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Selection of Lidar technology for limestone quarry in Thailand

Thailand produces construction aggregates from limestone, basalt and granite quarries. In one of limestone quarry, expansion of quarry is planned.With increase in limestone production, optimum blasting performance in terms of fragmentation and gradation is critical. Limestone is identified as weathered, highly weathered and massive limestone based on previous exploration. Based on geological strength index, limestone is classified as blocky, very blocky, blocky/seamy and disintegrated. Further observation is required on geological discontuities for all quarry faces. This paper evaluates technological options of unmanned aerial vehicle (UAV) with photogrammetry and Lidar technology with digital images for recording and storing data of geological discontinuities.

Keywords: *Geological strength index, UAV with photogrammetry, Lidar technology with digital images.*

Introduction

Construction aggregates in Thailand consist of limestone, basalt and granite. Potential aggregate resources and working quarries are located in various regions of Thailand [Fig.1]. Large aggregate quarries produce exceeding 200,000 cubic meter per month and otherwise termed as 'small size' quarries[1]. Most of large quarries are in central part of Thailand, 100 km north of Bangkok. Large limestone quarries are mainly supplying limestone for manufacturing portland cement.

Limestone deposit consists of highly weathered limestone, laminated limestone, somewhat weathered limestone and massive limestone. Geological map and section are shown in Figs.2 and 3 respectively.

Existing system of mine planning

Exploration of limestone deposit has been done with 500 m × 500 m grid pattern. Based on exploration data, geological block model is developed. Mine planning (long term > 5 years; medium term – yearly up to 5 years and short term – weekly to quarterly) is based on this block model. Minesight mine planning is used for short term quarry planning which is based on weekly to quarterly production planning and based on blending of various grades of limestone. Limestone is supplied to aggregate crushing plant and needs particular size gradation to have optimum production of aggregates from primary crushing plant. Fragmentation, back break with blast

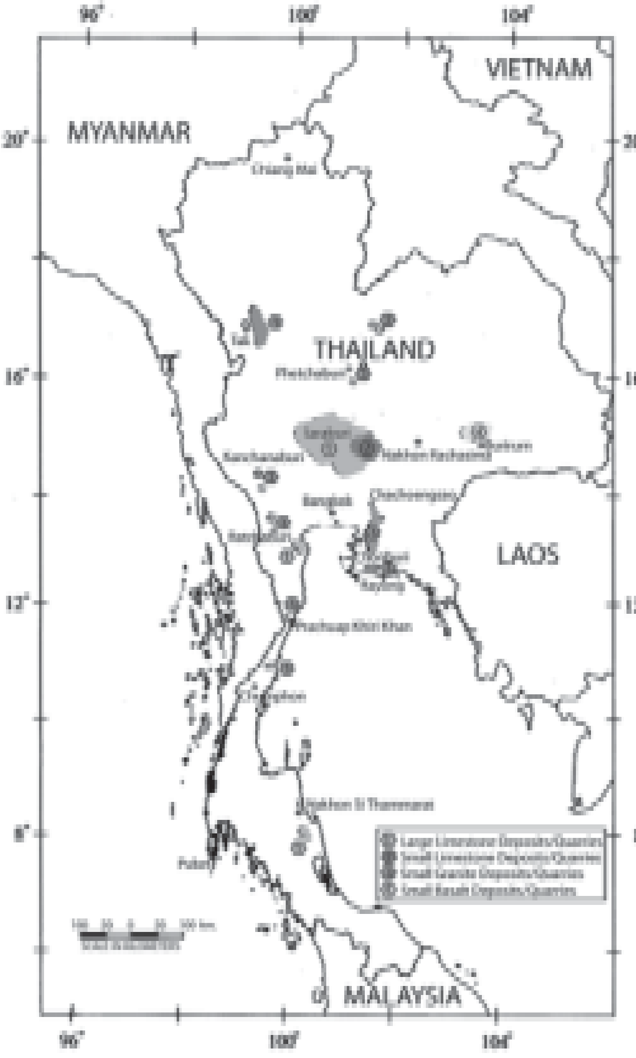

Fig.1 Location of aggregate resources and quarries in Thailand [1]

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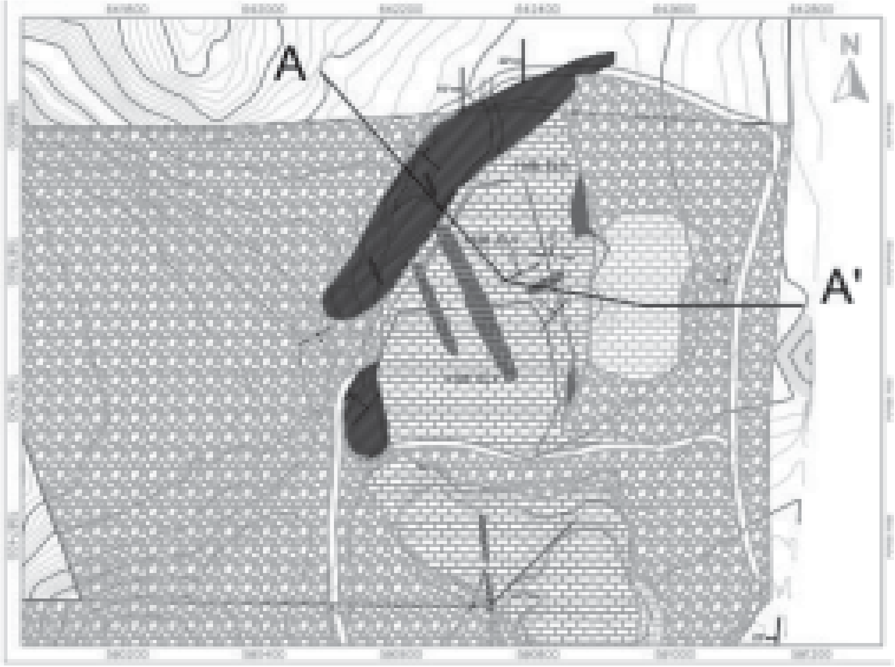


Fig.2 Geological map of limestone quarry

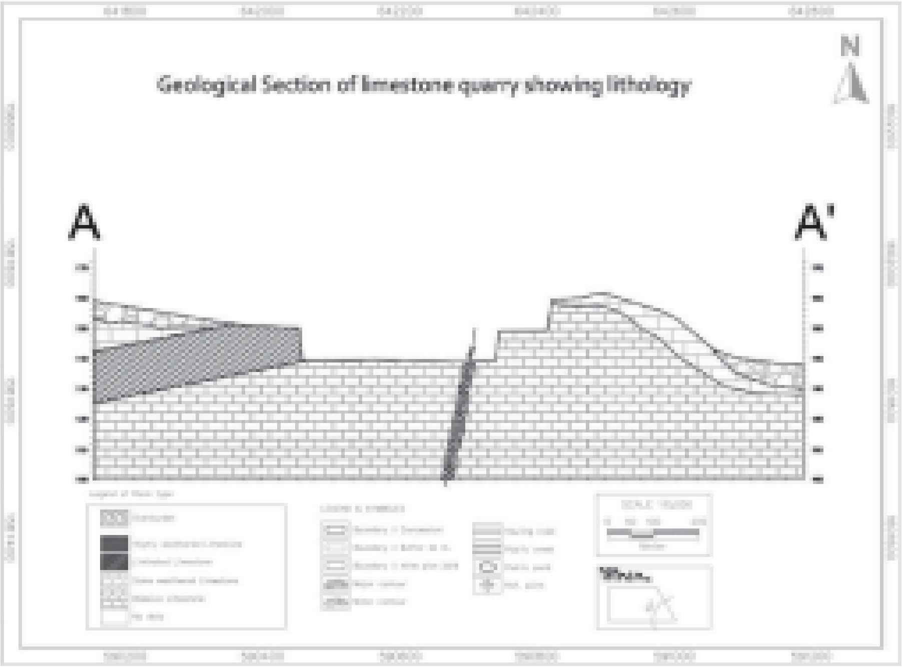


Fig.3 Geological section of limestone quarry

design data record is maintained for individual blast performance monitoring.

Expansion of quarry

It is proposed to expand existing quarry capacity. For meeting large blasted volume, it is proposed to have 127/150 mm dia drills as compared to existing fleet of 76 mm dia drills. It is well known that there is economical saving with higher diameter drills. Drilling cost per tonne decreases with increase in hole diameter. Following are common consideration for selecting drill hole diameter:

1. Desired fragmentation size and gradation: With increase in hole diameter, spacing and burden is increased which results in higher fragmentation and with coarse fragmentation, loading, crushing and secondary breaking will be high [2-8,10]. Thus, fragmentation is a determining factor that restricts the maximum blasthole diameter. Maximum permissible size for primary crusher is 800 mm and too fine fragmentation is not desirable.
2. Rock characteristics: Rock characteristics in terms of RQD, UCS, jointed rock mass affect drilling and blasting operation [2-11]. Through jointed rock masses, blasting gases escape easily causing coarser fragmentation-slab type. Hence, geology of quarry faces need to be understood for controlling fragmentation.
3. Bench height: Existing bench height is 10 m and changing drill hole diameter from 76 mm to 127/150 mm is within permissible limit [12].
4. Environment considerations: With increase in hole diameter undesired environmental effect such as fly rock, ground vibration and AOP increases [2-11]. Quarry is located far off from any local community and shall not have any impact.

According to Thornton et al. [13], fragmentation is influenced by (i) rock mass properties, (ii) blast geometry and (iii) explosive properties. Rock mass properties such as joints, UCS, density, Young's modulus are not controllable while other two parameters blast geometry and explosive selection are controllable parameters.

Study was undertaken of existing limestone quarry faces based on geological strength index as suggested by Hoek and Mong as shown in Fig.4 [14]. With preliminary observation, limestone is classified as (i) blocky, (ii) very blocky, (iii) blocky/seamy, (iv) disintegrated based on GSI classification (Fig.5).

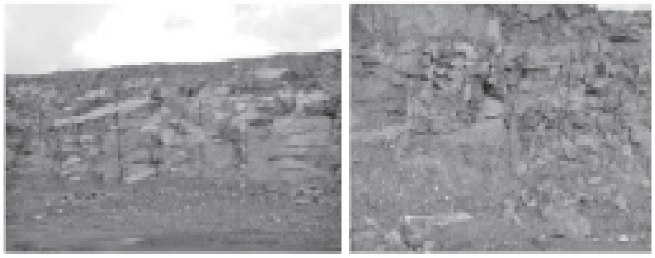
Fig.4 Rock classification geological strength index [14]

As ISRMC, joint is defined as "joint is a discontinuity plane of natural origin along which there has been no visible displacement" [15]. Further details on 'joints' are as under:

1. Each type of discontinuity has variable span: micro-cracks (<0.01 m), partings (0.008 to 0.9m), cracks (0.01 to 1.1 m), fissures (0.3 to 10 m), bedding planes (0.1 to 80 m), seams/ shears 2 m to 1 km), joints (0.05 to 100 m) and faults (5 m to 10 km) [16].
2. Important characteristics of joints are length, separation and joint surface and filling material. Joint sets may be in two or three dimensions. Joints are classified as very short (<1 m), short (1-3 m), medium long (3-10 m) and very long (>10 m) [17].
3. Separation is the maximum distance between two joint walls. Perpendicular distance between adjacent walls of joint is called aperture. Separation of joints is classified as very tight (<0.1 mm), tight (0.1-0.5 mm), moderately open (0.5 -2.5 mm), open (2.5 -10 mm) and very open (10-25 mm) [17].
4. Joints are also classified wavy joints, planer to wavy joints and planer joints [18].
5. Smoothness of joints is described as slicken sided, polished, smooth, slightly rough, medium rough, rough and very rough [17].

(a) Developed limestone faces showing benches

(b) Blocky limestone (c) Very blocky limestone



(d) Blocky/seamy limestone (e) Disintegrated limestone

Fig.5 Limestone quarry faces and classification of limestone based on GSI

6. Absence of joint filling material is described as clean. Joint filling material is classified as stained, coated or filled. A filling material may be hard and resistant minerals, soft minerals, soluble minerals, swelling minerals or loose material.
7. Joint orientation is described with respect to particular plane and described as dip and strike to that plane.
8. Discontinuity type and its origin is useful for blast design. For example bedding planes have greater impact than cross joints in limestone. Faults, folds, dykes and shear zone may be described individually.

Further minute study of quarry faces is required for finding various joint details such as spacing, orientation, roughness which will be useful for short term mine planning and planning individual blast for achieving desired fragmentation and gradation. Considering large field data to be collected, following two technological options are considered for collection of discontinuity data.

1. UAV WITH PHOTOGRAMMETRY

Unmanned aerial vehicle (UAV) is found useful for three dimensional (3D) mapping data for surveying applications in shortest possible time. In recent years, with improvement in gyroscope technology and precision in GPS, UAV application has become more reliable for payload, endurance and flexibility. With light weight digital video cameras and highly mobile sensors has become advantageous. Thus, it is also possible for photogrammetric flight planning for acquisition of 3D point clouds from digital mobile images [19]. UAV systems have found competitive as compared to conventional surveying system due to rapidly decrease in purchase price and maintenance cost. Some of the criteria for selection of UAV are area of survey, flying attitude, video camera and mounting system, physical obstacles if any, take off and landing space and whether persons work in the proposed area. Comparison of plotting with manual survey and UAV photogrammetric are shown in Fig.6.

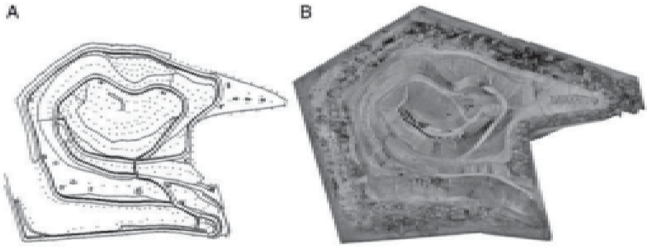


Fig.6 (a) Plotting of survey manually by using GPS survey points (b) 3D Mobile images plotted from UAV photogrammetric surveying using the UAV with millions of color-coded measurement points autonomously [19]

An experiment was conducted by Falcon 8 octocopter (UAV) from Ascending Technologies equipped with a high-resolution camera to capture building images and found that the accuracy with UAV was comparable with the results of sensing with light detection and ranging (LiDAR) with terrestrial scanner [20]. However, general principle of various surveying techniques and comparison with UAV photogrammetry is shown in Fig.7.

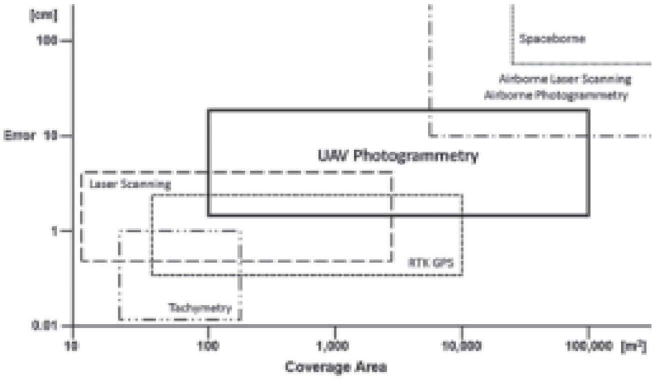
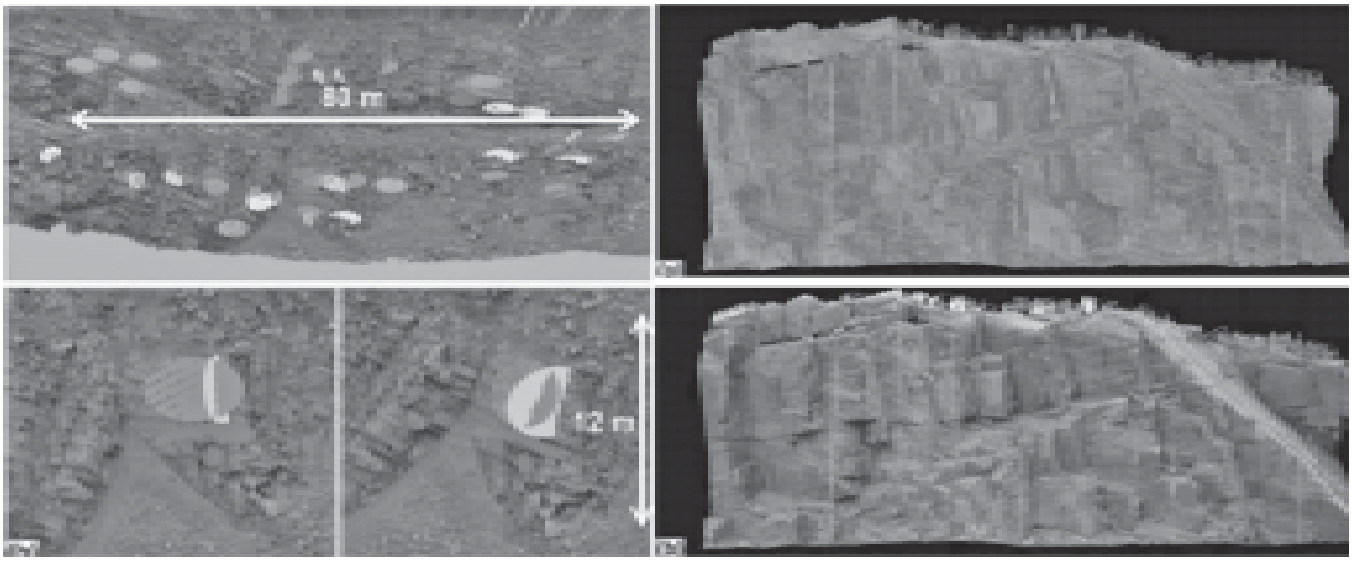


Fig.7 Comparison of UAV photogrammetry with other surveying systems [21]

Recent Lidar technology studies show that 3D point cloud images by ground based laser scanner and video or photo cameras can create 3D object models successfully [22-26]. Thus UAV technology has to be competitive in data acquisition as compared to Lidar technology in the field.

2. Lidar technology

Geotechnical investigation can be easily done with recent advancements in Lidar scanning and processing technology. Remote sensing technology of Lidar allows point cloud data to be used virtually for finding discontinuities such as joint set orientations, spacing and roughness [27]. For avoiding line of sight bias, survey team has to scan rockmass from multiple locations instead of single location and merge data [28]. Comparison of images with Lidar technology and RGB photo image is shown in Fig.8.



Upper image shows two benches with numerous identified discontinuity surfaces. Lower images are zoomed images

Rock outcrop(a) shaded by laser intensity and (b) associated photo RGB values

Fig.8 Images with Lidar technology and comparison with RGB photo image [27]

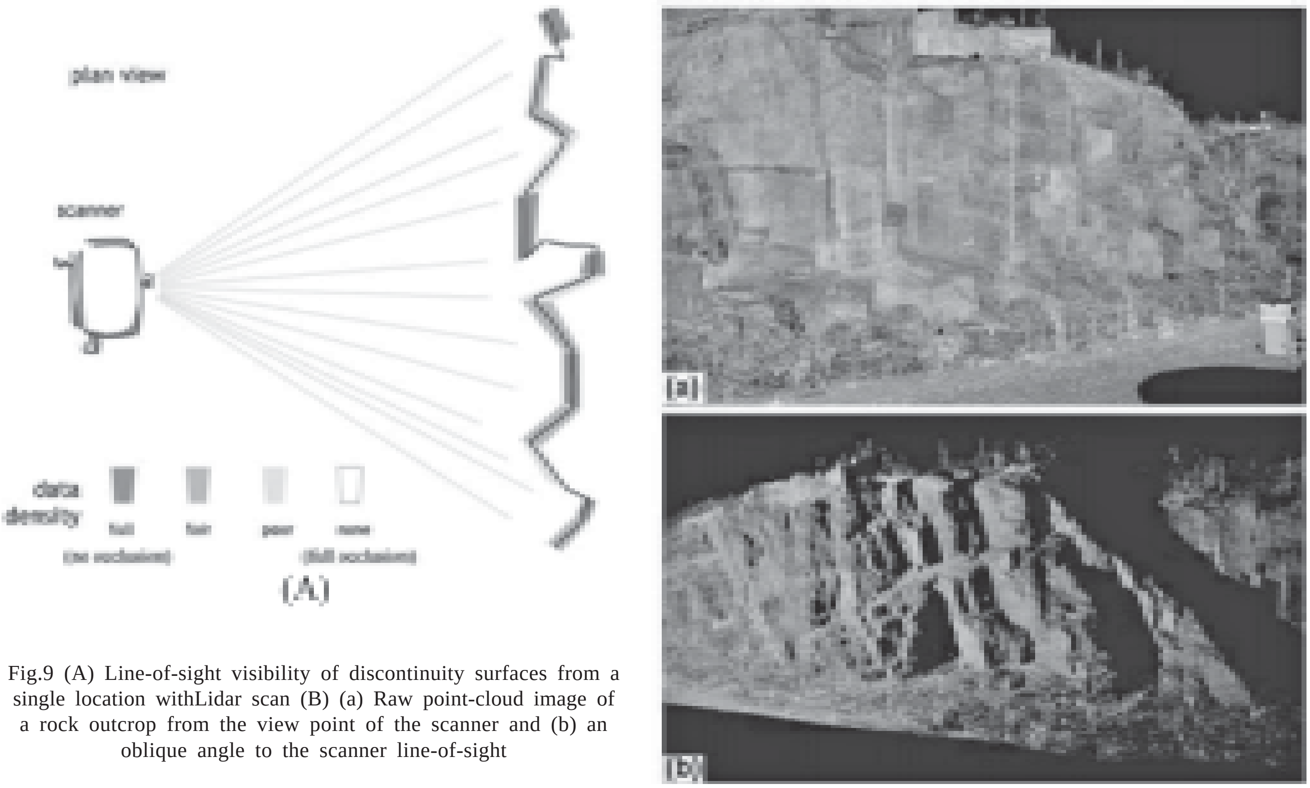


Fig.9 (A) Line-of-sight visibility of discontinuity surfaces from a single location withLidar scan (B) (a) Raw point-cloud image of a rock outcrop from the view point of the scanner and (b) an oblique angle to the scanner line-of-sight

(i) Discontinuity measurement

With manual method Brenton compass and inclinometer are used to measure dip and strike of quarry face. High-resolution virtual 3-dimensional (3D) point-clouds of rock surface or any solid object are created with Lidar. Orientation of discontinuity can be measured through manipulation of point clouds (3D). Through visualization by selecting Lidar data points, planer or discontinuity surfaces can be created and thus orientation of discontinuity can be calculated. This process can be automated or manual for discontinuity measurement [29-30].

(ii) Data collection

Principle of data collection is based on collection of several thousands to millions of 3D images per second with X, Y and Z coordinates based on reflection of laser focused beam on the surface and location is accurately calculated with respect to scanner lens [31]. Scanner measures reflectivity of material and colour intensity inred-green-blue (RGB) values are collected.

(iii) Orientation detection

Maximum biased result is produced when the angle between surface of discontinuities and line of sight is 900 and the discontinuity is under-sampled or occluded [27]. This practically means that when the look direction of the Lidar scanner approach parallel to strike of a discontinuity, it will not be sampled and therefore be occluded in the point-cloud. On stereonet sampled data is misrepresented if the discontinuity surface is occluded. Hence, in case of static scanner it is essential that more data is collected for discontinuities from different locations. There is impact on image quality based on Lidar scanner location with respect to the discontinuity surface Fig.9.

A ground-based Lidar and digital photogrammetry survey complement each other to analyze geoengineering work [32]. Thus Lidar images can be incorporated in block model produced based on exploration work. The alignment of Lidar scans from successive exposed quarry faces after each blast offers additional interpretation and thus data can be easily correlated. In aligning Lidar scans, larger scale features such as bedding planes, faults can be readily identified [33].

Conclusions

1. With increase in limestone production, higher diameter drill 127/150 mm is selected for overall economy. Spacing and burden will increase with higher hole diameter and geological discontinuity will play more role in fragmentation and gradation of blasted material.
2. Exploration at limestone quarry was done at 500 m × 500 m interval. Thus, there is a need for collecting geological features and discontinuity for mine planning and individual blast design with suitable technology.
3. Limestone quarry faces are classified based on geological strength index (GSI) – blocky, very blocky, seamy and

disintegrated limestone which is one input for blast design.

4. Discontinuity such as joint spacing, roughness, orientation, filling material need to be recorded for all working quarry faces.
5. Tecnology such as UAV with photogrammetry and Lidar technology with digital images for collection of geological discontinuities are considered.
6. UAV with photogrammetry has been used for collection of survey data. Ascending Technologies collected building images with UAV and reported accuracy of survey data is comparable with Lidar technology. However, based on general principle of surveying, Lidar technology with terrestrial scanner has better accuracy.
7. There is higher safety by using 3-D laser scanning and digital imaging technologies as person need not make physical contact with the rock surface to measure discontinuity properties such as orientation
8. Lidar technology with bigger statistical sample is possible and not restricted to only those parts of the rock face that is accessible. There is bias due to humans which is very common traditional manual methods. With Lidar technology, bias is minimum. Limitation of Lidar technology is that from more than one location, data to be captured and analyzed.
9. Finally, Lidar technology provides faster way data collection and the analysis of discontinuous rock.

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