

Study on Royalty for Sri Lankan Quarry Mining of Industrial Minerals using Photogrammetric 3D Modelling

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Abstract

Royalty is a payment made to the owner of mineral rights for the privilege of extracting minerals from the ground on a lease agreement. Globally, there are three main methods used for the royalty calculation; namely unit based, value based and profit based methods. A combination of unit and value based systems is practised in Sri Lanka. However an explosive based equation without any scientific base is adopted for the determination of excavated quantities of some minerals. The main objective of this study was to find an accurate method to calculate excavated quantity of a rock for calculation of royalty for industrial minerals in Sri Lanka. Initially, a multiple-borehole blast was carried out in a selected 'A Grade' quarry. A total station survey and an Unmanned Aerial Vehicle (UAV) survey were conducted to determine the excavated rock volume. The collected aerial photographs for photogrammetric 3D modelling were processed using Agisoft PhotoScan, Bentley ContextCapture and DroneDeploy softwares. The accuracy of each method was determined by comparing each estimated depleted volume with the value obtained from weighing the blasted tonnage. Photogrammetric 3D modelling gave the least deviation from the actual volume.

Keywords: Aerial Photograph, Drone, Excavated Quantity, Total Station, UAV

1 Introduction

Sri Lankan royalty system for minerals can be considered as a combination of unit based and value based systems and it depends on the commodity. Currently, the royalty levy for industrial minerals is calculated by an equation based on the amount of explosives used. A study conducted by the Geological Survey and Mines Bureau (GSMB) has revealed that in

some cases the total tonnage calculated from the equation, widely differs from the true value. As royalty levy on minerals is part of the government revenue, any errors in the calculation is not admissible.

The explosive-based method adopted by the GSMB is an indirect method for the calculation of royalty levy in the absence of an accurate, reliable method for the calculation of the excavated quantity. The equation is as follows;

$$T = 2 \times (a + b) + c \quad \dots(1)$$

T - Excavated quantity in cubes

(1 cube = 2.83 m³)

a - Amount of Water Gel used in kg

b - Amount of ANFO (Ammonium Nitrate + Fuel Oil) used in kg

c - Amount of Black Powder used in kg

2 Methodology

2.1 Site Selection

The 'A Grade' metal-quarry located approximately 25km away from the Kaluthara was selected for the survey. The site surveyed was approximately 5km² area with vegetation, steep and rough faces as well with typical open quarry environment. A multiple borehole blast was conducted in the quarry. Details of the blast are shown in *Table 1*;

Table 1: Details of the Blast

	Amount	Unit
ANFO	60	kg
Water Gel	4.5	kg
ED	36	No.
Spacing	1.6	m
Burden	1.2	m
Depth	3.6	m

2.2 Weighing the Blasted Tonnage

This can be considered as one of the most accurate methods in determining the depletion of a rock. The negative aspect of this method is that it requires a weighing bridge. Blasted rock volume was calculated using the following equation;

$$\text{Blasted Volume} = \frac{\text{Tonnage hauled}}{\text{Rock density}} \dots (2)$$

The tonnage hauled was calculated by multiplying the total number of loads by the average tonnage per load. Rock density was calculated on the field and it was 2.7195 t/m³ (1 t/m³ = 1000 kg/m³). Metal Quarry administration has measured the density of the rock in

2016 and it was 2.737 t/m³, which is very close to the value we obtained.

2.3 Total Station Survey

The specifications of the total station (TS) used are in *Table 2*;

Brand: *Leica flex line Ts02/Ts06/Ts09*

Table 2: Total Station Specifications

Description	Specification
1" Angular accuracy enhanced the measurement accuracy to prism	2mm+2ppm
Reflectors measurement range	500m option
Display with graphics and display illumination	Black and White high resolution

Before the blast, location of the total station was entered as the base point. Then the total station was tilted to the reference direction (north in our case) and the angular measurement was set to zero to get a reference coordinate for the instrument location. Then many points of the upper and lower surfaces of the pre-blast face were taken in non-prism mode.

After the blast, surrounding area near the rock face was cleared. Several readings were taken from top and bottom surfaces of the post blast face using both prism and non-prism modes. Prism mode was used in places where there were obstructions between the instrument and the post blast face.

2.4 Drone Image Processing

2.4.1 Data Acquisition

A DJI Phantom 4 Pro drone was used in data acquisition. The drone consisted of a polarizer that can be used to control the reflection from shiny surfaces in the ground and natural objects such as tree leaves. Specifications of the drone [2] are shown in *Table 3*;

Table 3: Drone Specifications

Aircraft	
Weight	1388 g
Diagonal Size (Propellers Excluded)	350 mm
Max Speed	S-mode: 45 mph A-mode: 36 mph P-mode: 31 mph
Max Tilt Angle	S-mode: 42° A-mode: 35° P-mode: 25°
Max Angular Speed	S-mode: 250°/s A-mode: 150°/s
Max Flight Time	Approx. 30 minutes
Gimbal	
Stabilization: 3-axis (pitch, roll, yaw)	
Controllable Range Pitch: -90° to +30°	
Max Controllable Angular Speed: Pitch: 90°/s	
Angular Vibration Range: ±0.02°	
Camera	
Sensor	1" CMOS Effective pixels: 20M
Lens: FOV 84° 8.8 mm/24 mm (35 mm format equivalent) f/2.8 - f/11 auto focus at 1 m - ∞	
Operating Temperature Range: 32° to 104°F (0° to 40°C)	
Image Size: 3:2 Aspect Ratio: 5472 × 3648 4:3 Aspect Ratio: 4864 × 3648 16:9 Aspect Ratio: 5472 × 3078	
Remote Controller	
Operating Frequency	2.400 - 2.483 GHz and 5.725 - 5.825 GHz
Max Transmission Distance	2.400 - 2.483 GHz (Unobstructed, free of interference) FCC: 4.3 mi (7 km) CE: 2.2 mi (3.5 km) SRRRC: 2.5 mi (4 km)

2.4.2 Data Processing

Three photogrammetric 3D modelling softwares were used to generate 3D models of the quarry. Those are;

1. Agisoft PhotoScan
2. Bentley ContextCapture
3. DroneDeploy

3 Results

3.1 Total Station Data Processing

Pre-blast rock face was drawn in AutoCAD, with the data obtained before the blast. Post blast rock face was drawn from data obtained after the blast.

After importing all the coordinates to AutoCAD, the 3D solid was generated (refer *Figure 1*) in order to find the volume of the blasted rock. The volume that was obtained using AutoCAD software was 254.837 m³.

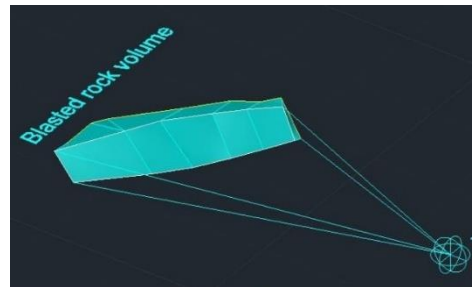


Figure 1: Generated Solid using AutoCAD

3.2 Volume Estimation using Agisoft PhotoScan

Here the blasted rock volume was calculated using 2 methods;

1. Measuring the volume using pre blast and post blast faces
2. Measuring the volume of blasted rock pile

3.2.1 Measuring the volume using pre blast and post blast faces

In Agisoft, only Orthophoto or DEM (Digital Elevation Model) could be

used to measure distances, areas and volumes. First, the post blast face was marked on the post blast Orthophoto as a polyline. It is easier to mark the blast face on Orthophoto than in DEM, as we can easily recognize the features in it. Followed by that, post blast face was imported into pre-blast Orthophoto.

As Ground Control Points (GCPs) were not used when aerial photographs were taken, both pre-blast and post blast models were not properly geo-tagged. Both models were shifting slightly from their original positions. ArcMap software was used to bring the post blast face shape file (polyline) into its correct position relative to the pre-blast orthophoto. Then the blast area can be demarcated as follows (see *Figure 2*);

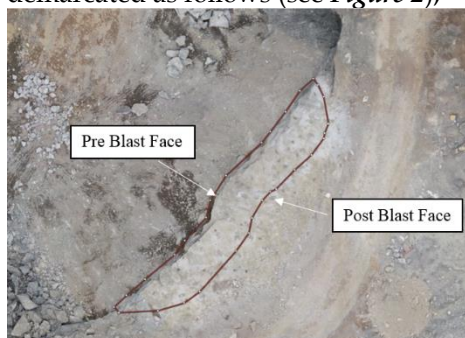


Figure 2: Demarcating the Blast Area

To determine base level or bench height of the blast, a polyline was drawn close to selected area and heights along the line was checked and the minimum height was taken (see *Figure 3*).

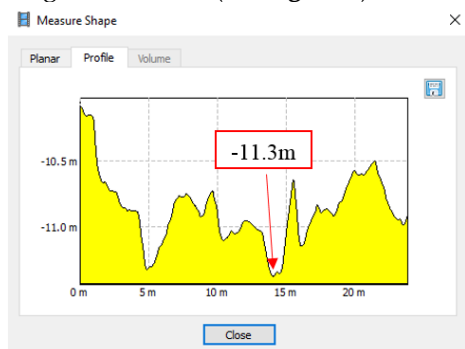


Figure 3: Finding the Minimum Height

3.2.2 Measuring the Volume of the Blasted Rock Pile

Here the volume of the blasted rock pile was taken directly. A polygon was drawn close to the blasted rock pile (refer *Figure 4*) and the volume of the blasted rock pile was estimated. Fly rock travelling to greater distances were neglected.



Figure 4: Demarcating the Extent of the Pile

Agisoft PhotoScan software has the ability to identify visible air spaces in the model and when calculating volumes, these spaces are taken into account. But internal spaces are not visible in the exterior view. However, most of the spaces can be identified if the blast is well distributed on the ground. Although the volume that we obtain from Agisoft is an intermediate value between in-situ and bulk volumes, it is closer to the in-situ volume. Estimated volumes using the above two methods were 262.727 and 252.028 m³.

3.3 Volume Estimation using Bentley ContextCapture

In Agisoft, Orthomosaic or the DEM had to be generated to calculate volumes. Therefore only a 2D image was available to calculate the blasted rock volume. But in ContextCapture, 3D Mesh could be used for the purpose.

Therefore, it is easier to demarcate areas/ planes using ContextCapture.

The following two methods were used to calculate the blasted rock volume;

1. Measuring the blasted volume by demarcating the blast area
2. Measuring the volume of blasted rock pile

3.3.1 Measuring the blasted volume by demarcating the blast area

A difficulty faced here was that we didn't have the capability to import or export shape files to ContextCapture. However, the blast area could be demarcated using the locations of the blast holes (refer *Figure 5 and 6*).

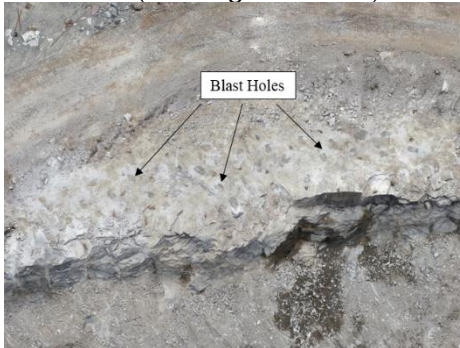


Figure 5: Identification of Blast Holes

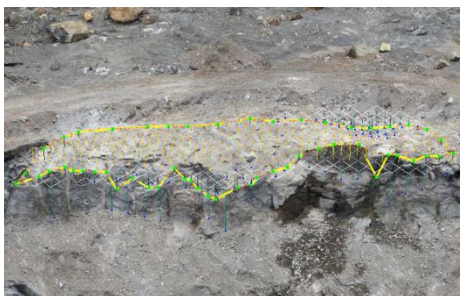


Figure 6: Demarcating the Blast Area

The bench height was considered as the height of the blast. Then to get the blast volume, bench height was reduced from the mean level and the cut volume above the custom plane was considered (see *Figure 7*).

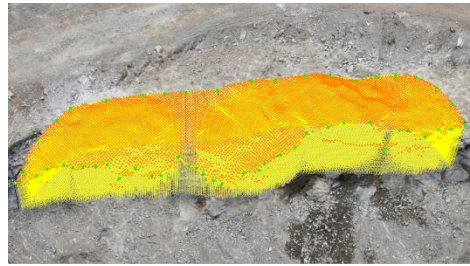


Figure 7: Blasted Volume for 0.1 m Sampling Distance

Blast volumes of 288.27, 271.38 and 266.31 m³ were obtained for 0.59189, 0.1 & 0.05 m sampling distances as shown in *Figure 8*.

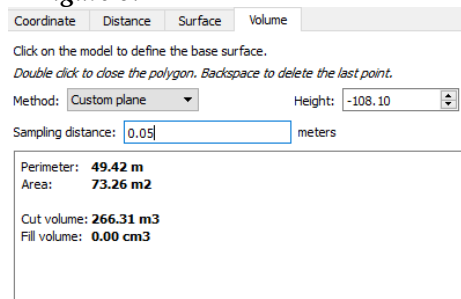


Figure 8: Volume Measurements with 0.05 m Sampling Distance

3.3.2 Measuring the volume of blasted rock pile

To measure the volume of the blasted rock pile, the area occupied by the muck pile has to be demarcated accurately. As mentioned before using ContextCapture distances, surfaces and volumes can be measured in 3D space. Therefore unwanted rocks and benches could be avoided easily (see *Figure 9*).

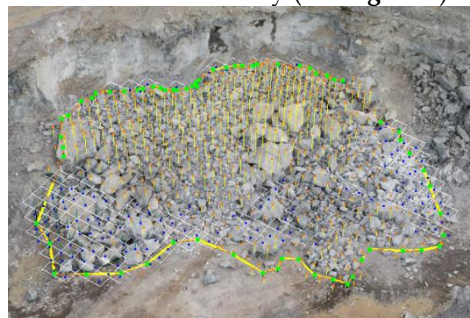


Figure 9: Selecting the Extent of the Blasted Rock Pile

Volumes of 257.93 and 257.50 m³ were respectively obtained for 0.1 and 0.05 m sampling distances (refer *Figure 10*).

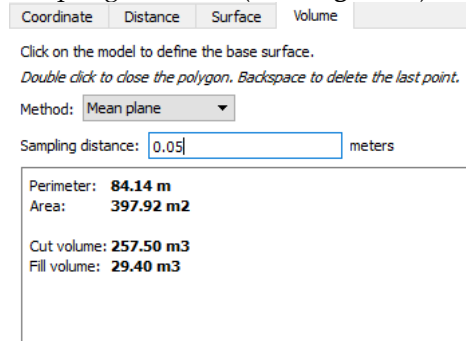


Figure 10: Volume Measurements with 0.05 m Sampling Distance

3.4 Volume Estimation using DroneDeploy

Three base-plane options are available for volume calculation (see *Figure 11*) using DroneDeploy. Namely Linear Fit, Lowest Point and Triangulated. The cut volume above the base-plane of the selected area was considered.



Figure 11: Demarcating the Blast Area

Here, *Table 4* shows the volume measurements which have been obtained using DroneDeploy.

Table 4: Volume Measurements using DroneDeploy

Method	Cut Volume (m ³)	Fill Volume (m ³)	Actual Volume (m ³)
Linear Fit	240.3	-28.6	211.7

Triangulated	240.7	-15.3	225.4
Lowest Point	733.2	0	733.2

4 Discussion

Each method has its own positive and negative aspects. If weighing the blasted tonnage is preferred, a weighing bridge should be installed in each and every quarry, which is impractical.

Although the point measurements by total station are accurate, discontinuous faces cannot be mapped easily using the total station and it is a time consuming method.

Agisoft PhotoScan is not costly (Full license for commercial use is \$3499 and academic use is \$549), and it has a good accuracy while having a simple workflow. But, data processing is time consuming than other softwares and measurements can only be taken in a 2D plane.

On the other hand, Bentley ContextCapture had the best accuracy among the three softwares. It is less time consuming and all measurements can be taken in 3D, which is the biggest advantage of this software. However, the interface of the software is relatively complex.

DroneDeploy consumed the least time to process aerial photographs, being the simplest method comparatively. All the photos can be uploaded to the software online, without a need for sophisticated machine requirements. As the free version of the software was used, it gave the least accuracy among three softwares. As in Agisoft, measurements could only be taken in a 2D plane.

5 Conclusion

Shown below (*Figure 12*) is the blasted volume comparison of the values that were obtained from all methods;

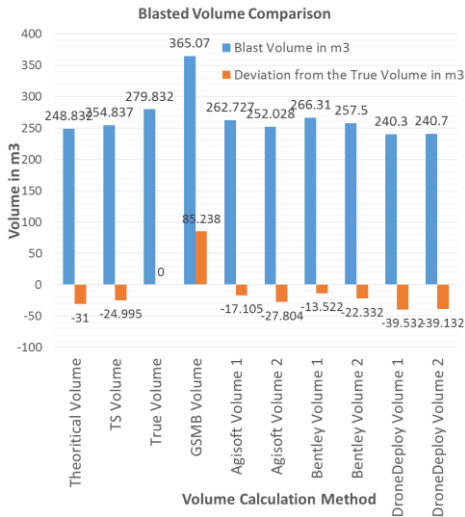


Figure 12: Blasted Volume Comparison

Table 5: Obtained Blasted Volumes

	Blasted Volume in m³	Deviation from the True
Theoretical Volume	248.83	-31.00
TS Volume	254.84	-25.00
True Volume	279.83	0
GSMB Volume	365.07	85.24
Agisoft Volume 1	262.73	-17.11
Agisoft Volume 2	252.03	-27.80
Bentley Volume 1	266.31	-13.52
Bentley Volume 2	257.50	-22.33
DroneDeploy Volume 1	240.30	-39.53
DroneDeploy Volume 2	240.70	-39.13

In this chart, the vertical axis represents the in-situ volume of the blasted rock in cubic meters (m³) and the horizontal axis represents the volume calculation method. It can be clearly observed in the graph, GSMB volume deviates widely from the true/actual volume. Therefore, this method should not be used to calculate the mining royalty. From the methods used to calculate the blasted volume, the values obtained from Bentley ContextCapture shows

the least deviation from the actual volume. Implying that it is the most suitable software to obtain volume measurements using photogrammetric 3D modelling.

However, it shows a deviation of -13.5 m³ and -22.3 m³ from the actual value. This may have resulted as the volume above an inclined plane was considered. The inclined plane was not a uniform one, it consisted of small holes. The volume calculation would have been closer to the actual value, if the volume measurement was taken above a flat surface.

6 Recommendations

The positional accuracy of a drone image is directly correlated with the inbuilt GPS unit. The typical GPS units attached in consumer grade drones provide satisfactory levels of navigation accuracy. However, when drones are used for surveying purposes higher accuracy is needed. Survey grade drones like eBee™ by SenseFly offers higher accuracy data which would directly influence the accuracy of the volume calculation derived from the 3D model or the DEM.

In the case of royalty calculation for Sri Lanka, since the adoption of the drone system will generate greater revenue, the higher costs associated with the capital investment on a survey grade drone can be justified.

The second most commonly used technique in photogrammetry is to increase the accuracy of measurements involved in the use of ground control points. During the study, no ground control points (GCPs) were used to register higher positional accuracy as it is a redundant factor in the volume calculation by the difference in the dimension of time. However, since royalty levies involve a legal framework, it is recommended to use

GCPs so that any protest made by the quarry owners challenging the volume calculation can be effectively nullified with reasons.



Figure 13: Establishment of GCPS

The establishment of at least three GCPs surveyed by the Survey Department, in the vicinity of the quarry at the start of a quarry (refer **Figure 13**) can be made compulsory in order to receive the license for quarrying. Such requirement fulfilled will be beneficial throughout the life time of the quarry, both for the owners of the quarry and the GSMB in volume calculation for royalty payment. Such a previously surveyed point can easily be used to adopt a Real Time Kinematic (RTK) or Post Processing Kinematic (PPK) system which will greatly improve the accuracy of the measurements.

If such surveyed points are unavailable, it is recommended to use a survey grade GNSS receiver to establish the ground control points. In this case, both natural and artificial GCPs can be laid as required on the day of the drone run and such points need not be permanent.

The use of photogrammetric 3D modelling will not only provide volume measurements, it will provide useful information about the bench heights maintained by the quarry owners, safety berms, status of the

access roads, amount of vegetation removal and successive rehabilitation of the vegetation. Therefore, it is recommended to establish a separate unit within the GSMB for the proper monitoring of the quarries along with a well maintained database of information which will ensure the sustainability of the mining industry.

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8 References

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- [2] DJI Official. (n.d.). DJI Phantom 4 Pro - Specs, Tutorials & Guides - DJI. [online] Available at: <https://www.dji.com/phantom-4-pro/info> [Accessed 3 Jan. 2019].