabilities of failure' for a given failure mechanism. For example, circular failures in weak rock masses, soil slopes, embankments and lagoons; and planar, wedge, and toppling failures in rock masses (figs 9 & 10).

Furthermore, the enhanced survey detail obtained by LiDAR surveying also greatly increases the engineer's ability to analyse the potential trajectories of rockfalls. Figure 11 shows Rockscience's 2D RocFall software being used with an 'older' cross-section obtained by direct-reflective (DR) surveying techniques. This cross-section compares with figure 12 which shows a more recent RocFall analysis based upon a high-definition LiDAR face survey.

The overhangs and ledges on the detailed LiDAR survey can clearly be seen to be playing a major part in the potential trajectories of rockfalls. These could easily have been missed on 'simpler' cross-sections and the resultant remediation measures (eg rock traps) under-designed.

Recent software developments (notably in the US) have used long-range, high-definition LiDAR surveys to assess the potential locations and hazards associated with landslides and rockfalls on to public highways, railways and other infrastructure.

QuarryDesign are working with a US-based company to provide 3D simulations of the potential trajectories of rockfalls from quarry faces (fig. 13).

One of the exciting potentials of this new software is that it can account for the breaking up of larger blocks into smaller fragments and project their potential trajectories as well as for the whole block. It also demonstrates the mitigation effect of rock traps and fences. Moreover, it is influenced by whole sections of the quarry face and not just single cross-section locations. In figure 13, the path of the trajectory is clearly oblique to the quarry face and would not have been predicted in a 2D analysis. With the new 3D approach, sloping ledges are accounted for and can be shown to cause rockfall material to bounce tangentially across as well as down a quarry face.

Requirements during and after construction

As LIDAR scanning produces a rapid detailed survey of a given quarry face or slope, it can be undertaken on a periodic basis to accurately measure and record potential changes in slope geometry, and can satisfy (where required) a need for monitoring.

Using LiDAR surveying techniques it is possible to monitor the performance of slopes, tips and lagoon walls, and to calculate the rates of any developing circular failures, wind erosion of sand faces etc.

QuarryDesign are currently trialling seasonal monitoring of several natural and quarried faces to ascertain if small changes between successive surveys might allow the measurement of potential rock-mass displacement, due to either repeated freeze/thaw cycles or a reduction in normal stress due to 'unloading'. It is hoped that such displacement measurements might be used to predict the location of future rockfall events before they occur (fig. 14).

Moreover, with the average spacing of the fractures being obtained from the point-cloud analysis described above in the Site Investigation section, the correct rockfall seeding location and block size can be determined and used in the 3D rockfall software shown in figure 13.

Conclusion

Long-range, high-definition LiDAR surveying techniques can be used as part of an integrated approach to geological and

Fig. 11. DR survey and 2D rockfall analysis

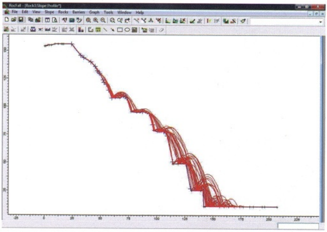
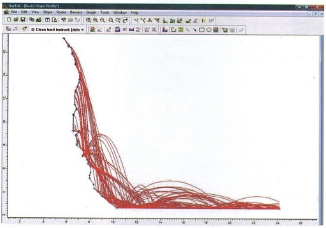


Fig. 12. LiDAR survey and 2D rockfall analysis



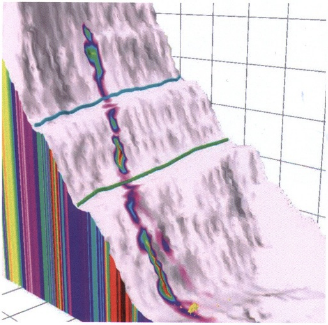


Fig. 13. LiDAR survey and 3D rockfall analysis

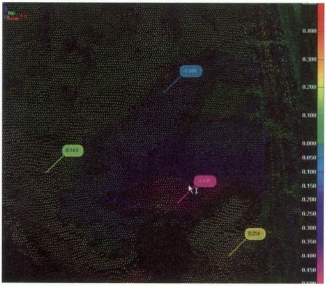


Fig. 14. Displacement measurements between successive rock face monitoring surveys showing expansion of the rock mass (green) and rockfall location (blue and pink)

geotechnical mapping, and to allow more accurate data to be collected significantly quicker and more safely.

Furthermore, advances in both computer processing power and software engineering are allowing more complex (and realistic) simulations to be undertaken.

All of this means that, as well as removing the potential risk to the engineer, the quarry design criteria or remediation advice being offered by the engineer should be more accurate.

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