STUDY ON ROYALTY FOR INDUSTRIAL MINERALS AND BUILDING MATERIALS IN SRI LANKAN MINING

K. P. S. R. Jayawardana   140824R

H. M. D. Chathuranga   140806N

D. R. M. Athukorala   140803D

M. Chrishoban   140808X

J. A. B. Sampath   140850R

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Department of Earth Resources Engineering

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Supervised by:

Eng. P. V. A. Hemalal, Prof. P. G. R. Dharmaratne, Dr. H. M. R. Premasiri, Dr. S. P. Chaminda & Mrs. M. A. D. M. G. Wickrama

Prepared by:

K. P. S. R. Jayawardana	140824R
H. M. D. Chathuranga	140806N
D. R. M. Athukorala	140803D
M. Chrishoban	140808X
J. A. B. Sampath	140850R

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K. P. S. R. Jayawardana

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H. M. D. Chathuranga

………………………………
D. M. R. Athukorala

……………………………..
M. Chrishoban

………………………………
J. A. B. Sampath

"The undersigned hereby certify that the thesis have been read and recommended for acceptance in partial fulfilment of the requirements for the Degree of Bachelor of Science of Engineering"

………………………………
Eng. P. V. A. Hemalal

……………………………..
Prof. P. G. R. Dharmaratne

………………………………
Dr. H. M. R. Premasiri

………………………………
Dr. S. P. Chaminda

………………………………
Mrs. M. A. D. M. G. Wickrama

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Abstract

Mining activities creates wealth or economic surpluses. So many companies tend to explore, develop, and then exploit mineral deposits. Royalty is a payment made to the owner of mineral rights for the privilege of extracting the mineral from the ground based on a lease agreement. There are three methods used in the world for the royalty payments. Commonly, Unit based royalty, Value based royalty and Profit based royalty methods were used. There are advantages and disadvantages in every method.

In Sri Lanka Royalty for mining minerals were taken by GSMB. Unit based and Value based systems are occupied in Sri Lanka. However an explosive based equation (indirect method) is used to determine the royalty for industrial minerals. Which is having no relationship with fragmentation of rocks. To overcome this current situation, several methodologies were listed and carried out in this research, i.e. Photogrammetry Volume calculation and Total station survey volume estimation. Both methods are direct methods to calculate Royalty.

Initially an A grade quarry was selected. Then a total station survey was carried out and images were taken by drone (for photogrammetry 3D modelling) for a specific blast, before and after. The collected data were processed by both ways and 3D mesh were created and through that volumes were calculated with the use of AutoCAD, Bentley, and Pix4D. Sample rocks collected at the site and specific gravity was measured for the actual volume modification. Used explosives [amount, type], Time consumption for volume estimation, Cost effectiveness were analyzed with the results. Depleted volume estimation through Photogrammetry 3D modelling is less time consuming than the total station method. For the nationwide purpose photogrammetry 3D modelling is most suitable with best practices.

KEY WORDS: Total station, Photogrammetry, GSMB

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List of Abbreviations

DEM – Digital Elevation Model

TS – Total Station

GSMB – Geological Survey & Mines Bureau

RAM – Random Access Memory

NSW – New South Wales

GCP – Ground Control Points

UAV – Unmanned Aerial Vehicles

1 INTRODUCTION

1.1 Research Topic

Study on Royalty for Industrial Minerals and Building Materials in Sri Lankan Mining

1.2 Background

Mining activities creates wealth and economic surpluses. Many state and private companies are engaged in the exploration, development and mining of mineral deposits. Royalty is a payment made to the owner of mineral rights for the privilege of extracting the mineral from the ground based on a lease agreement. In other words, it is a payment made to the Government to compensate for the extraction/ depletion of a resource owned by the state. Currently, there are about 1700 quarries operating in Sri Lanka producing industrial minerals.

The global royalty taxation systems are different from one country to another. They can be mainly classified into three types, namely *unit based*, *value based* (ad valorem) and *profit based*. Unit based or tonnage basis is mostly applied to high volume, low-value homogenous minerals. It is the mostly applied method in the world (Andewal K., 2014). The ad valorem based system needs the knowledge of mineral value. Those two methods are mainly used in developing countries, with some countries used to combine two or three methods and form a hybrid system to calculate royalty. The profit based royalty system is common in developed countries.

1.3 Problem Statement

Sri Lankan royalty system can be considered as a combination of unit based and value based system and this depends on the commodity. Currently, the Royalty levy for industrial minerals is calculated by an equation based on the amount of explosives used. Detailed study conducted by the Geological Survey and Mines Bureau (GSMB) has revealed that in some cases the total tonnage calculated from the equation, drastically 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, an indirect method for the calculation of royalty levy in the absence of an accurate, reliable method for the calculation of production is as follows;

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

T – Excavated quantity in Cubes

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

The excavated quantity is solely based on amount of explosives used and the margin of error is too high and may result in a tremendous amount of loss of revenue the country. The error originates from the fact that the depletion of the ore depends on the degree of fragmentation of the rock. Therefore, this explosive based system not suitable to estimate the depletion of a blasted rock.

The royalty is being made with an explosive based volume calculation equation in Sri Lanka by GSMB. The volume calculated through is having unavoidable error margins. As a government organization, the GSMB needed to solve this situation and to make a practical solution which can be adaptable to Sri Lankan situations. Several test blast reports from several sites were analyzed and a graph was plotted to analyze the deviation of *GSMB Volume* from the *Expected Theoretical Volume*.
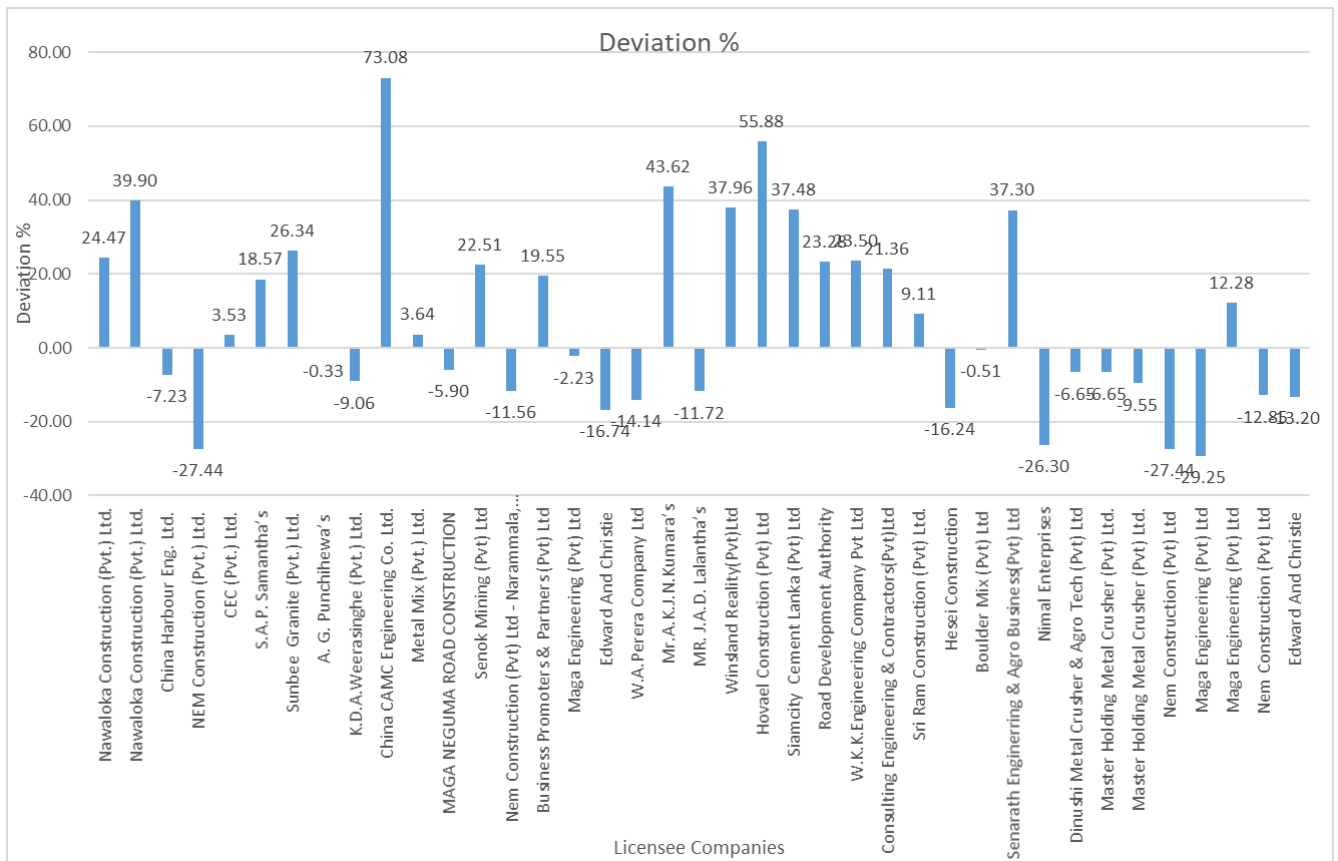
Figure 1-1: Deviation of GSMB Volume

The horizontal axis is showing licensee companies and the vertical axis is showing the Percentage Deviation between Expected Volume & GSMB Volume. Commonly every test blast reports have accountable deviation. Especially China CAMC Engineering Co. Ltd having the largest deviation that is 73.08 %. It has happened because their borehole diameter is larger (110 mm). the larger BH Diameter having a large deviation in volume calculation. As per the graph, it is clearly visible that errors occurring by the current methodology of volume calculation are very large.

Indirect methods are not practicable in Sri Lankan conditions due to the trustworthy between GSMB and licensee is very poor. The research is carried out to provide a better solution to overcome this volume estimation error. The solution should be conditions and also lesser time consuming, economically efficient and most importantly it should be adaptable to Sri Lankan

1.4 Significance of the Research

Country's mineral potential should be exploited in an optimum manner which will generate maximum benefit to the national economy.

This is a highly important study as this directly affects to the finance body of the country. And based on our suggestions royalty calculation system of Sri Lanka might change totally. Therefore, this research can be a turning point in mining industry of our country and will highly contribute to the national economy.

1.5 Aims & Objectives

- Main objective of the research is to propose an accurate and practical method to evaluate the excavated quantity of the mineral during the time period specified by the regulatory body.
- Introducing a simple-to-Implement methodology of implementation using the state-of-the-art methodology of measurement, calculation and collecting the levy
- Raise the awareness among licensees how the mining royalty is calculated

2   LITERATURE REVIEW

2.1   Introduction

Royalty is a payment made by the licensee to another that owns the particular asset. The royalty is generally progressed with a percentage of revenue or fixed price per unit of an asset. World widely this royalty payments were made by various methodologies. Basically there are 03 basic methods;

- *Unit based (Tonnage based)*

  Assessed on the quantity of mineral produced, mostly applied to high volume, low value homogenous minerals

- *Value based (Ad valorem)*

  These royalties are imposed on the market value of the mineral produced without regard to the costs incurred by the miner

- *Profit based*

  It is a rate assessed on the profit of the operation

This literature review is mainly focused on royalty systems in Asian, African and Australian continents which are highly concentrated with mining industries. Furthermore volume estimation via photogrammetric 3D modelling is also discussed here.

2.2   Sri Lankan Royalty System

2.2.1   Overview

Sri Lankan royalty system can be considered as a combination of unit based and value-based system, and this depends on the commodity. Royalty for industrial minerals are calculated by an equation based on the number of explosives used. Following four categories are used in Sri Lanka when deciding the royalty for a particular mineral;

Table 2-1: Sri Lankan Royalty System

Category	Commodity	Remarks
Explosive Basis	Mostly for *Aggregates*	For both Single-hole, Multiple-hole blasts
Based on the factory letter	Non-Exporting-Industrial Minerals *Ex: Calcite, Mica, Feldspar, Limestone, Kaolin*	Royalty value depends on the industry
Custom Declaration	Exporting – Industrial Minerals *Ex: Graphite, Quartz, Ilmanite, Rutile, Zircon, Dimension stones*	Amount declared by custom is considered to calculate royalty
Based on License Agreement	*Sand, Gravel, Soil*	Maximum allowed monthly production

Explosive basis method is used mainly for *Aggregates* in A, B and C Grade Quarries. It doesn't depend on whether it a single-hole blast or a multiple-hole blast. This method is explained in detail in the problem statement.

For non-exporting industrial minerals such as *Calcite, Mica, Feldspar, Limestone* and *Kaolin* royalty is determined based on the factory letter. GSMB have come to an agreement with them regarding the royalty and those factories will issue a letter mentioning how much of material is extracted each month or quarter. Based on this letter royalty will be calculated. In most cases these factories have their own weighing bridges.

In the Palavi Processing Plant of Siam City Cement (Lanka) Ltd, they have occupied the following method to calculate the daily limestone dispatch from the quarry. Royalty for limestone will be calculated based on this amount. When the train arrives at the plant, first two wagons will be uncoupled from the rest and a shunting locomotive will haul these two wagons to the weighing bridge. The weight of an empty wagon is 9500kg.

Total material weight is calculated as follows; (n - Number of wagons)

$$\text{Total Amount of Limestone} = \left(\frac{\text{weight of 2 wagons}}{2} - 9500 \text{ kg} \right) \times n$$

This process will be repeated for other train trips as mentioned above. Finally, the amount of limestone arrived at plant will be calculated daily. This weight is used for royalty calculations. Furthermore, this is a unit-based royalty system.

3rd Category of calculating royalty is based on the custom declaration. When we export a mineral, all the materials will be properly checked and quantified by the custom. So that no one can provide false data. This will be the best method to calculate the royalty although it is time consuming. Royalty for exporting industrial minerals (*Graphite, Quartz, Ilmanite, Rutile, Zircon, Dimension stones etc.)* are calculated from above method.

In the final category, royalty will be calculated based on the license agreement. Maximum amount allowed for each mineral per month is considered as the amount that they have extracted within a month. And the royalty will be calculated based on this amount. For *Sand, Gravel* and *Soil* royalty will be calculated under this category.

2.2.2   Royalty rates in Sri Lanka

Royalty rates of some minerals in Sri Lanka based on market value of the mineral produced are shown below;

Table 2-2: Royalty Rates in Sri Lanka

Commodity	Royalty rate
Valuable Metal	4%
Industrial Minerals (non-Exporting)	3%
Industrial Minerals (Exporting)	4%
Building Materials	1%
Aggregate (Exporting)	4%
Other Metals	3%

Sri Lanka, 2005, 1992 No. 33 Mines and Mineral Act

2.3   Indian Royalty Regime

Before 2009, India has used two methods to calculate mining royalty as alternatives. They are given below;

   (1) Tonnage based

   (2) Ad-valorem based

Before 2009, nine minerals (Chrysotile Asbestos, Dolomite, Limestone, Lime Kantar, Lime Shell, Monazite, Ochre, Slate and Tungsten) covered tonnage based and remaining minerals covered ad-valorem based. But in 2009 HODA Committee submitted report to government. After the HODA committee submission, some royalty system features of India is changed as given below;

- ✓ Royalty rates for minerals (Amphibole Asbestos, China Clay/Kaolin (including Ball Clay, White Shale and White Clay), Graphite, Iron ore, Quartz, Silica sand, Moulding sand and Quartzite) to be shifted from tonnage basis system of royalty to ad valorem basis.

- ✓ Royalty rates for 9 minerals (Chrysotile Asbestos, Dolomite, Limestone, Lime Kankar, Lime shell, Monazite, Ochre, Slate and Tungsten) has been continued to attract unit of production based royalty, because it was held that shifting over to ad valorem rates for these minerals is not administratively feasible

- ✓ For the base metals (Copper, Zinc, Lead) rates of royalty has been continued to be linked to the international benchmark metal prices

Below table contains main mineral royalty rates in India in 2009;

Table 2-3: Mineral Royalty Rates in India

MINRALS	ROYALTY METHOD in 2009
China Clay/ Kaolin	Crude 8% of sale price on ad valorem basis
Garnet	3% of the sale price on ad valorem basis
Glass sand	2% of London Bullion Market Association price
Graphite	40 % or more fixed carbon -2% of sale price on ad valorem basis
Quartz	15% of sale price on ad valorem basis
Gem	10% of the sale price on ad valorem basis
All other minerals (not herein before specified)	10% of sale price on ad valorem basis

2.4 Royalty Systems in South Africa

In South Africa three royalties have been used so far and the best method is Ad-valorem/ Sales royalty. Those royalty methods are listed below.

- ✓ *Production/ Unit royalty* - Assessed on the quantity (i.e. ounces or tons) of mineral produced, and the value is independent of the commodity price
- ✓ *Profit-based royalty* - Profit-based royalty is a rate assessed on the profit of the operation.
- ✓ *Ad-valorem/ Sales royalty* - The last kind of royalty is assessed on the market value of the mineral produced, and unlike the first kind, it is highly dependent on the relevant commodity price. This is the most common royalty used in Africa

Royalty method of Ad-valorem percentage calculating formula is given below as Finance Management in south Africa, Act, 1999 (Act No 1 of 1999), the formula presently applicable in section 4(2) is as follows;

$$\text{Royalty percentage} = 0.5 + \frac{\text{(earnings before interest and taxes)}}{\text{(gross sales in respect of unrefined mineral resources x 9)}} \times 100$$

9

In terms of section 4(3) (b), the percentage determined in terms of the formula must not exceed 7%.

Below table includes royalty rates of different countries for *Base Metals* and *Precious Metals*;

Table 2-4: Royalty Rates in Different Countries

Countries	Enactment Year of the Mining/ Mineral Code/ Legislation	Royalty Rates	
		Precious Metals	Base Metals
Botswana	1999	5%	3%
Burkina Faso*	2003	3%	5%
Cameroon§	2001 (amended 2010)	2.5%§	
Central African Republic	2010	3%	4%
Congo, Democratic Republic of	2002	2.5%	1%
Congo, Republic of	2005	5%	3%
Gabon	2000	4% to 6%	
Ghana**	2006 (amended 2010)	5%	
Guinea	1995	5%	3.5%
Ivory Coast	1995	3%	
Liberia	2000	3% - 10%	
Mali	1999	3%	
Mauritania	2008	4%	2%
Morocco	2005	3%	
Namibia	1992	3%#	
Niger	2006	5.5%	
Nigeria†	2007	Not specified	
Senegal	2003	3%	
Sierra Leone	2009	5%	3%
South Africa	2004 (royalty added 2008)	0.5% - 7%	
Tanzania	2010	4%	3%
Uganda	2003	3%	

2.5   Australian Royalty System

2.5.1   New South Wales

A mineral royalty is an amount charged by the country for the transfer of the privilege to extract a mineral resource. There are mainly three type of royalty system has been occupied in Western Australia. Such as coal royalties, mineral (non-coal) royalties and petroleum royalties. Mineral royalty can be divided into two main groups and the royalty rates are recommended under the Mining Act 1992 in NSW.

- *Quantum Royalty* (unit based)

  The royalty system based on the unit of production basis and generally applied for the low volume of minerals such as gypsum limestone, and clays.

- *Ad-valorem Royalty* (value based)

  The royalty system generally applied for high volume minerals. That system based on 4% rate of the ex-mine value of minerals. Ex-mine value is the value of the mineral once it is mined and brought to the surface. Sometimes the expenses related to the processing it may be allowable deductions. And also, costs associated with the exploration, development, and rehabilitation of the site are not considered as allowable deductions.

	Quantity Tonnes	Amount $
Export Sales	0	0
Local Sales or other disposals	7,500	150,000
Total value of disposals	**7,500**	**150,000**
Plus value of closing stock	300 @ $20	6,000
(finished product at last sale price or ruling spot price, whichever more closely reflects the realisable value of the stock)		
Less value of opening stock	500 @ $15	7,500
(as per previous return)		
Gross value of mineral recovered	**7,300**	**148,500**
Amount of royalty payable (at 35 cents per tonne)		**2,555**
Export Sales	4,500	2,600,000
Local Sales or other disposals	3,500	2,000,000
Total value of disposals	**8,000**	**4,600,000**
Plus value of closing stock	250	137,500
(finished product at last sale price or ruling spot price, whichever more closely reflects the realisable value of the stock)	@ $550	
Less value of opening stock	500	312,500
(as per previous return)	@ $625	
Gross value of mineral recovered	**7,750**	**4,425,000**
Less Allowable deductions -		
• Onsite treatment expenses		1,500,000
• Realisation expenses		50,000
• one-third of onsite administration expenses		65,000
• Depreciation		
▪ Treatment Plant	885,223	
▪ Tailings Dams	148,833	
▪ Component of asset attributable to treatment and realisation:		
○ Workshop	3,938	
○ Motor vehicles	15,541	
○ Buildings	15,101	1,068,636
Total allowable deductions		**2,683,636**
Ex-mine value		**1,741,364**
Amount of royalty payable (at 4%)		**69,654.56**

Figure 2-1: Royalty Calculation Method in NSW

2.5.2 Western Australia

Royalties prescribed under the Mining Act 1904 and Mining Act 1978, as well as under state agreements. In Western Australia, two main type of royalty system has been used. There are *Specific Rate Royalty* and *Ad-valorem Royalty*. In some cases, they have used a *Netback Royalty* system.

Specific Rate Royalty system applies to the low value of materials such as clay, gypsum, and sand, also apply to some industrial minerals, such as salt and talc. Royalty is calculated by applying a rate to each ton produced. For an example, the rates of 62 cents and $1.00 per ton apply in Western Australia.

Ad-valorem Royalties apply to metallic minerals and generally higher value industrial minerals. The royalty is calculated as a percentage of sale value or metal value. There are three ad valorem rates, which can be used in Western Australia. Those are express as, 7.5% applies to bulk material, 5% for mineral concentrates and 2.5% for minerals in metal.

Netback royalty system calculated by applying a rate to the value of minerals, when they first extracted from the ground. It is based on the mine head value of the owner and this system is mainly used in petroleum industry.

2.6 Photogrammetric 3D Modelling

'Photogrammetry', as its name indicates is a 3-dimensional coordinate assessing technique that uses photographs as the major medium for measurement. The ultimate principle used by photogrammetry is triangulation or more precisely termed as 'Aerial Triangulation'. By capturing minimum two photographs from two different locations, the line of sight can be developed from each camera to points on the object. These lines of sight commonly termed rays are precisely intersected to produce the 3-dimensional coordinates of the points of interest.

In a very simple manner photogrammetry involves the inverse practice of photography. In photography, a camera projecting the 3D world into a 2D plane (image negative). In photogrammetry, multiple photos which represents the object from various lines of sight are used to reproduce the 3D world it was originally projected from.
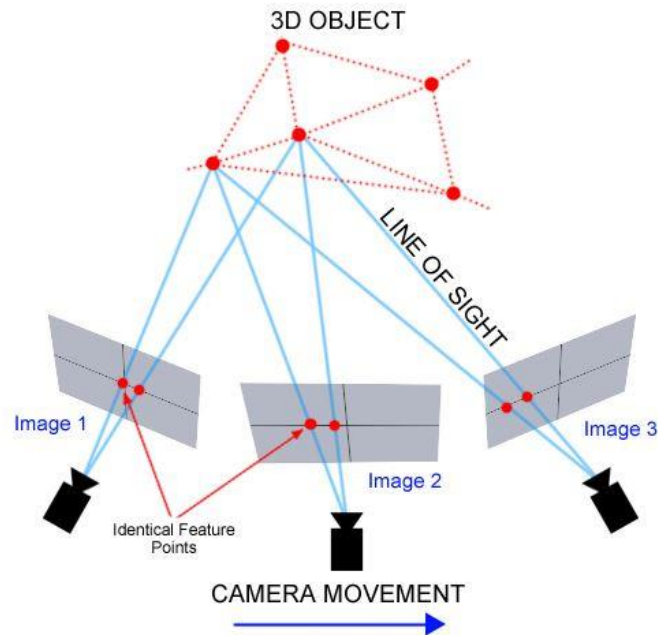
Figure 2-2: Concept of Photogrammetry

2.6.1   Techniques and Methodologies

The generation of 3D models based on the actuality of large and complex sites or structures is currently carried out using passive sensor and image data methodologies, active optical sensors, and image data. Distance, conventional surveys (e.g. total stations or GNSS) or integration of the above techniques. For architectural engineering and the construction industry, 3D geometric models can also be created from existing 2D drawings or maps, interactively and using extrusion functions. The choice or integration depends on the accuracy required, the dimensions of the site and the object, the constraints of the location, the portability and the user-friendliness of the instrument, the characteristics of the surface, experience of the work team, project budget, end goal etc.

Active optical sensors, such as laser scanners (pulsed, phase shift or triangulation instruments) and tape projection systems, have received a lot of attention in recent years for 3D documentation and modeling applications.

They directly provide ranges (for example, distances and thus 3D information in the form of unstructured point clouds) and become quite general in the heritage field, despite their high costs, weight and usual lack of texture satisfactory. For surveying, the instrument should be placed in different places where the object is moved so that the instrument can see it from different points of view. Successively, raw data requires the removal of errors and outliers, noise reduction and sometimes the filling of holes before alignment or registration in a single reference system to produce a single point cloud of the scene or object studied. Recording is usually done in two steps:

1) Manual or automatic gross alignment using targets or data
2) Final global alignment based on the closest point method procedures. Or least squares.

After global alignment, redundant points must be removed before a surface model is produced and textured.

The scanning results are a function of:

- Intrinsic features of the instrument (calibration, measurement principle, etc.)
- Features of the scanned material in terms of reflection, light diffusion, and absorption (amplitude response)
- Features of the working environment
- Coherence of the backscattered light (phase randomization)
- Dependence from the chromatic content of the scanned material (frequency response)

Terrestrial range sensors operate from very short range (a few centimeters) to a few kilometers, according to surface properties and environmental characteristics, providing 3D data with positioning accuracy ranging from a few hundred microns to a few millimeters. Distance sensors, associated with GNSS / INS sensors, can also be used on aerial platforms in general for DTM / DSM generation, city modeling and archaeological applications. While conscious of the potential of the image approach and its latest improvements in automated and dense image matching, the ease of use and reliability of active optical sensors for point cloud acquisition amorphous and dense are usually much higher.

This fact has made active sensors such as laser scanners a very common 3D recording solution, especially for non-trained users. Active sensors regularly also include radar instruments, which are not generally seen as optical sensors. However, they are frequently used in 3D documentation or environmental mapping of cultural heritage.

Under other conditions, image data requires mathematical formulation to transform two-dimensional image measurements into three-dimensional coordinates. Image-based modeling techniques (mainly photogrammetry and computer vision) are commonly chosen in the case of lost objects, monuments or architectures with regular geometric shapes, low budget projects, good experience of the work team or time or place limitations for the data acquisition and treatment. In addition, the images have all the information needed to acquire the 3D shape of the scene studied as well as its graphic aspect (texture). Image-based 3D modeling usually requires user interface at various stages of the modeling pipeline to obtain exact results, its use being kept for experts, while fast 3D results are primarily useful for simple visualization. Commonly, minimum two images are required to derive 3D information from the corresponding image points, but there are also some ways for developing 3D data from a single image.

2.6.2   Steps in generation of a 3D model using photogrammetry

2.6.2.1   Data acquisition

This can be any type of camera with geo-referencing if the final output is to be measured in metric units. Even a camera without geo-referencing option can be coupled to a GNSS receiver to collect geo located images. Thus, even smart phones with the availability of GPS location are a viable option for data acquisition.

With the evolving improvement of drones as a remote sensing platform, photogrammetry has also made great steps in eliminating the biggest problem of photogrammetric data acquisition, namely the collection of data at higher altitudes. This has expanded the ability of photogrammetry to be used in larger scale objects, such as open pit modeling, which was originally limited to a smaller object, such as a car, a statue or a man.

2.6.2.2 Data processing

After the data acquisition, the collected data is processed using computer vision algorithms for aero-triangulation, point cloud generation and finally the 3D mesh generation. This 3D mesh can then be used for linear measurements (length, height, width, etc.), area measurement and volume measurement.

2.6.2.3 Calculating depleted rock volume using Pix4D and OpenDroneMap

2.6.2.3.1 Pix4D Mapper

Pix4Dmapper spontaneously transforms images taken by drone, by hand or by plane and provides 2D maps and very accurate and geo-referenced 3D models. They are customizable, timely and complete a wide range of applications and software. This can be used to calculate the volume difference of a studied area at two points in time. The images of each flight must be processed in a separate project, in which the volume of the area at that moment is calculated. Then, the results of these calculations can be used to calculate the difference in volume of a zone.

CAPTURE   PROCESS   ANALYZE

Figure 2-3: Pix4D Process

CUT BEFORE ➡ CUT AFTER
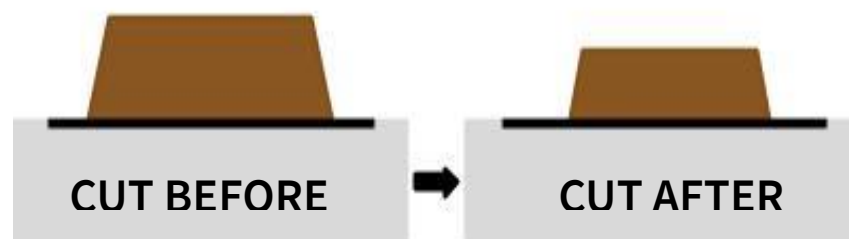
·   *Figure 2-4: Depletion of the Volume*

Volume Difference = Cut After - Cut Before.

If the volume difference has a negative value, then material has extracted.

Figure 2-5: Volume Calculation

2.6.2.3.2 Open Drone Map

The volume calculations between the base-plane and the terrain surface of your area of
interest is given in terms of the volume that would need to be removed (in the case of a
stockpile) and/or added (in the case of a hole) in order to flatten the surface so that it's
the same as the surrounding ground.
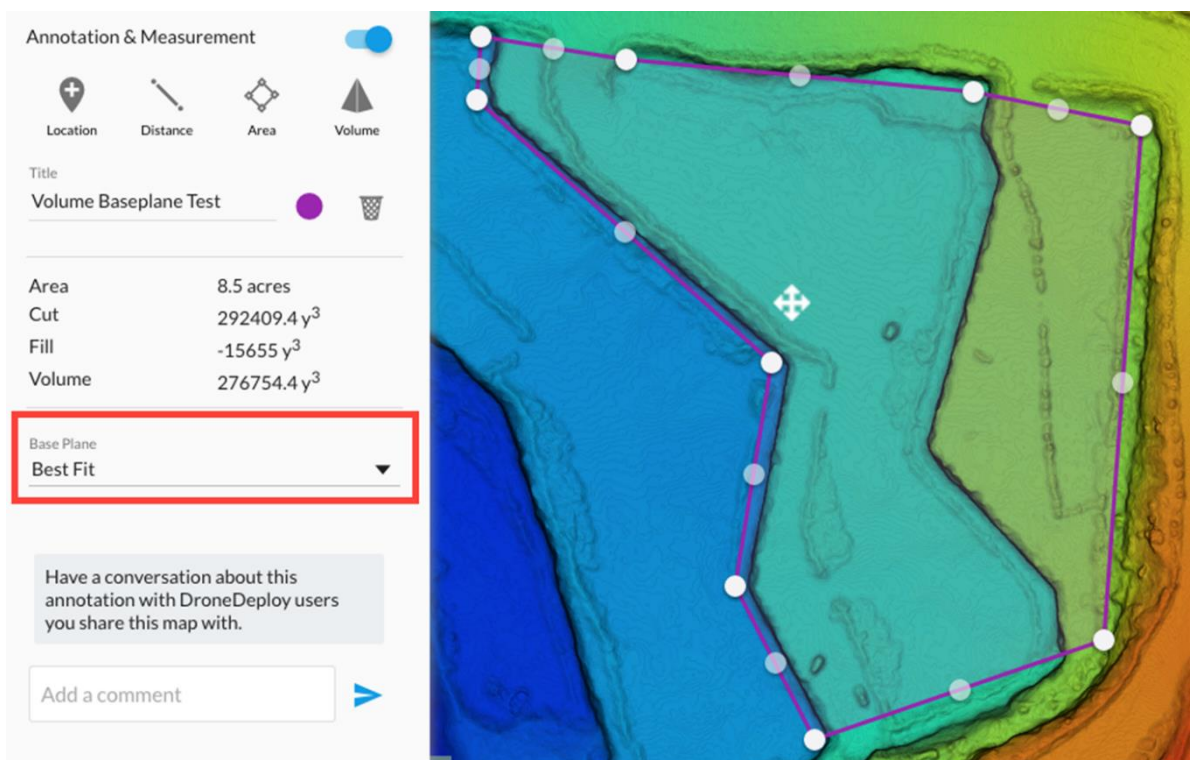
Figure 2-6: Volume Calculation using Open Drone Map

2.6.3   Significance of Photogrammetric 3D modelling

In most practical applications, the making of digital 3D models of quarries or sites for documentation and preservation requires a technique or methodology that has the following properties:

- ✓ *Accuracy*: precision and reliability are two vital aspects of the surveying work and final 3D outcomes, if not the work is done for simple and quick visualization
- ✓ *Portability*: the technique must be as portable as promising due to accessibility problems, absence of electricity, location constraints, etc.
- ✓ *Low cost*: generally surveying projects have limited budget to perform and expensive documentation and instruments will cost more than the budget
- ✓ *Fast acquisition*: most of the sites or quarries allow a limited fly time for the drone` and documentation not to disturb restoration works or the visitors;
- ✓ *Flexibility*: due to the great diversity and dimensions of sites and objects, the technique should allow different scales and it should be applicable in any possible condition.

All these are often not applicable to a specific procedure. As a result, most survey projects related to large and complex sites (Quarries) integrate and combine multiple sensors and techniques. However, the image-based approach has different advantages over the beach-based approach and is often chosen although it sometimes necessitates user interaction and some knowledge with acquisition and data processing.

2.7   Multicopter UAV and Total Station for Estimating Stockpile Volumes

There are several UAV systems on the market place today for commercial applications, including multicopter or multi-engine UAVs. Their main benefit is ease of use, flexibility and stability. The modern prototypes offer a load of up to 5 kg and can contain complex and heavy surveying systems, such as single-lens reflex cameras. The commonly used multicopters have at least four rotors, i.e. a quadricopter, but may have a hexacopter or an octocopter for redundancy purposes.

2.7.1 UAV Photogrammetry

The use of UAV Photogrammetry gives a real time application and low-cost substitutions to the manually driven aerial photogrammetry. The pixel value of multicopter UAV can be less than 5cm x 5cm (at altitude level of 20-30m). Through this 3D model or DSM can be generated. For the data acquisition purpose DJI phantoms can be used here.

2.7.2 Volume Estimation

To obtain stock volume values, initially images has to be adjusted with GCP. These points were the same geo-referenced points (with GNSS) around the stock that has been use to organize the TST. Then the Pix4D software to estimate the volume. Initially a stockpile object should be drawn then the tie points of the stockpile base has to be changed to 3D GCPs. The altitude of the 3D GCPs has to be changed to the desired altitude of the volume base. And for the new volume calculation *raycloud* should be opened and stockpile object must be selected.

Figure 2-8: UAV Point Cloud with stockpile drawing top view
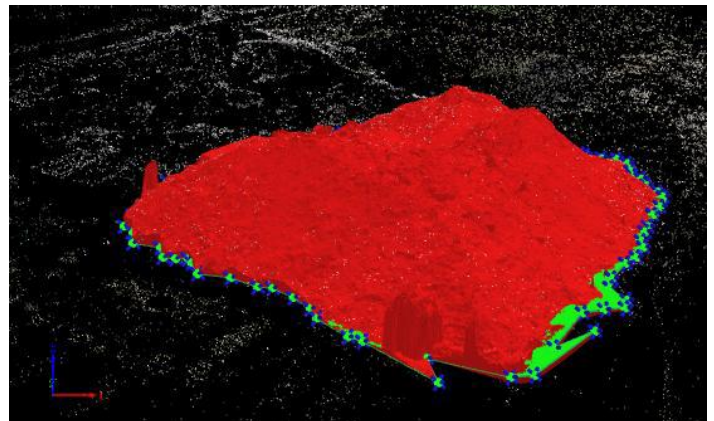
Figure 2-7: UAV Point Cloud with stockpile 3D view

2.8   Conclusion

All of these above methodologies are based on royalty systems which are followed in many countries worldwide. As was mentioned in previous sections, Sri Lankan system is an explosive based royalty calculation method with a high error. It is not practical to practice ad-valorem or tonnage based methods in Sri Lanka with the existing technologies due to the impracticality of obtaining accurate basic information and lack of a reliable monitoring and tracking system. Therefore, in this research, in the methodological approach presented below in the form of a flow-chart, adoption of 3-D modeling I shown conducting relevant field studies.

3 METHODOLOGY

3.1 Area of Study

"A Grade" metal-quarry located approximately 25km away from the Kalutara has been selected. The site surveyed was approximately 5km^2 of area with vegetation, steep and rough faces as well as a typical open quarry environment. The site chosen is a 25 m section of the quarry site. The site was selected to evaluate the suitability of the UAV for calculation of rock volumes. The main objective of the survey is to estimate the volume of in situ rock. Surveying is a necessary activity to determine the elevations, distances, and angles for a specific area.
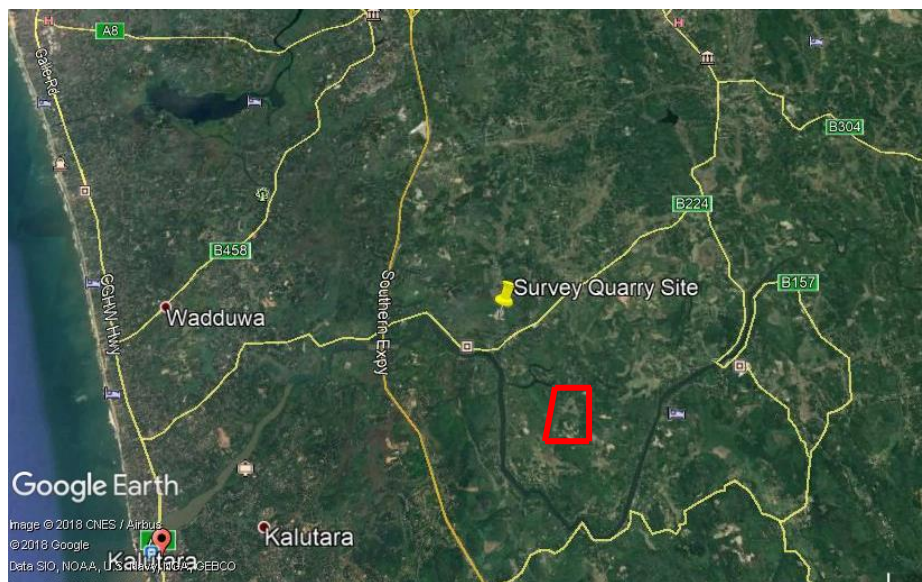
Figure 3-1: Location of the Quarry Site

3.2 Weighing the Blasted Rock Tonnage

3.2.1 Overview

This can be considered as one of the most accurate methods in determining the depletion of a rock. The issue with this method is we must need a weighing bridge to measure the tonnage. It's not practical to have a weighing bridge for each and every quarry in Sri Lanka. However, this method will provide an accurate value for the blasted volume than other methods as we are directly measuring the tonnage.

3.2.2 Swell factor

One cubic meter of earth material measured in the natural position (in situ) swells to more than one cubic meter after it is excavated. The swell factor used to calculate the volume increase. Because it is void spaces increase. It is can be expressed as a percentage to the natural volume.

$$Swell\ Factor = {Loose\ or\ Bulk\ Volume}/{Insitu\ Volume}$$

Our surveyed rock is Charnockite which swells factor normally calculated as the value of 75-80%. However mass of the rock will not change in bulk form.

3.2.3 Calculation of the depleted volume

Here are the steps to calculate the depleted volume using blasted tonnage;

$$Total\ Tonnage\ Hauled$$

$$= Total\ Number\ of\ Loads\ \times Average\ Tonnage\ per\ Load$$

$$Insitu\ Volume = {Insitu\ Mass}/{Insitu\ Density}$$

However in most cases, In-situ Mass = Bulk Mass = Total Tonnage Hauled. Therefore;

$$Insitu\ Volume\ or\ Blasted\ Volume = {Total\ Tonnage\ Hauled}/{Specific\ Gravity}$$

3.2.4 Determination of specific gravity of the rock

Specific gravity was calculated on site with a simple experiment;
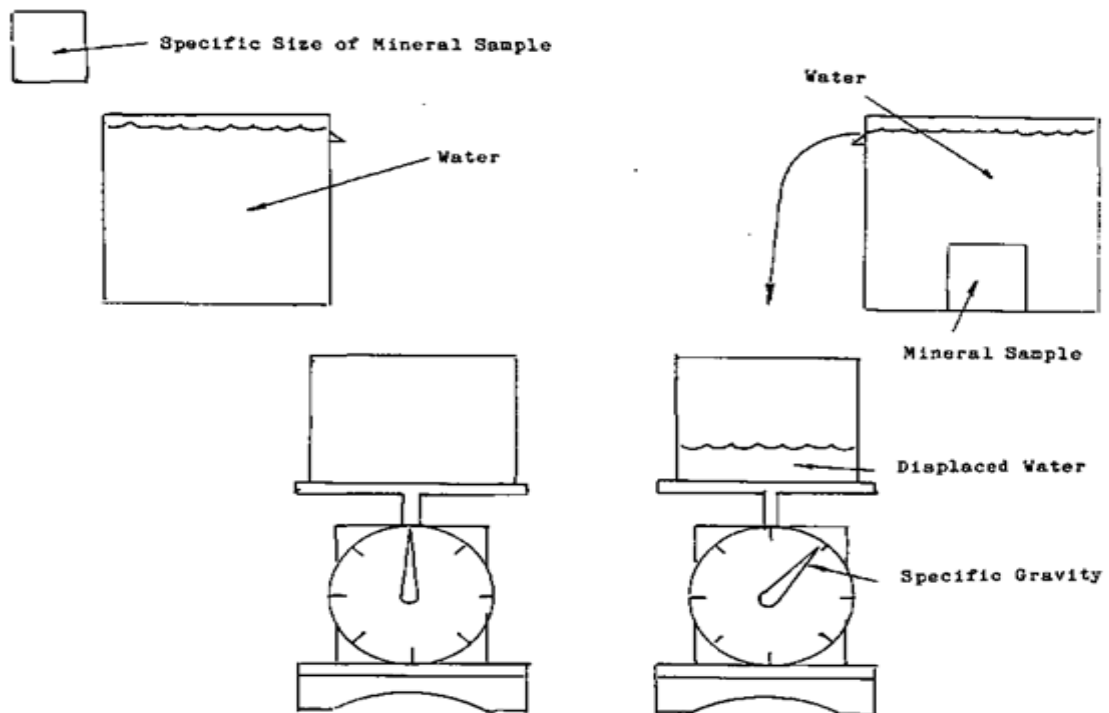
Figure 3-2: Determination of Specific Gravity

1) Approximate 1kg of in-situ rock sample was obtained and weight of the rock piece in the air was measured using electronic balance. (W1 = 1.115kg)
2) Water was filled to 3/4 volume of the beaker and a small hole was created just above that level so that excess water would flow outside.
3) Then the rock piece was put into the beaker.
4) Weight of the outflowing water was recorded. (W$_2$ = 0.410kg)
5) Finally specific gravity of the rock was calculated as below; (g = 9.81ms^{-1})

$$Specific\ Gravity$$
$$= {Weight\ of\ the\ substance} / {Weight\ of\ the\ equal\ volume\ of\ water}$$
$$= {1.115g} / {0.410g} = 2.7195$$

Wimal Quarry administration have measured the specific gravity of the rock (in a laboratory) in 2016 and that was 2.737 which is really close to our value. As we measured this value on site, we decided to use their value as the correct specific gravity for our calculations.

3.3   Total Station Survey at Metal Mix Quarry Site

3.3.1   Overview

Total station can determine the coordinate of an unknown point relative to the known coordinate. Using the trigonometry and triangulation, 3D coordinate of the point was measured is determined. Survey data was downloaded to the computer for the processing purposes and we have generated 3D model by using AutoCAD software. The accuracy of the coordinate is for mm level. But when the survey area becomes large it can result in some issues of accuracy. As most of Sri Lankan quarries do not have a proper bench system. Although A Grade quarries have some benches, B and C Grade quarries doesn't have a proper bench system.

3.3.2   Specification of the total station

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

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

3.3.3   Distance measurement

First step of the total station survey was find a suitable location (spot) one processing sight lines to all major point and solid ground. Total station generated laser that reflected by a prism reflector. Modulation pattern in the returning signal is read and interpreted by the computer in the total station. The distance is determined by emitting and receiving multiple frequencies and wave length.

The distance measured is always sloping direction from instrument to the object. The accuracy of measurement varies from 5mm to 10mm per km measurement.

3.3.4 Angle Measurement

When taking the horizontal angle, we can get measurement to any convenient direction as reference direction. In our case we have taken measurement with respect to the north direction. Angle measurement accuracy varies from 2 to 6 seconds.

3.3.5 Measuring pre-blast and post blast faces

3.3.5.1 Pre-blast rock face

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

3.3.5.2 Post blast rock face

After the blast, surrounding area near the rock face was cleared. Then we have taken several readings from top and bottom surfaces of the post blast face using both prism and non-prism modes.

3.4 Drone Image Processing using Agisoft PhotoScan

Following steps are followed in order to get a product using Agisoft PhotoScan;

1) Loading photos
2) Aligning photos
3) Building Dense Point Cloud
4) Building Mesh
5) Building Model Texture
6) Building Tiled Model
7) Building Digital Elevation Model (DEM)
8) Building Orthomosaic

Here are the steps to carry out a volume calculation using Agisoft PhotoScan;

3.4.1 Loading photos

To load a set of photos

Select *Workflow menu → Add Photos* or click *Add Photos* toolbar button on the Workspace pane.

Then select the photos or photo directory and click *Open* button. Selected photos will appear on the Workspace pane.

3.4.2 Aligning photos

In this step all photos are aligned and properly oriented. Software builds a *Sparse Point Cloud* after finding the camera position and orientation of each photo.

Select *Workflow menu → Align Photos*

Here we have used the *Medium Accuracy* settings for most of our models as *High Accuracy* settings are time consuming. Anyway we can reduce the processing time by utilizing *Pair Selection* option.
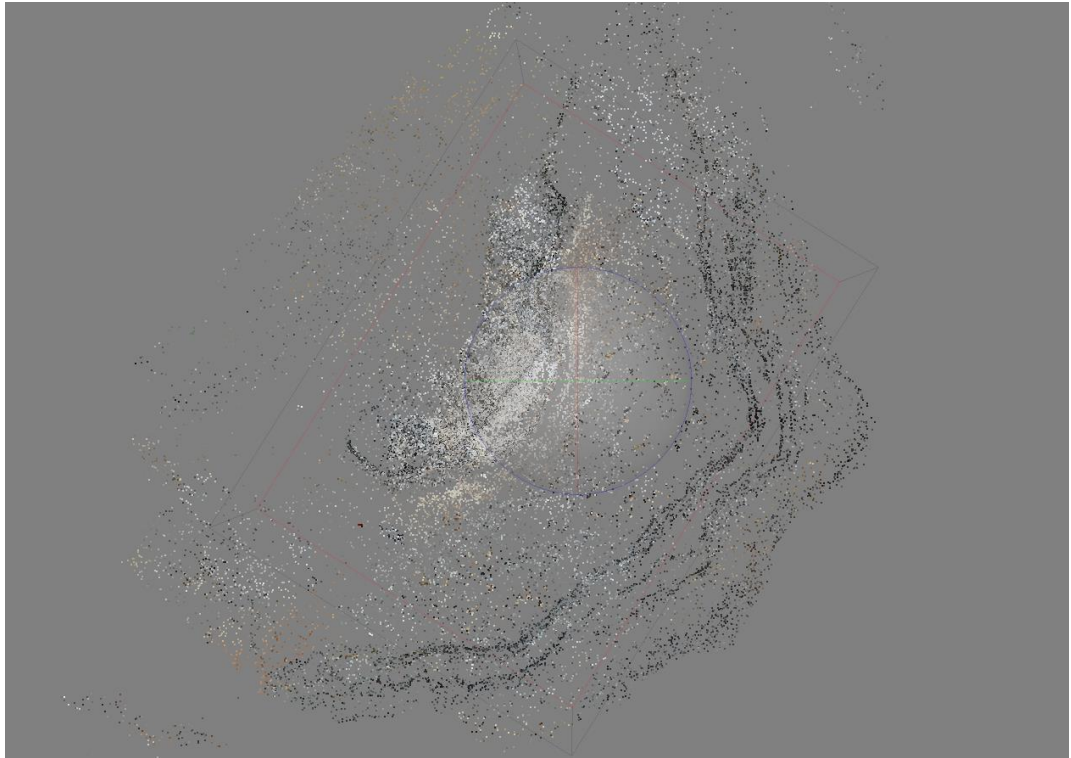
Figure 3-3: Sparse Point Cloud

3.4.3 Building Dense Point Cloud

Program combines depth information which have been obtained from all the cameras to a single *Dense Point Cloud.* We can adjust the position of reconstruction volume bonding box depending on our region of interest.

Select *Workflow menu → Build Dense Cloud*

Like in the aligning step we selected *Medium Quality* as it consumes less time, but it is better to select *High Quality* for more detailed and accurate geometry.

In the *Depth Filtering Modes,* we have to select different modes based on our requirement;

- *Mild –* If there are small details (which can be spatially distinguished) that we need to reconstruct.
- *Aggressive -* If area doesn't contain any meaningful small details
- *Moderate –* To get intermediate results
- *Disabled –* This mode is not recommended
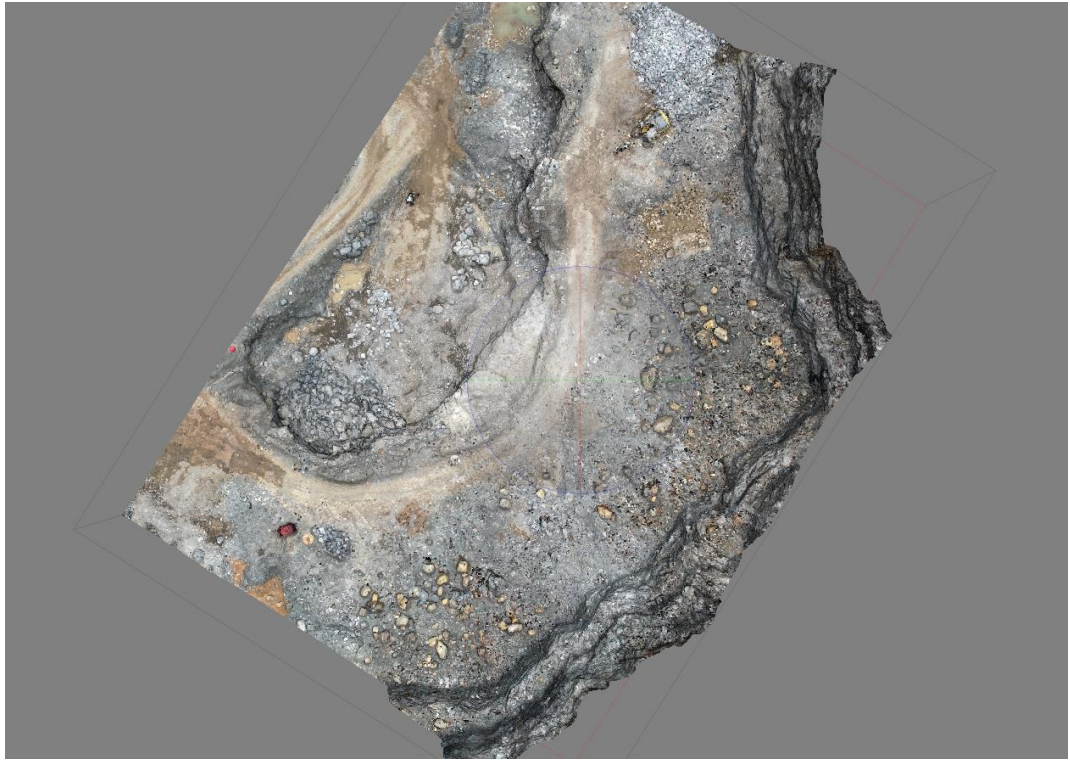
Figure 3-4: Dense Point Cloud

3.4.4   Building Mesh

Mesh is a collection of vertices, edges and faces that defines the shape of an object or a model. Here we have selected *Dense Point Cloud* as the source for the *Mesh*.

Select *Workflow menu → Build Mesh*

3.4.5   Building Model Texture

Even though we get considerable appearance after generating *3D Model*, we will get better appearance for the model after building *Model Texture*.

Select *Workflow menu → Build Texture*

3.4.6   Building Tiled Model

This is an additional feature for our project. We can obtain large area 3D models in high resolution using this option.

Select *Workflow menu → Build Tiled Model*

3.4.7 Building Digital Elevation Model (DEM)

This is one of the most important steps in calculating the volume of a feature using Agisoft PhotoScan. To calculate the volumes in Agisoft, we can use only the DEM (Digital elevation Model) or the Orthomosaic.

Select *Workflow menu → Build DEM*
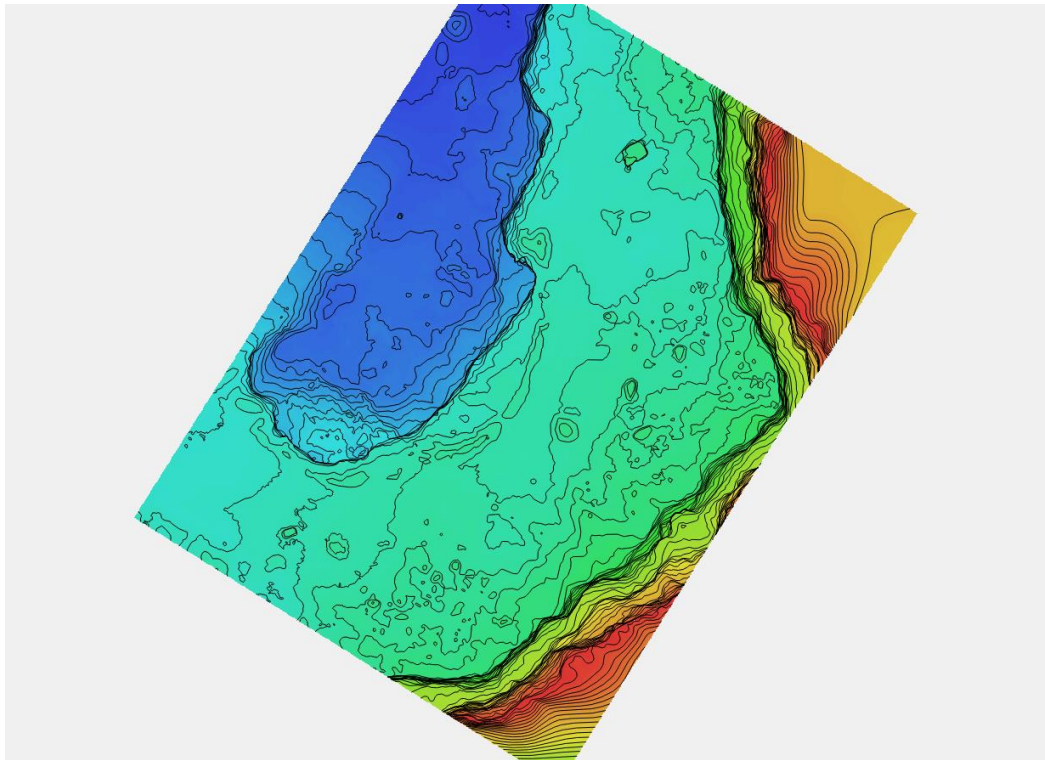
Figure 3-5: DEM (Contours at 0.5m Intervals)

3.4.8 Building Orthomosaic

The orthomosaic or the orthophoto is the best source to calculate true length, area and volume information. What we get from an aerial photograph is not an accurate representation of the earth's surface. In orthomosaic errors due to topographic relief, lens distortion and camera tilt are adjusted.

Select *Workflow menu → Build Orthomosaic*
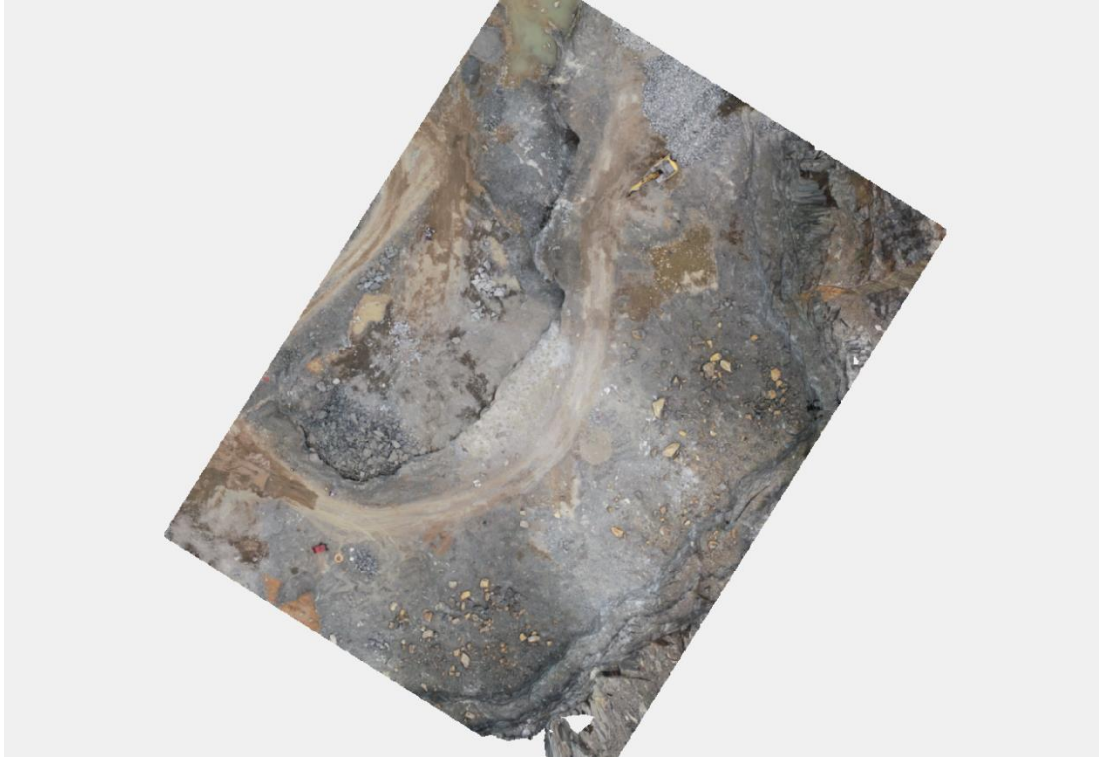
Figure 3-6: Orthomosaic or Orthophoto

An orthophoto or orthomosaic is an aerial photograph geometrically amended such that the scale is uniform, the photo has the same lack of distortion as a map. Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances, because it is a precise representation of the earth's surface, having been adjusted for topographic relief, lens distortion, and camera tilt.

Finally we have obtained following outputs using Agisoft PhotoScan software;

1) Pre Blast Face – Medium Quality

2) Pre Blast Full Quarry – Medium Quality

3) Post Blast Face – Medium Quality

4) Post Blast Full Quarry – Medium Quality

5) Post Blast Face – High Quality

3.5 Drone Image Processing using Bentley ContextCapture

Bentley ContextCapture is another 3D mesh generating software which has better capabilities than other softwares. Speciality with ContextCapture is we don't need build an orthomosaic or a DEM to do volume calculations. We can do it using the *3D Mesh*. Procedure for generating a *3D Mesh* using Bentley ContextCapture is as follows.

First we have created a project;

> *Project → New Project*

Now we can create any number of blocks under this project. For an example one block for pre-blast and another block for post blast etc. So we have added a block.

> *Block → New Block*

After creating a block next step is to add the photos, the *Add Photos* button was clicked.

> *Photos → Add Photos*

After uploading photos to the ContextCapture if there are any incomplete photos, we can estimate the missing information by *Aerotriangulation*. In the General tab we can find the Submit Aerotriangulation button.

> *General → Submit Aerotriangulation*
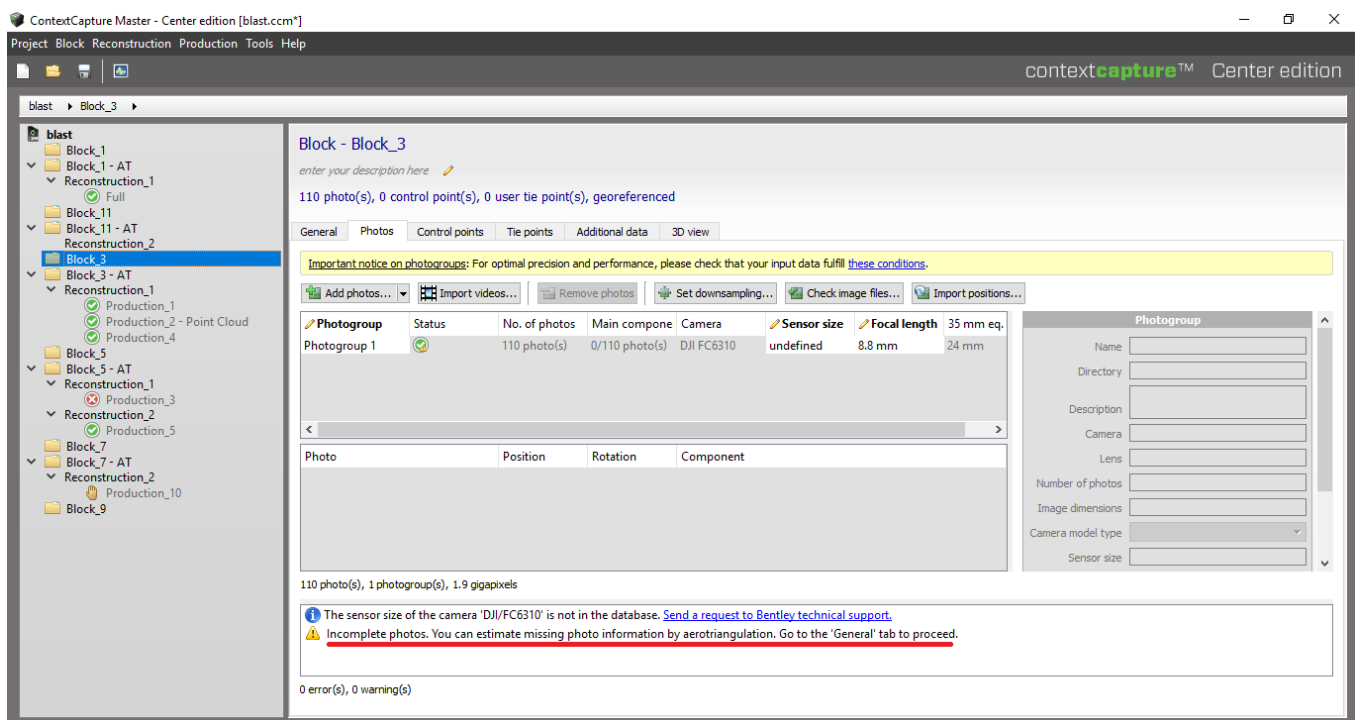
Figure 3-7: After Adding Photos to the Block

Next comes the Reconstruction step; we have divided the model into *Tiles,* otherwise it will take a higher time to generate the 3D mesh and sometimes software will ask for higher RAM capacity. Under the *Spatial framework* tab we have changed the tiling option to *Regular planar grid* in most cases. So that software will decide how many tiles that are needed to generate the *3D Mesh.* And we have used the *Medium Precession* setting for reconstruction due to the limited time.

General → New reconstruction

Figure 3-8: Submitting New Reconstruction

Next comes the most important step in *3D Mesh* generation, which is submitting the new production. Importance in Bentley ContextCapture is we don't need build dense cloud and generate mesh, we can directly generate the *3D Mesh.* Also we can incorporate this 3D Mesh for volume calculation work.

General → Submit new production

3.6   Drone Deploy Volume Calculation

3.6.1   Overview
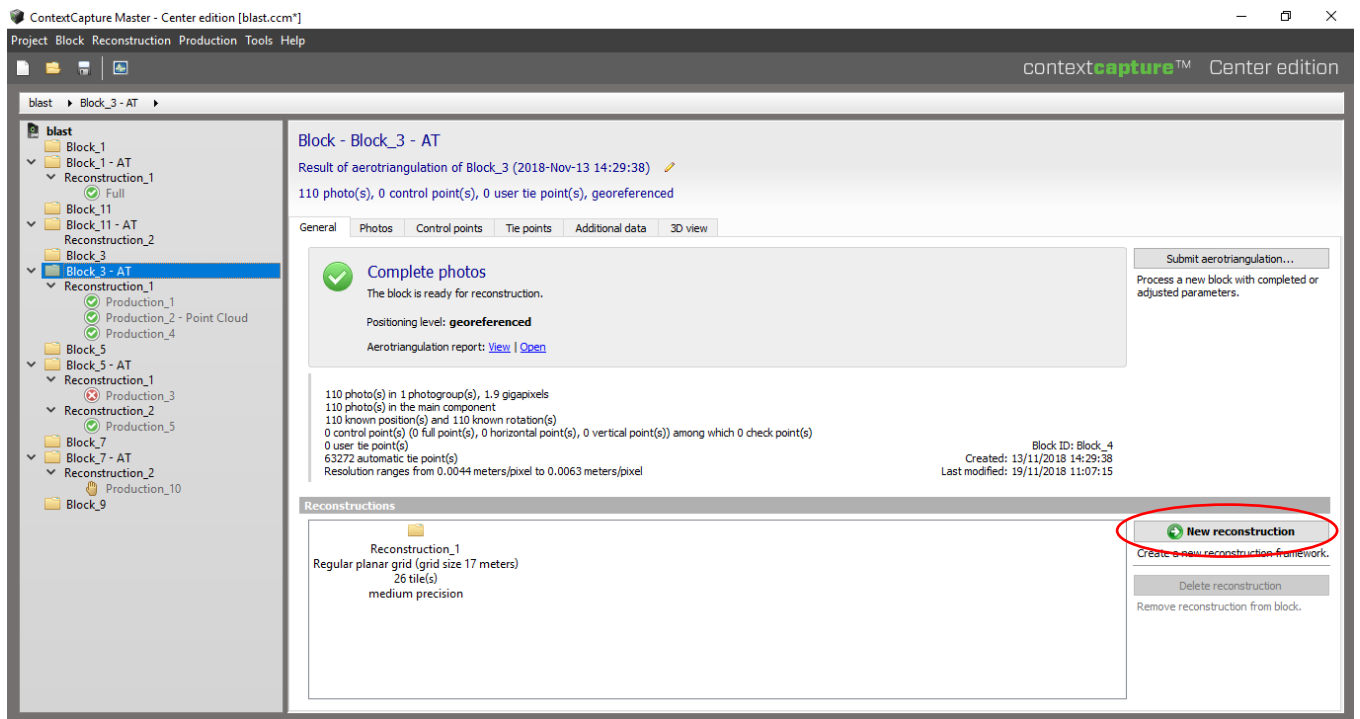
Volume estimation with DroneDeploy is a fast, accurate and practical to calculate the volumes on the maps from any device. DroneDeploy mainly used in mining industry various cases such as site survey and inspection, to equipment tracking and fragmentation analysis. DroneDeploy's volume estimations are accuracy level 1-2%. We did all data analysis using the 14-day trial of Drone Deploy Pro online version. Trial limited to 10 maps and models. The DroneDeploy software app automates the flight path of the drone and capture the aerial images. The DroneDeploy software platform used to processes the UAV images using the computer version. After that we can get 2D, 3D maps and models.

3.6.2   Measuring the volume using pre-blast and post blast models
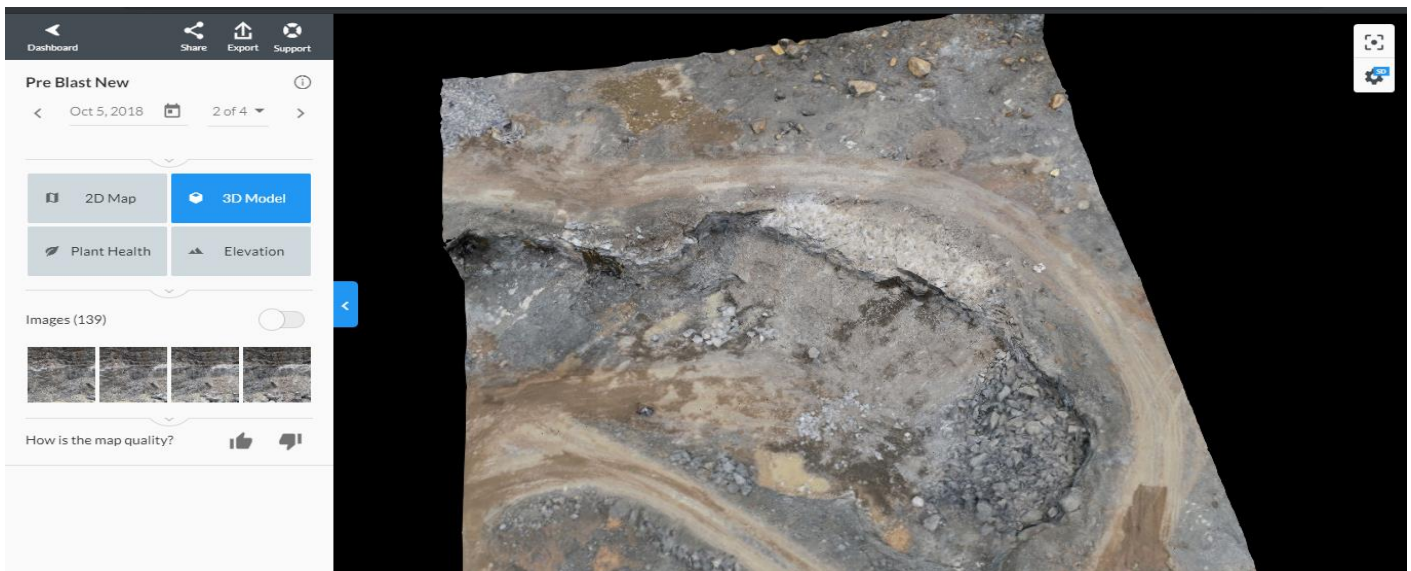
Figure 3-9: 3D Model of the Pre-Blast Quarry

Post Blast volume measurement by using Drone deploy software;

1) First need to select an area for which to compute the volume in the model
2) The *Volume* icon from the *Annotation & Measurement* space was chosen
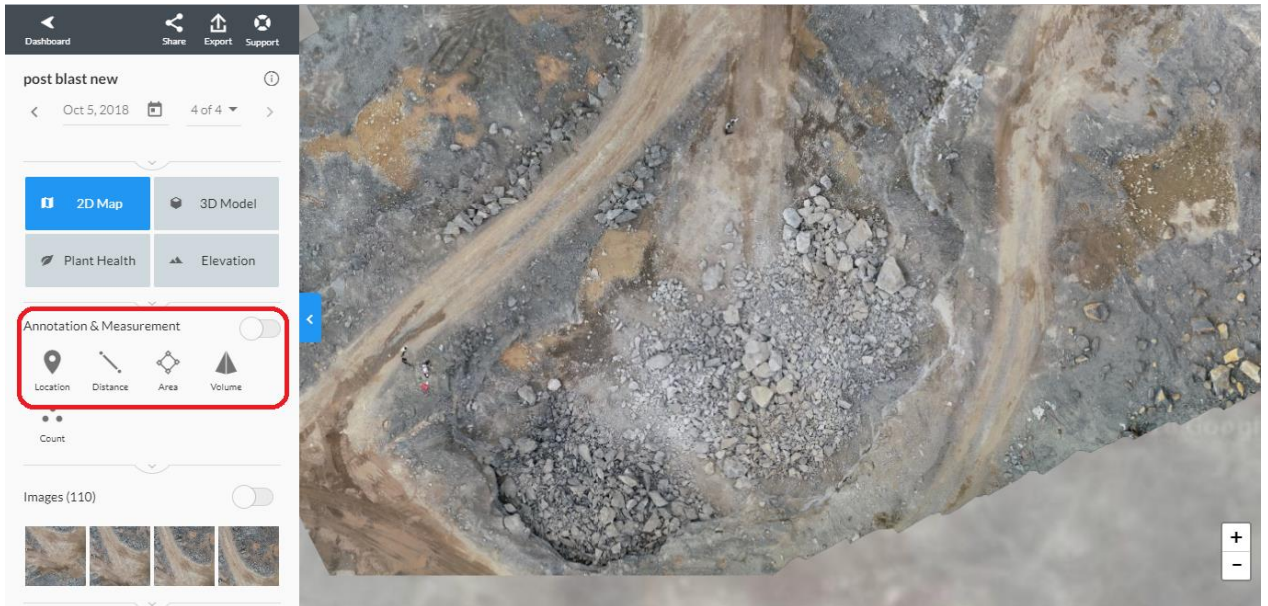
Figure 3-10: Post Blast 3D Model

3) The points were added around the rock pile to mark the polygon which we
   wanted to compute the volume

Figure 3-11: Drawing the Polygon around the Rock Pile

4   RESULTS & INTERPRETATIONS

4.1   Volume Measurement by Weighing the Blasted Tonnage

- Total Number of Loads = 75

- Average Tonnage per Load = 10.212 tonnes

- Specific Gravity of In-situ Rock = 2.737

$Total\ Tonnage\ Hauled$

$$= Total\ Number\ of\ Loads\ \times Average\ Tonnage\ per\ Load$$

$$= 75\ \times 10.212 = 765.9\ tonnes$$

$Insitu\ Volume\ or\ Blasted\ Volume =$

$Total\ Tonnage\ Hauled / Specific\ Gravity = 765.9 / 2.737 = 279.832\ \text{m}^3$

4.2 Measuring Rock Depletion using Total Station

4.2.1 Pre-blast survey data

Date: 2018.10.05

Time: 10:11am

Instrument/ Base Point coordinate: (1000, 1000, 100)

Instrument height: 1.57m

Brand: Leica flex line Ts02/Ts06/Ts09

Table 4-1: Pre-blast Survey Data

Point No	Easting Coordinate(m)	Northing Coordinate(m)	Height (m)
1	1043.713	1008.106	100.290
2	1041.604	1007.716	97.015
3	1039.537	1001.511	100.695
4	1036.241	1001.385	96.611
5	1037.560	998.031	100.771
6	1033.293	998.248	96.797
7	1033.758	994.126	100.975
8	1031.116	994.586	96.736
9	1031.606	991.034	100.603
10	1029.031	991.764	97.067
11	1028.656	988.816	100.854
12	1026.618	989.612	97.908

4.2.2 Post blast survey data

Date: 2018.10.05

Time: 2:00pm

Instrument coordinate: (1000, 1000, 100)

Instrument height: 1.46m

Brand: Leica flex line Ts02/Ts06/Ts09

Table 4-2: Post Blast Survey Data

Point No	Easting Coordinate(m)	Northing Coordinate(m)	Height (m)
1	1043.324	1006.416	100.468
2	1041.866	1006.199	97.668
3	1043.236	1002.202	100.624
4	1042.838	1002.181	97.830
5	1041.203	999.593	100.069
6	1034.638	999.818	98.511
7	1036.947	993.921	100.953
8	1036.892	993.942	98.312
9	1034.151	990.140	100.179
10	1033.548	990.328	97.595
11	1029.779	987.535	100.809
12	1026.302	988.990	97.930
13	1031.603	988.606	100.177
14	1029.579	989.336	97.507
15	1042.438	1000.430	100.462
16	1040.636	1000.412	96.955
17	1037.187	994.376	100.435
18	1036.099	994.318	97.134

4.2.3   Data processing and generation of the 3D model

Pre-blast rock face was drawn in AutoCAD, according to the data we obtained before the blast. Here we need to shift to 3D view as we are going to generate a solid.
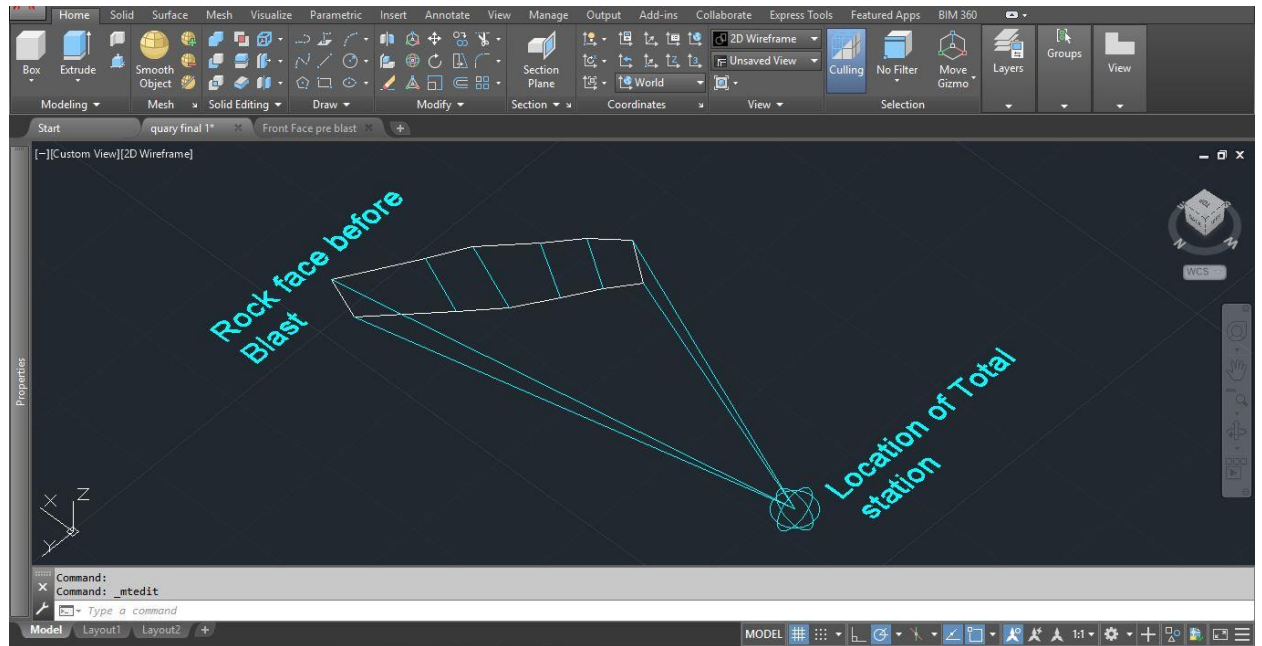

Figure 4-1: Pre-blast Rock Face

Post blast rock face was drawn based on the data obtained after the blast.
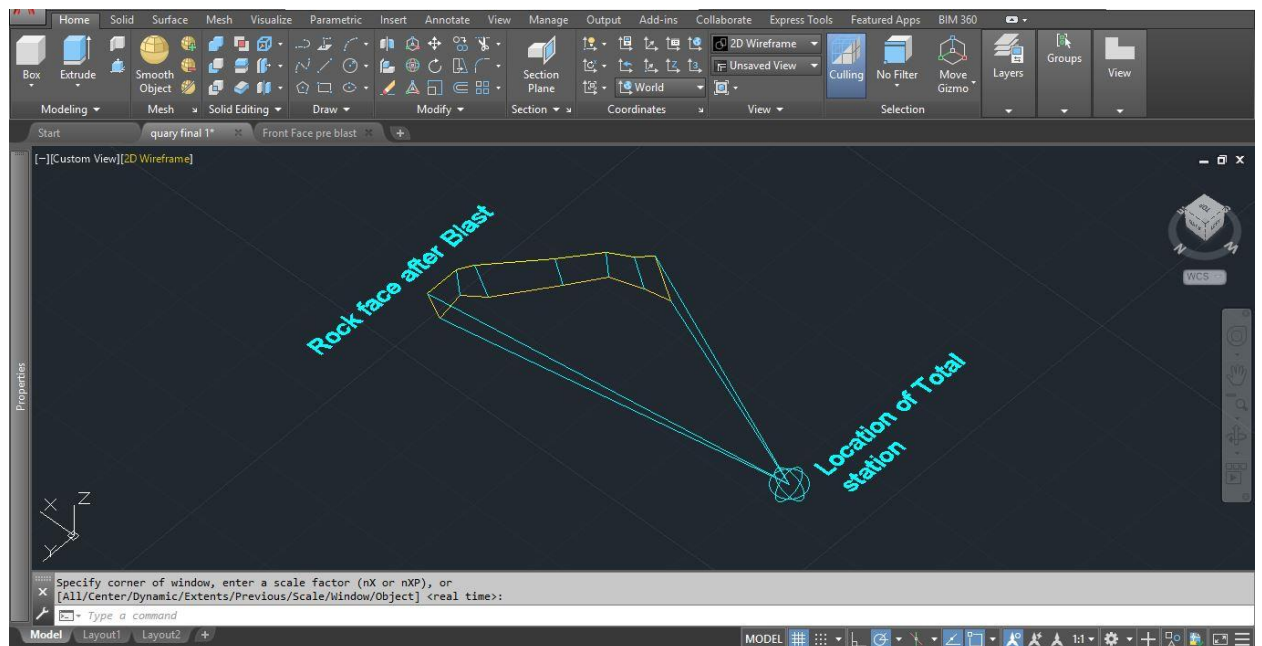

Figure 4-2: Post Blast Rock Face

After importing all the coordinates to AutoCAD, the 3D solid was generated in order to find the volume of the blasted rock. The volume that we obtained from AutoCAD software was 254.837 m^3.
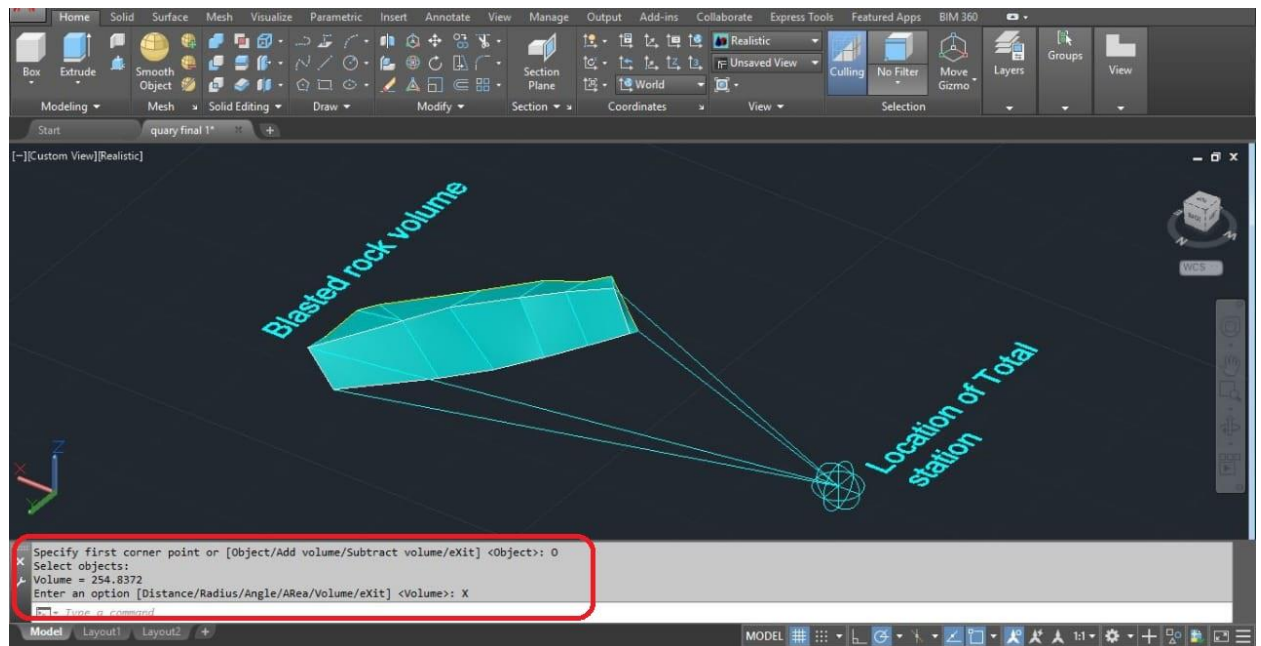
Figure 4-3: Blasted Rock Volume as a Solid

4.2.4   Advantages and disadvantages of Total Station Survey

Advantages of Total Station Survey

- Accuracy is high for point measurements
- Quick setup of the instrument on the tripod
- Reliable
- On board area computation
- Data can be saved and transference to PC
- No writing and No recording errors

Disadvantages of Total Station Survey

- Time consuming (more than a week to map some quarries)
- Skilled surveyors are needed
- Instrument cost is very high
- Skilled personnel are needed to process the data and it is time consuming

4.3 Volume Calculation using Agisoft PhotoScan

4.3.1 Overview

Here we have calculated the blasted volume of the rock using 2 methods;

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

4.3.2 Measuring the volume using pre blast and post blast faces

First step under this method is to mark the post blast face. For that we need to switch into a format or mode where we can draw shapes on top it. In that case, we can use *Orthophoto* or *DEM* to draw shapes. Also those can be utilized to calculate height, area and volume. After double clicking on *Orthophoto* or *DEM,* we can enter to this mode. In the Agisoft Toolbar, there is an option called Draw polyline, we can draw a polyline using that option.

Toolbar → Draw Polyline
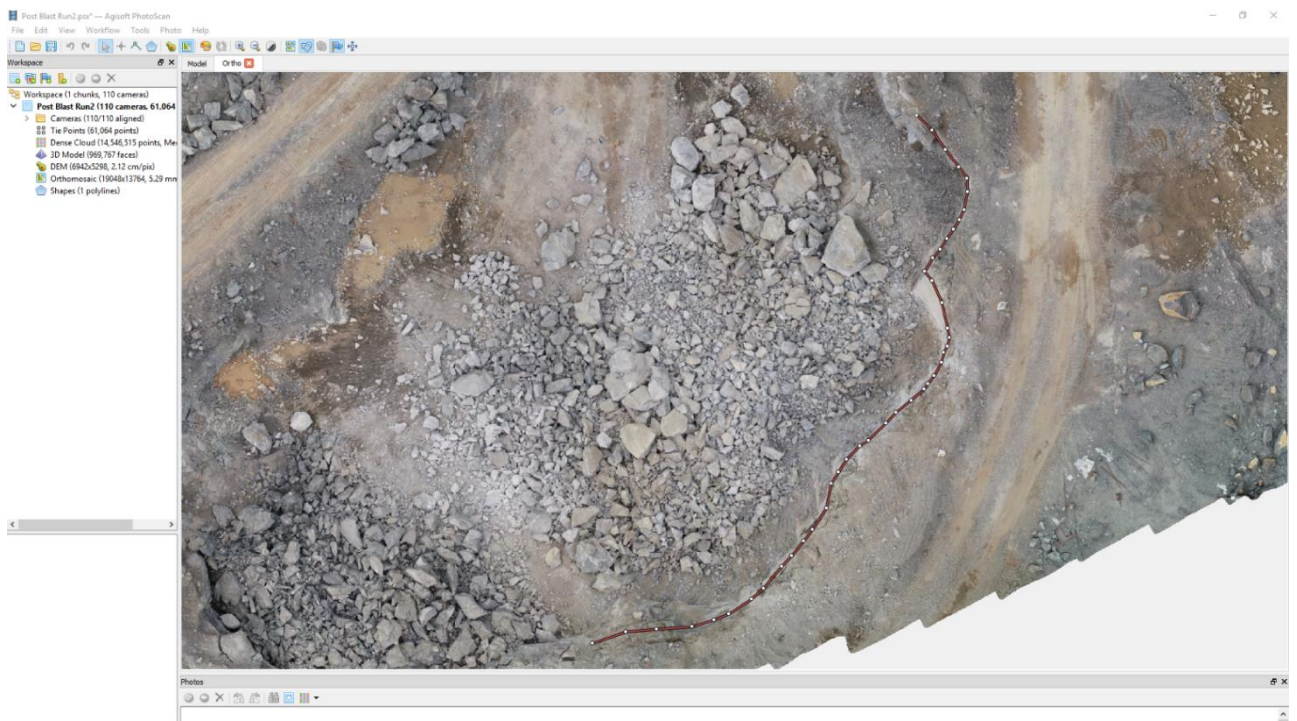
Figure 4-4: Post Blast Face

It is easy to draw the polyline with the presence of contours as it show the position of the steep slope correctly. We can generate contours by right clicking on DEM;

Right click on *DEM → Generate Contours*

Next step is to export this polyline (post blast face) as a shape file and import it into the pre blast model;

Tools → Export → Export Shapes

Tools → Import → Import Shapes

As we didn't use Ground Control Points (GCPs) when we took aerial photographs, both pre blast and post blast models are not properly geo-tagged. Both have shifted from its original position slightly. We had to use ArcMap software to bring the shape file into its correct relative position. Therefore before importing post blast face shape file into the pre blast model, it should be positioned correctly relative to the pre blast model using ArcMap. After importing post blast face, we can demarcate the area that we need to calculate the volume. For that use the *Draw Polygon* tool in the *Toolbar*;

Toolbar → Draw Polygon
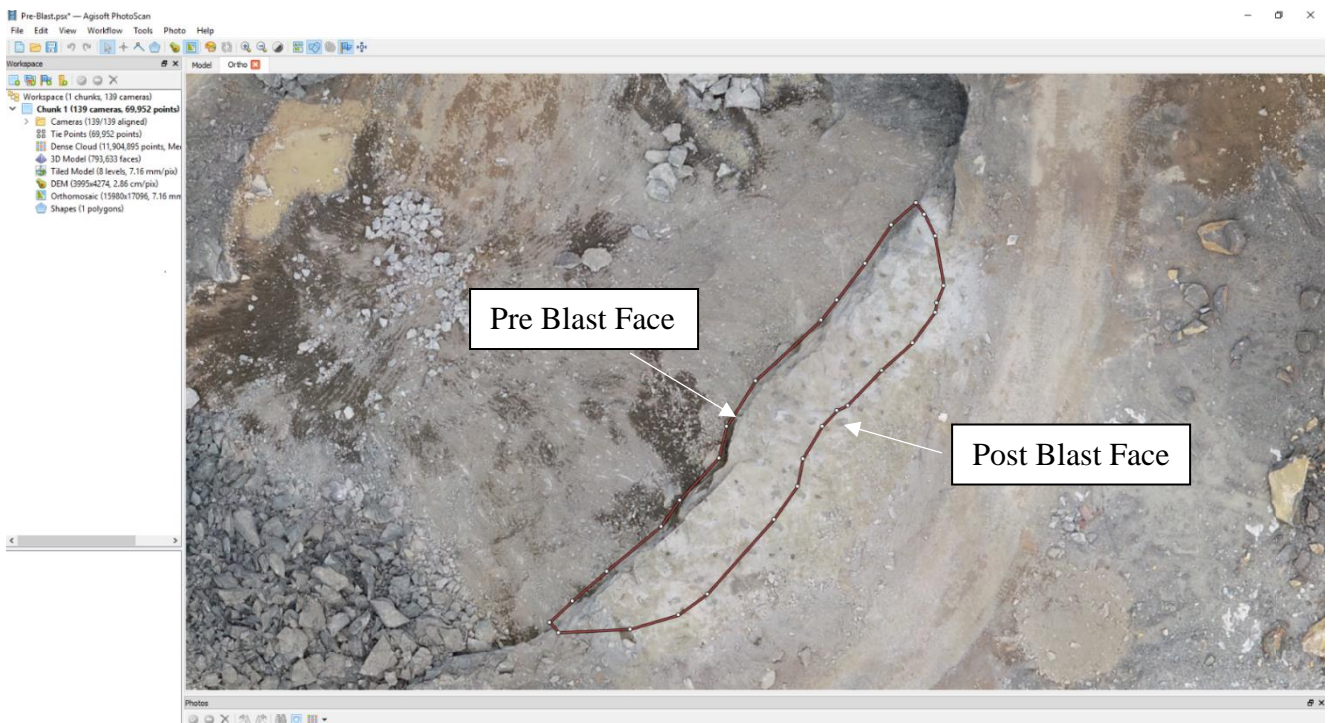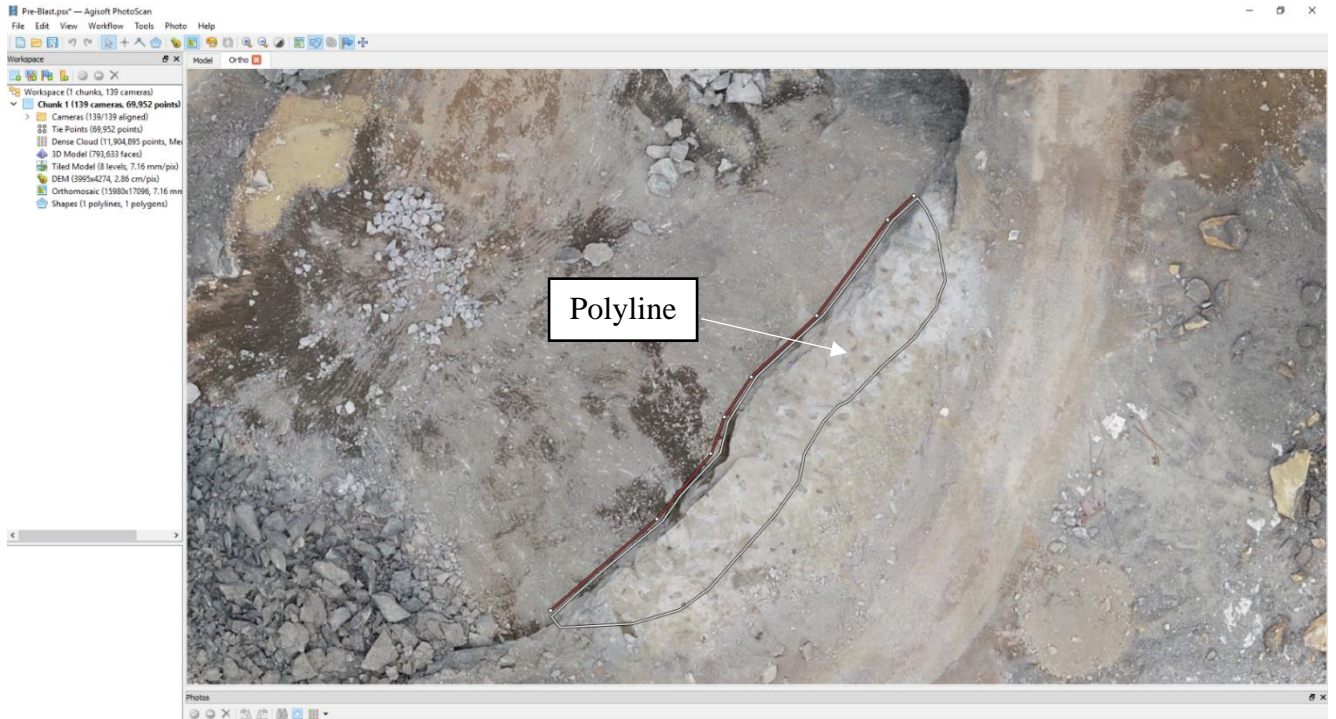

Figure 4-5: Blast Area

Figure 4-6: Polyline to Check the Ground Height

As the next step, we need to determine base level or bench height of the blast. To fulfill that objective we can draw a polyline close to selected area and check the heights/ levels along that line. See *Figure 4.6*;

Here we have selected the lower most level of this polyline as the base plane of the blast:

Point	Longitude	Latitude	Altitude (m)
1	80.026587	6.635735	-10.076
2	80.026628	6.635770	-11.110
3	80.026650	6.635795	-10.718
4	80.026655	6.635810	-11.046
5	80.026665	6.635825	-11.104
6	80.026690	6.635849	-10.848
7	80.026718	6.635886	-10.787
8	80.026728	6.635895	-10.907

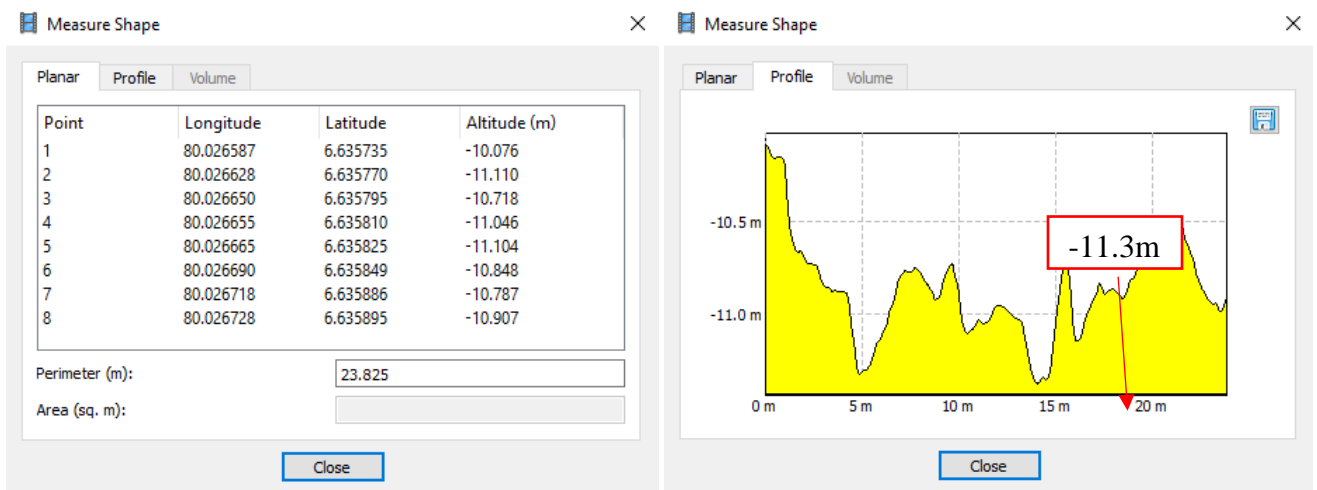Perimeter (m): 23.825

Area (sq. m):

Figure 4-7: Height Levels of the Polyline

So the lowest level that we got was -11.3m, so we decided to calculate the volume of the blast considering this level. By right clicking on the polygon we can calculate the blasted volume as follows;

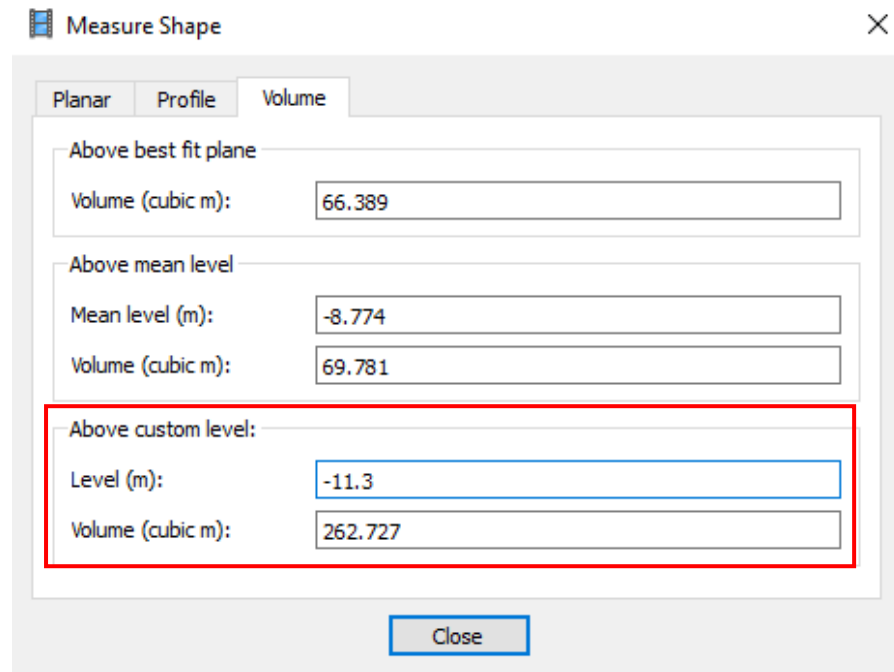*Right Click* on Polygon → *Measure* → *Volume*

Figure 4-8: Volume Measurement

Let's discuss about each volume that we got from this result;

- **Volume above Best Fit Plane:** This is plane is drawn minimizing point-plane distance of the base points, in other words sum of the absolute values of perpendicular distance from each base point to plane will be minimized. Cut volume above this plane will be considered. See figure

- **Volume above Mean Level:** Here average base height of the selected area will be taken as the mean height/ level. A horizontal plane will be drawn through the mean level and this plane is considered as the mean plane. Volume above this level will be considered.

- **Volume above Custom Level:** Here we can enter a level of our interest and calculate the cut volume above that plane.

As we select an area which lies on two levels (upper and lower surfaces of the blast face) we can't consider volumes above best fit plane or mean plane. So we have to enter the base level and calculate the blasted volume. See following *Figure 4.9* for better understanding;
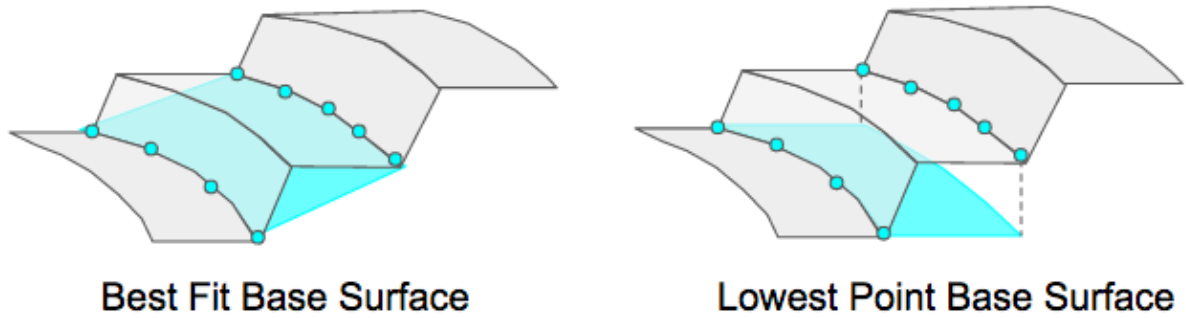
43

Figure 4-9: Different Types of Base Surfaces

4.3.3   Measuring the Volume of the Blasted Rock Pile

Here we try to get the volume of the blasted rock pile directly. For that we can draw a polygon very close to the blasted rock pile and get the volume of the blasted rock. Here we have to ignore rocks which have gone too far away.
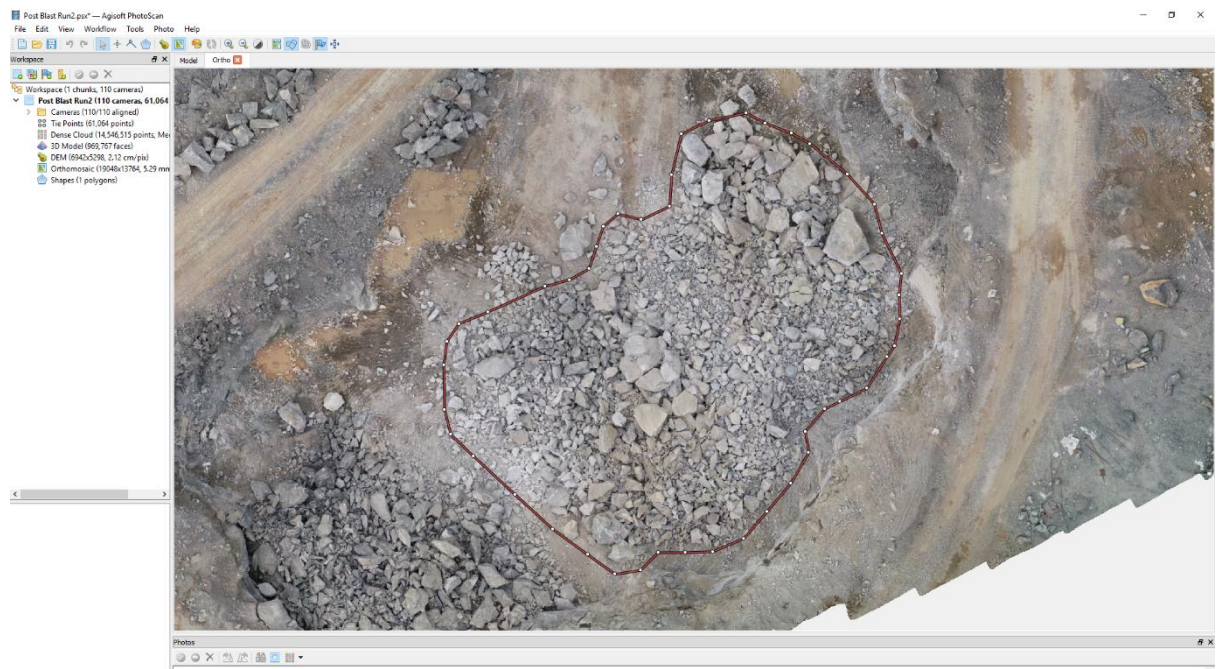
Toolbar → Draw Polygon

Figure 4-10: Demarcating the Extent of the Blasted Rock Pile

We have obtained a high quality post blast model and a medium quality post blast model to observe the volume difference. Here we need to consider volume above best fit plane as the blasted rock has fallen on top of an inclined plane. Results that we got for those both models are shown below;

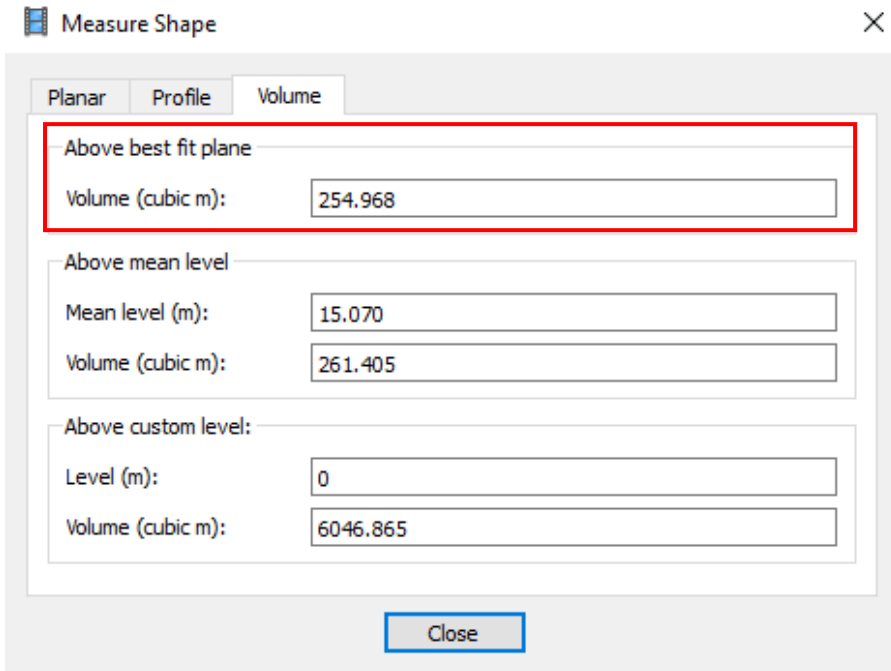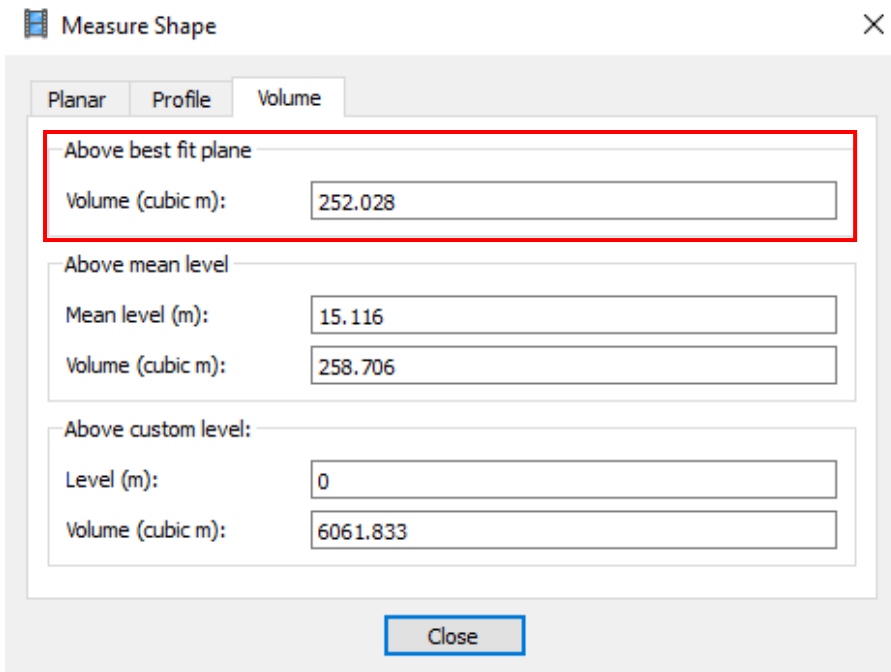*Figure 4-11: Blasted Volume - Medium Quality Model*

Figure 4-12: Blasted Volume - High Quality Model

Although it seems like we get a bulk volume as the volume reading, what we get here is an intermediate value between in-situ and bulk volumes. In-situ (in place/ on site) density is always higher than the bulk density. Air volume has increased after the breakage, therefore the density has reduced in bulk state.

Agisoft PhotoScan software has the ability to identify visible air spaces in the model and when calculating volumes, those spaces are considered. But the issue is there are spaces with air which are not visible from exterior view. Anyway most of the spaces are identified if the blast is well distributed. Therefore the volume that we get from Agisoft is an intermediate value between in-situ and bulk densities and it is more close to the in-situ density.

Figure 4-13: Post Blast 3D Model

4.3.4   Advantages and disadvantages of Agisoft PhotoScan

Advantages:

- ✓ Very cheap (Full license for commercial use is $3499, academic use is $549)
- ✓ Good Accuracy
- ✓ Simple workflow, relatively simple interface
- ✓ Good colour correction algorithm
- ✓ Easy dataset merging

Disadvantages:

- ✓ Relatively more time consuming
- ✓ Poor point cloud filtering
- ✓ Requires data manipulation
- ✓ Inefficient hardware utilization

4.4 Volume Calculation using Bentley ContextCapture

4.4.1 Overview

Same as in Agisoft, we can calculate the blasted volume in two methods;

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

In Agisoft we had to generate the *Orthomosaic* or the *DEM* to calculate volumes. So we only had a 2D image to calculate the blasted rock volume. But in ContextCapture we can use *3D Mesh* for this purpose. Therefore it is easier to demarcate areas/ planes using ContextCapture. Acute3D Viewer which is a product of Bentley software package, can be used in this purpose. We can calculate distances, areas and volumes using this software. Most importantly we can mark all points, lines and polygons in a *3D Mesh*.

4.4.2 Measuring the blasted volume using pre blast and post blast faces

Here we have faced a difficulty as we didn't have the capability to import or export shape files to ContextCapture. MicroStation is another product of Bentley software package, in which we can import shape files to the *3D Mesh* and export shape files from the *3D Mesh.* However we have demarcated blast area considering the locations of blast holes.
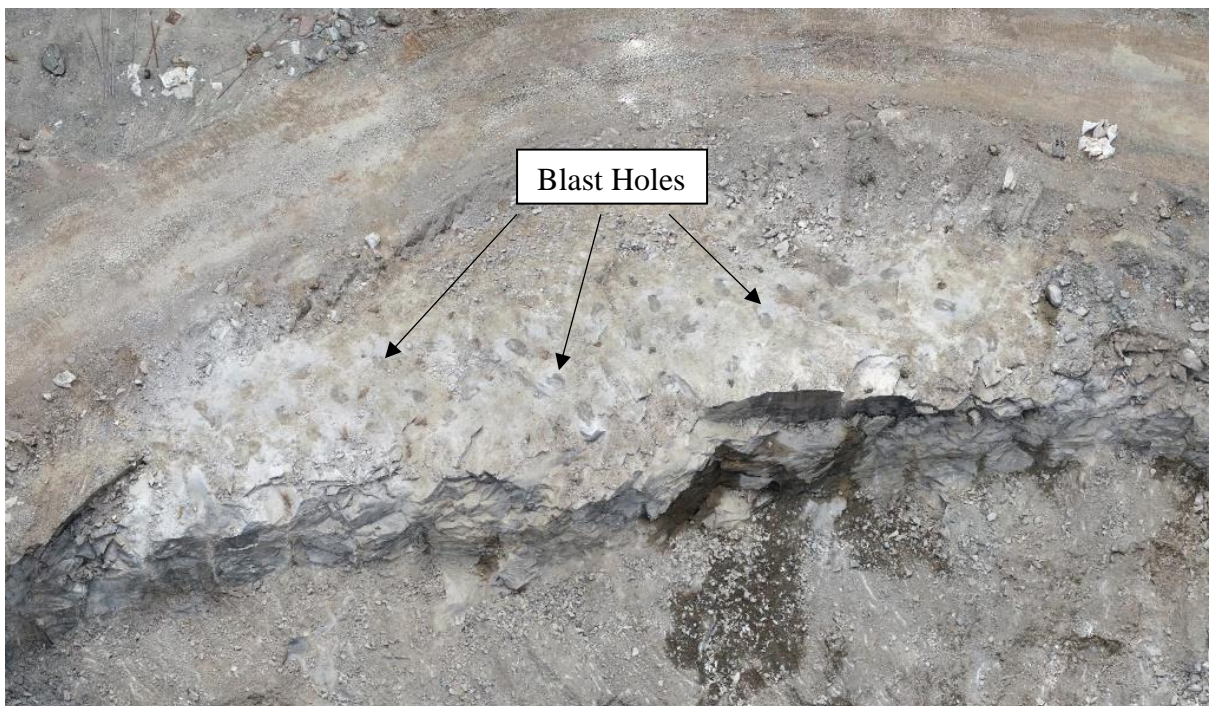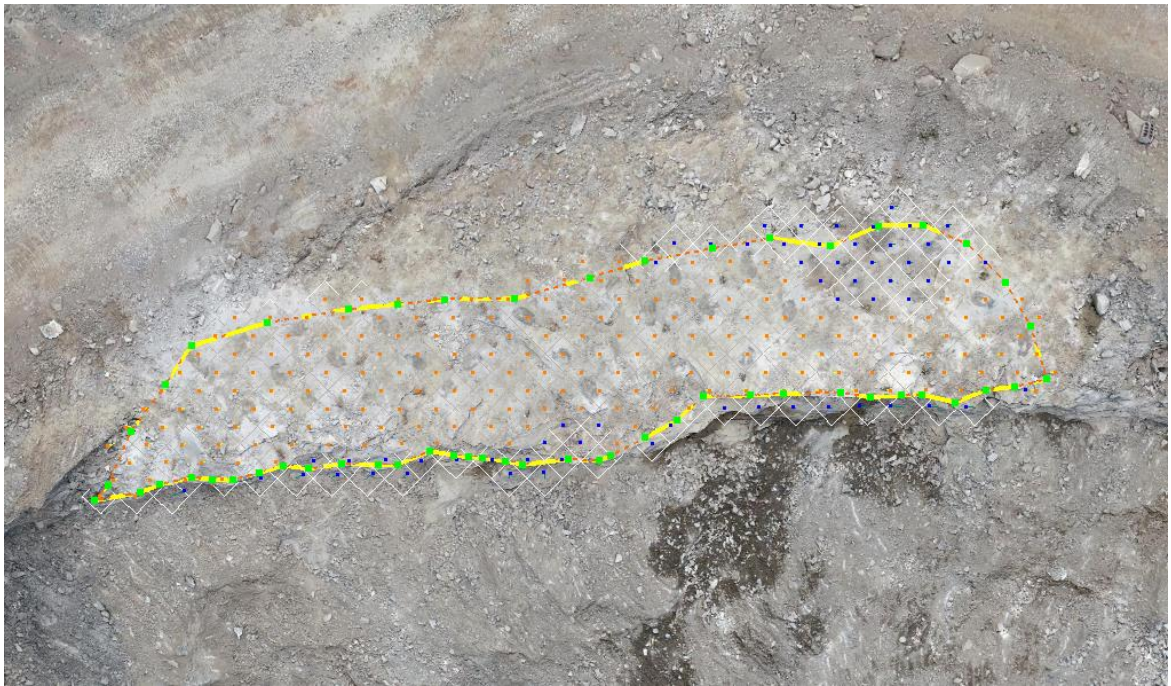

Figure 4-14: Identification of Blast Holes

After identifying the locations of blast holes, we have marked the blast area as follows;

Figure 4-15: Demarcating the Blast Area
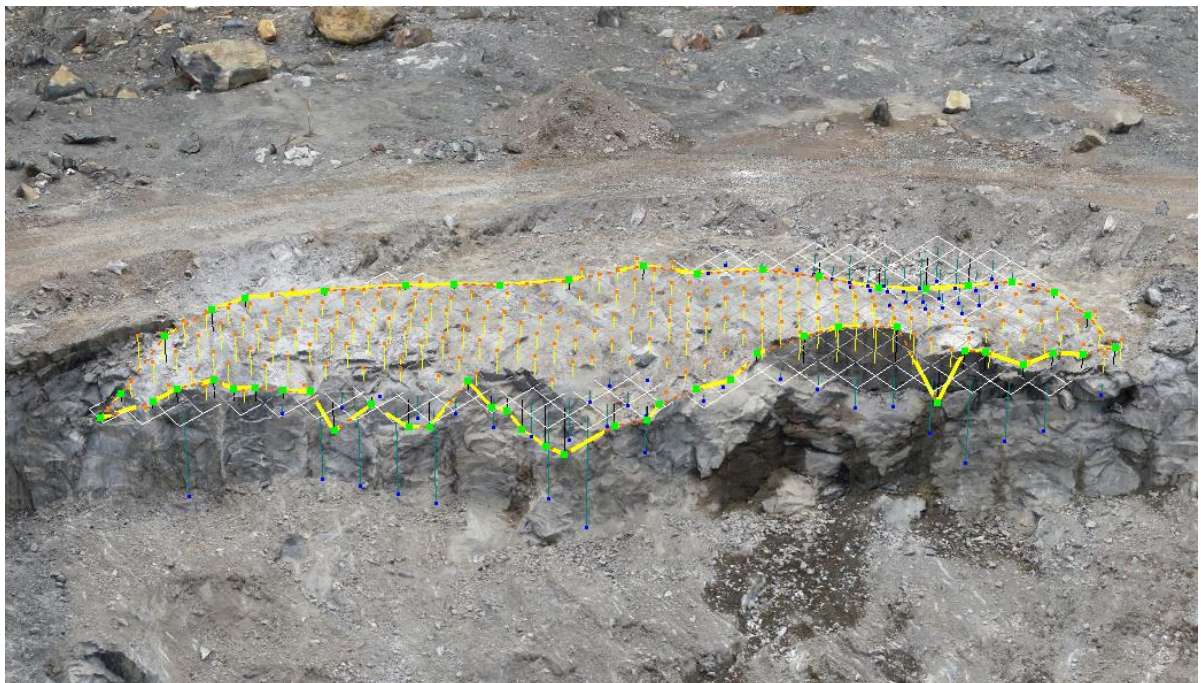
Figure 4-16: Blast Area - Front View

We have selected the bench height as the height of the blast. Therefore to get the blast volume we have reduced the bench height from the mean level and got the cut volume above the custom plane. Also we can clearly observe that software has identified the holes (in blue) within the blast area and those will be calculated as the fill volume.
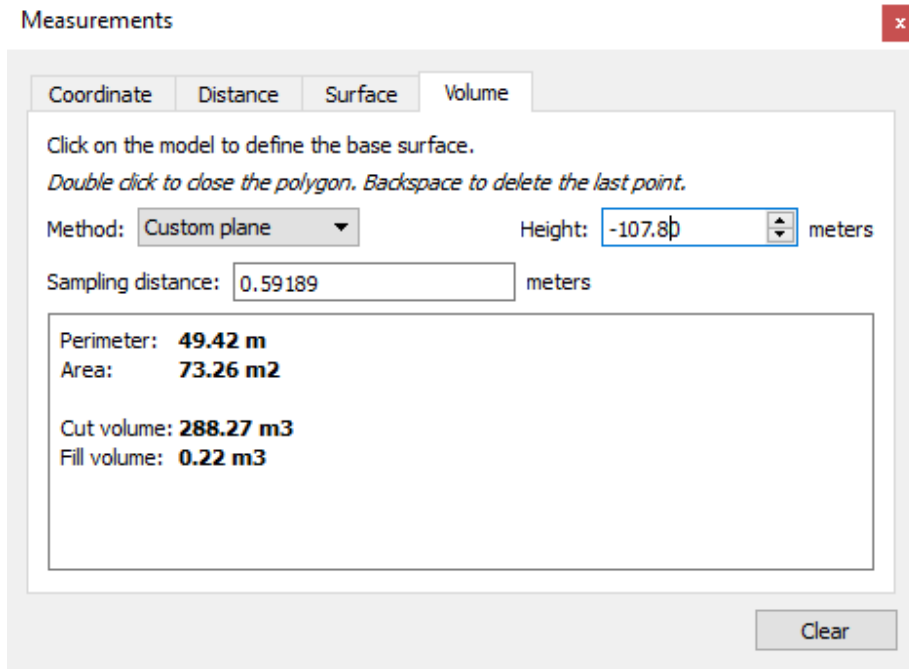
Figure 4-17: Volume Measurement

Here we obtained a volume of 288.27 m^3 for 0.59189 m sampling distance. Then we have reduced the sampling distance to 0.1 m and 0.05 m and obtained the volume measurements again.
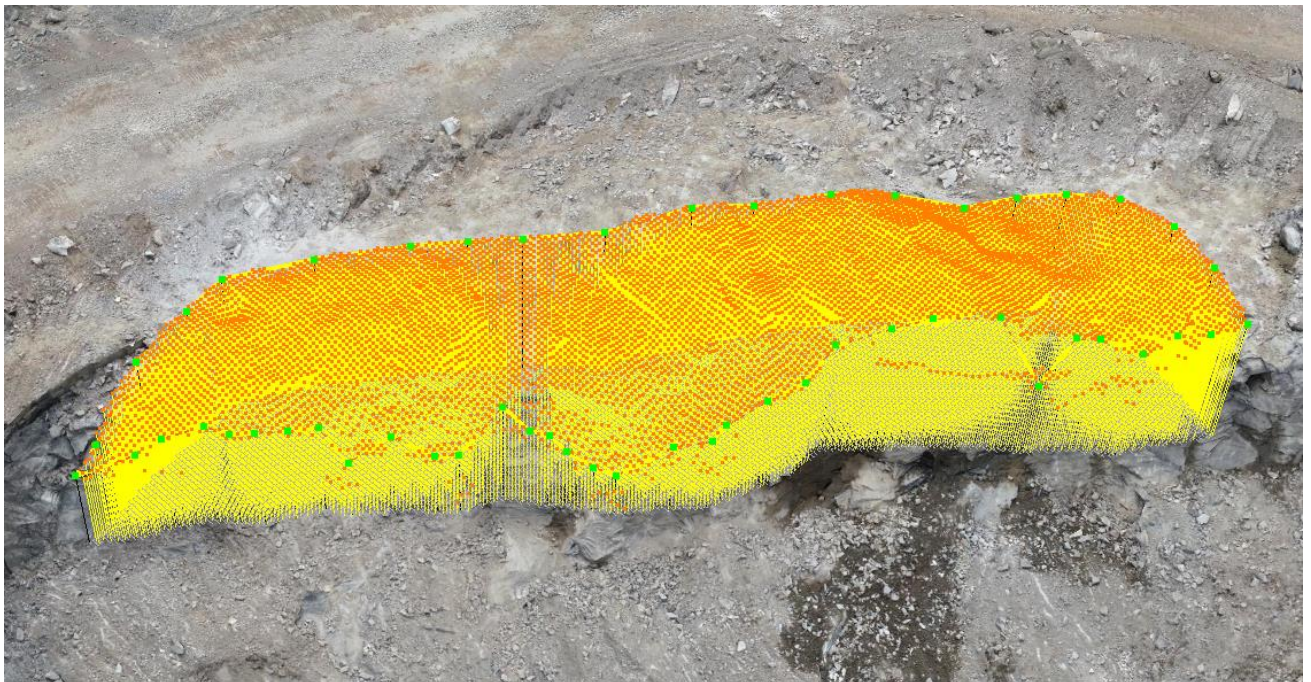
Figure 4-18: Blast Volume with 0.1m Sampling Distance
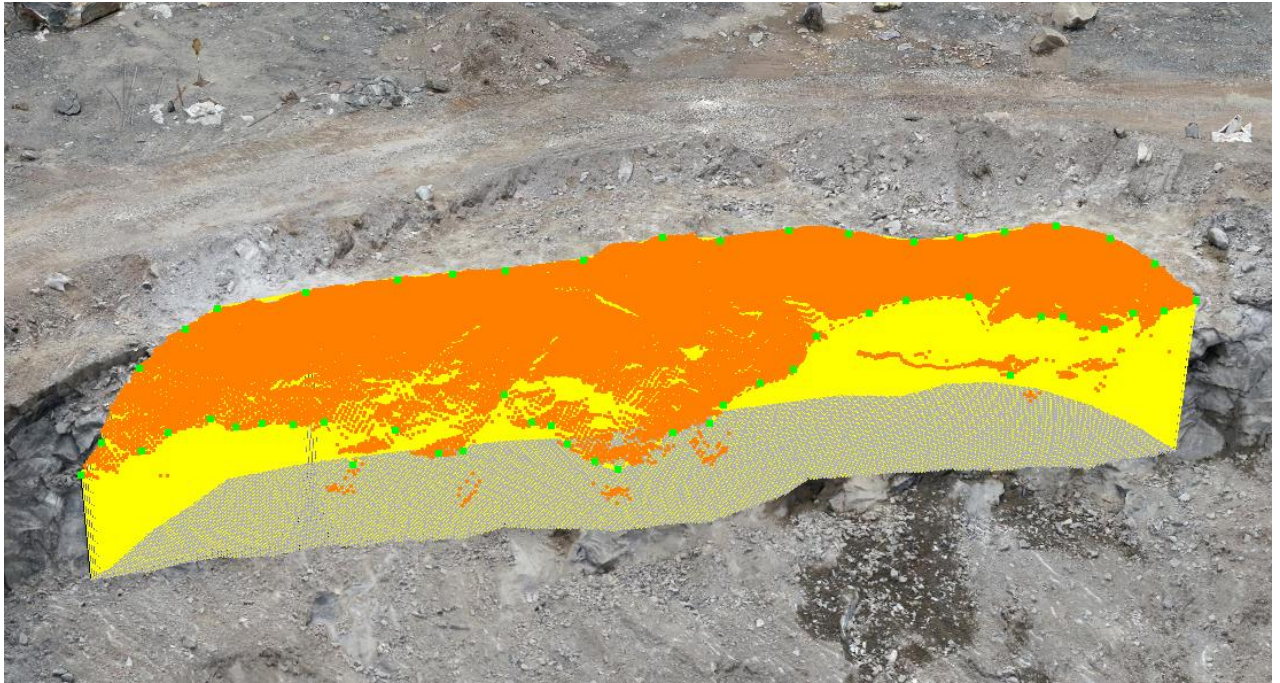
Figure 4-19: Blast Volume with 0.05m Sampling Distance
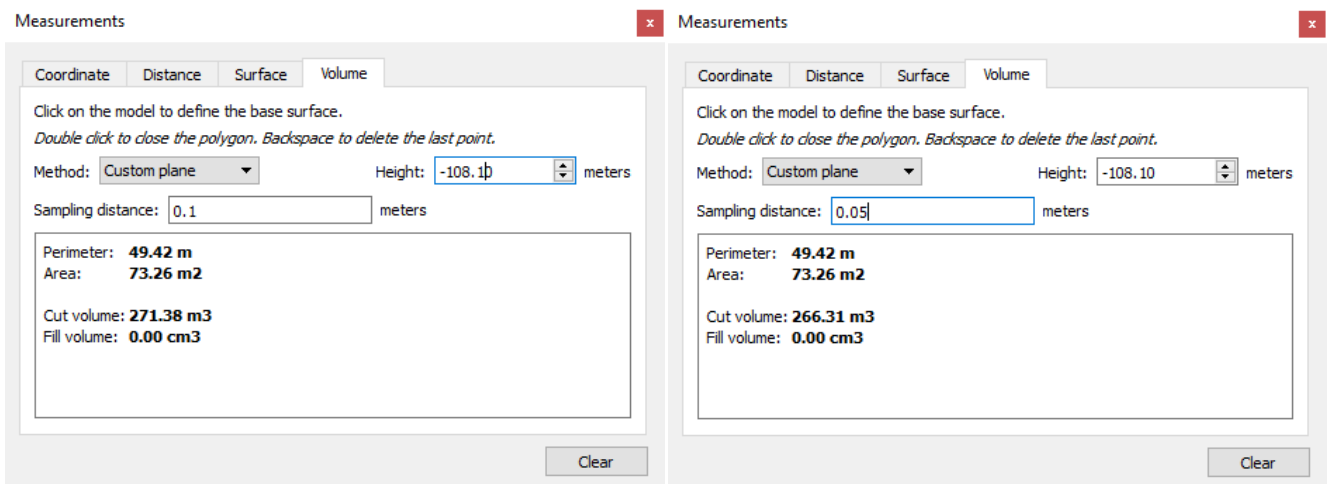
Figure 4-20: Volume Measurements with 0.1m & 0.05m Sampling Distances

4.4.3   Measuring the blasted volume of blasted rock pile

Here we need to properly demarcate the area of the blasted rock pile. As mentioned before we can draw it in a 3D space, so we can avoid unwanted rocks and benches easily.
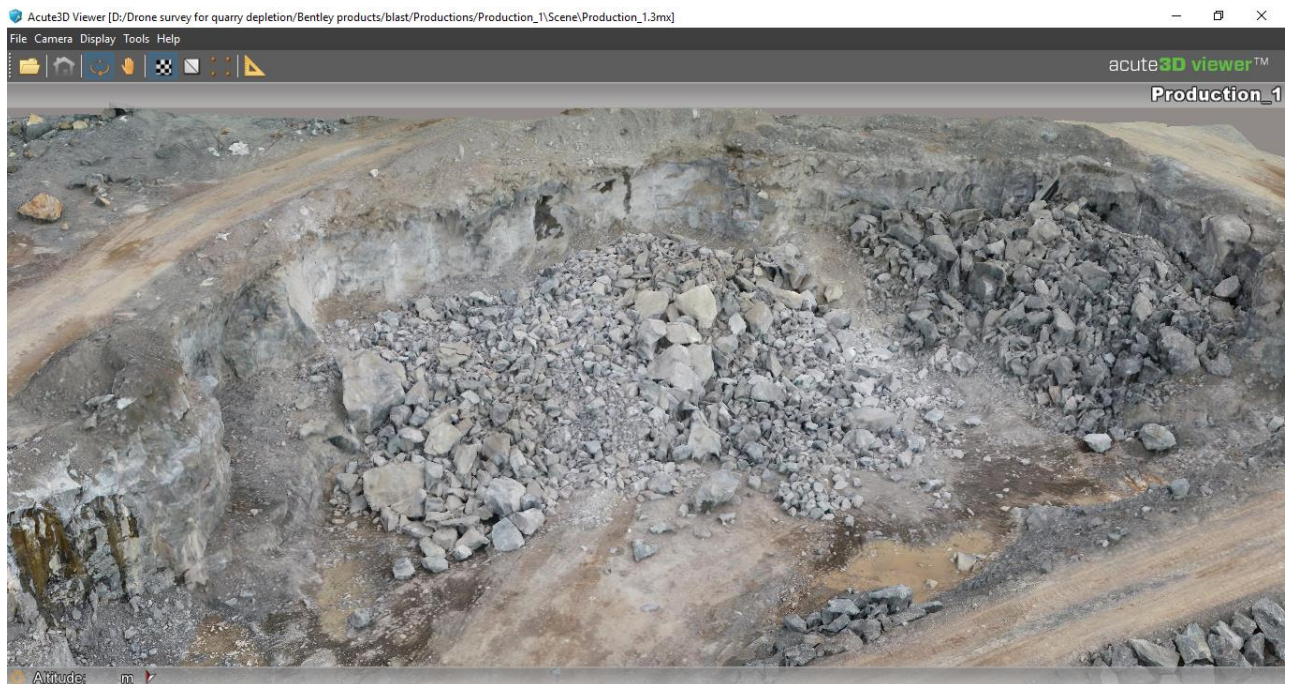
Figure 4-21: Post Blast Rock Pile
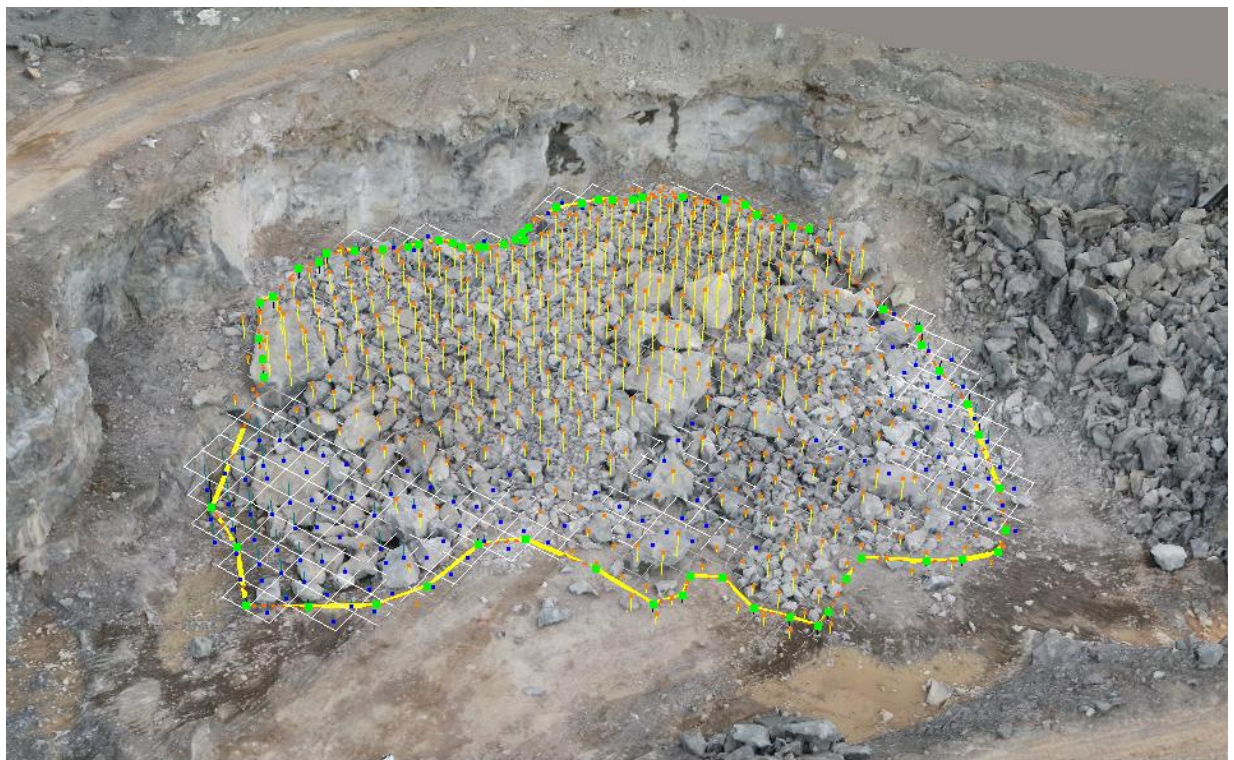
Figure 4-22: Selecting the Extent of the Blasted Rock Pile

Same as in previous case, we have decreased the sampling distance and got better volume measurements for the blasted rock pile.
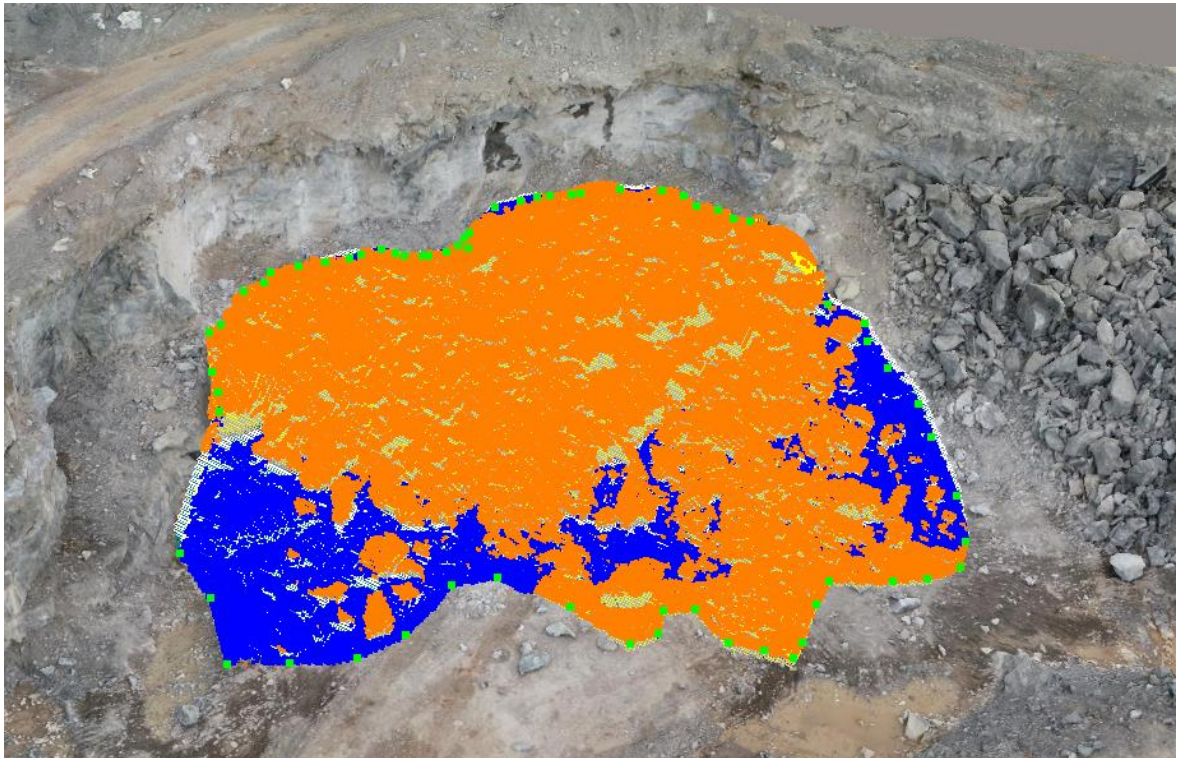
Figure 4-23: Blasted Rock Pile with 0.1m Sampling Distance
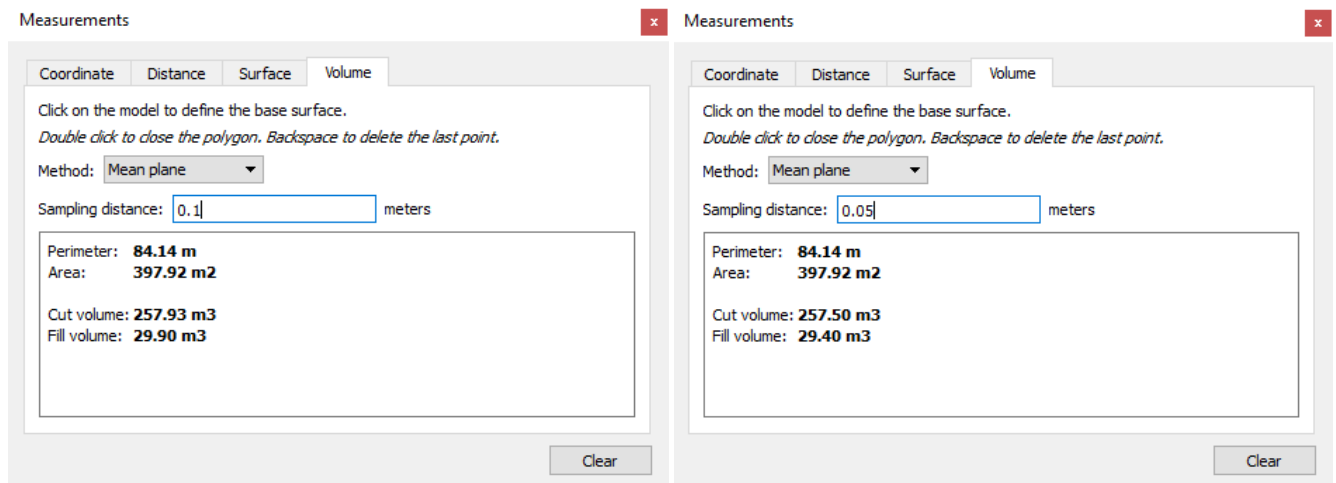
Figure 4-24: Volume Measurements with 0.1m & 0.05m Sampling Distances

4.5   Measuring the depletion using DroneDeploy

4.5.1   Selecting the right base plane

There are three base-plane options available for volume calculation. They are *Linear Fit, Lowest Point* and *Triangulated*. Here we need consider about cut volume of the selected area.

4.5.1.1   Measuring the volume above the Linear Fit

Figure 4-25: Linear Fit Volume

4.5.1.2   Measuring the volume with Triangulated option
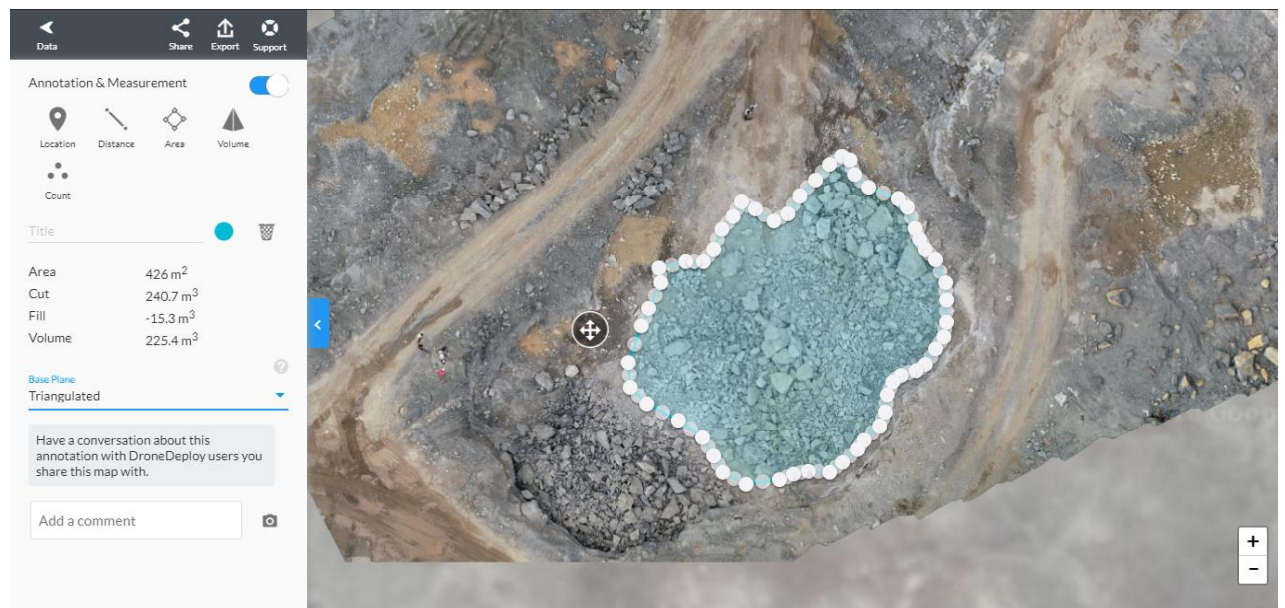
Figure 4-26: Triangulated Volume

4.5.1.3 Measuring the volume above the Lowest Point

Figure 4-27: Volume above the Lowest Point

Linear Fit (Best-fit plane) defines the base plane by fitting a perfectly flat plane, in 3D, through the chosen edge points.

Lowest Point calculates a horizontal base plane from the lowest edge point. This option is more suited to calculate the volume of benches or stockpiles on flat ground.

Triangulated joins up all the edge points to create a 3D surface under your stockpile. This is perfect for long thin stockpiles.
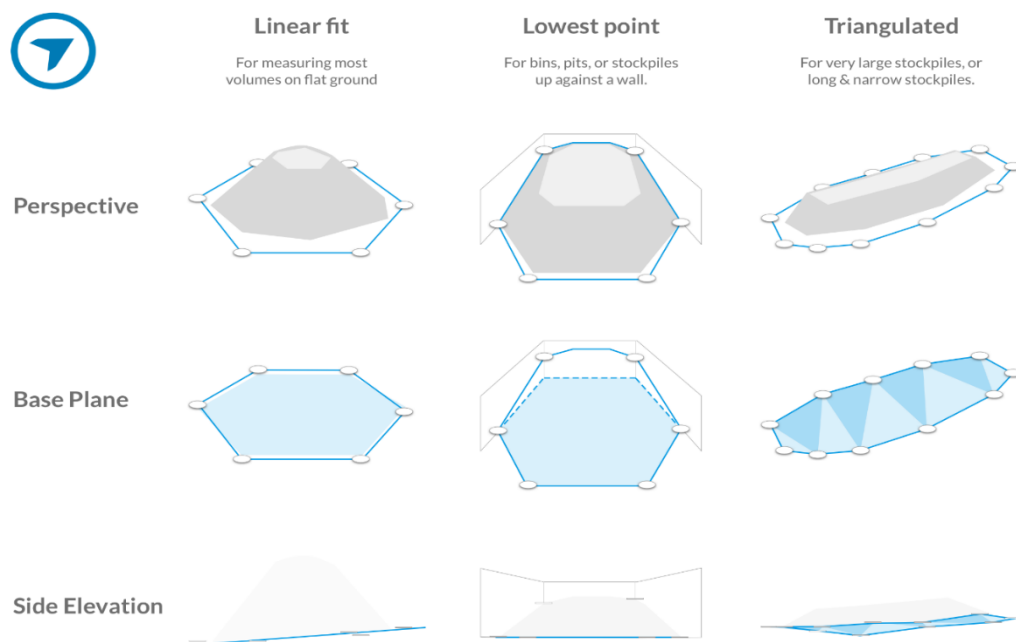
Figure 4-28: Different Base Planes

4.5.2 Cut and fill volumes

Cut refers to the volume we would have to remove from the area.

Fill refers to the volume we would have to haul in to that area.

Cut and Fill volumes are automatically shown on the map when calculating volumes. The actual volume measurement calculation is ***Volume = Cut - Fill***.

According to our data, Final output of the Drone Deploy Software

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

4.5.3 Elevation Model

Elevation model can be used for the volume calculation.
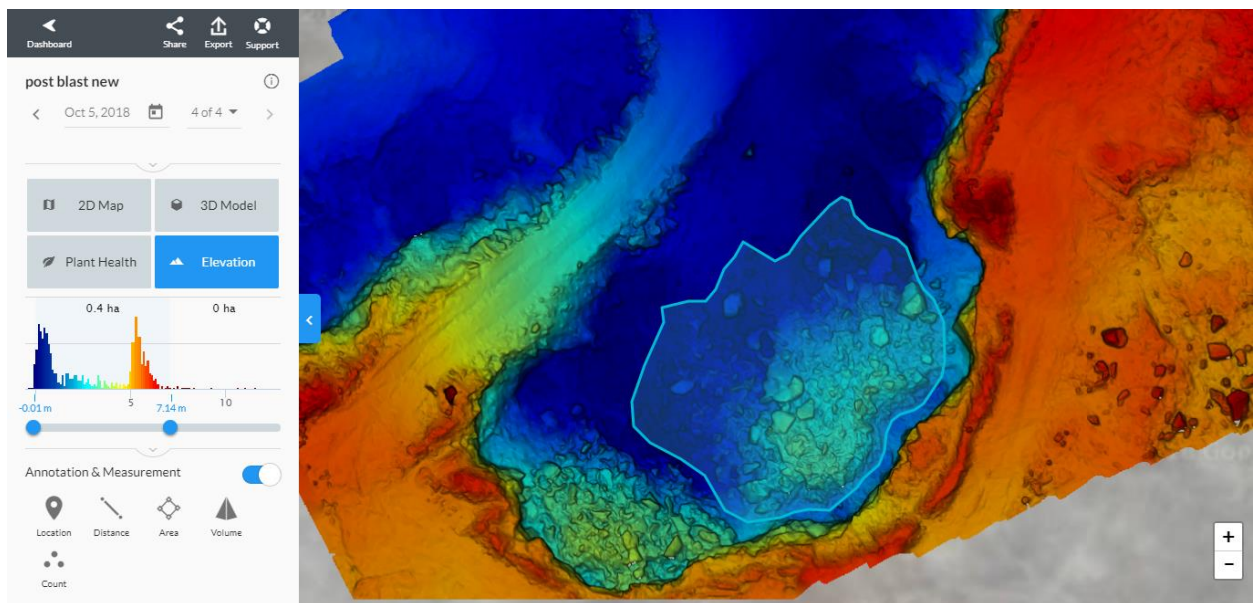
Figure 4-29: Elevation Model

Post blast model contained 110 images and their accuracy of the three axes of coordinate as follows. Accuracy level is less than other methods of the volume calculations;

X axis 1.2m, Y axis 0.5m, Z axis 0.4m
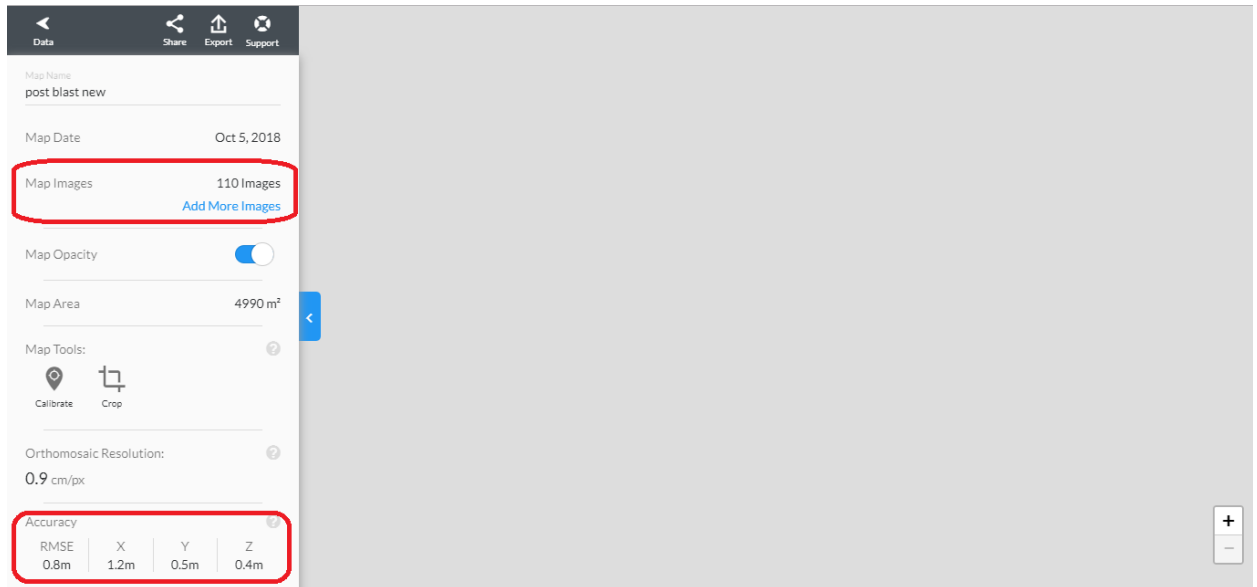
Figure 4-30: Accuracy of the Model

4.5.4 Advantages and disadvantages of the DroneDeploy software

Advantages of DroneDeploy

- Quick Processing time than other methods
- Supply 14-day trial online version
- No need Advanced knowledge to operate
- Output in many formats (JPG, TIFF, OBJ, LAS, SHP, DXF)
- Live Map (Real-Time Mapping)
- Can be added up to 1000 images

Disadvantages

- Less Accuracy
- Less Quality Output
- Minimum number of options in the software

5 DISCUSSION

5.1 Blasted Volume Comparison

Below shows the blasted volume comparison of the values that we obtained from measuring the blasted tonnage (true value), total station survey and volumes that we got from Agisoft, Bentley and DroneDeploy softwares;
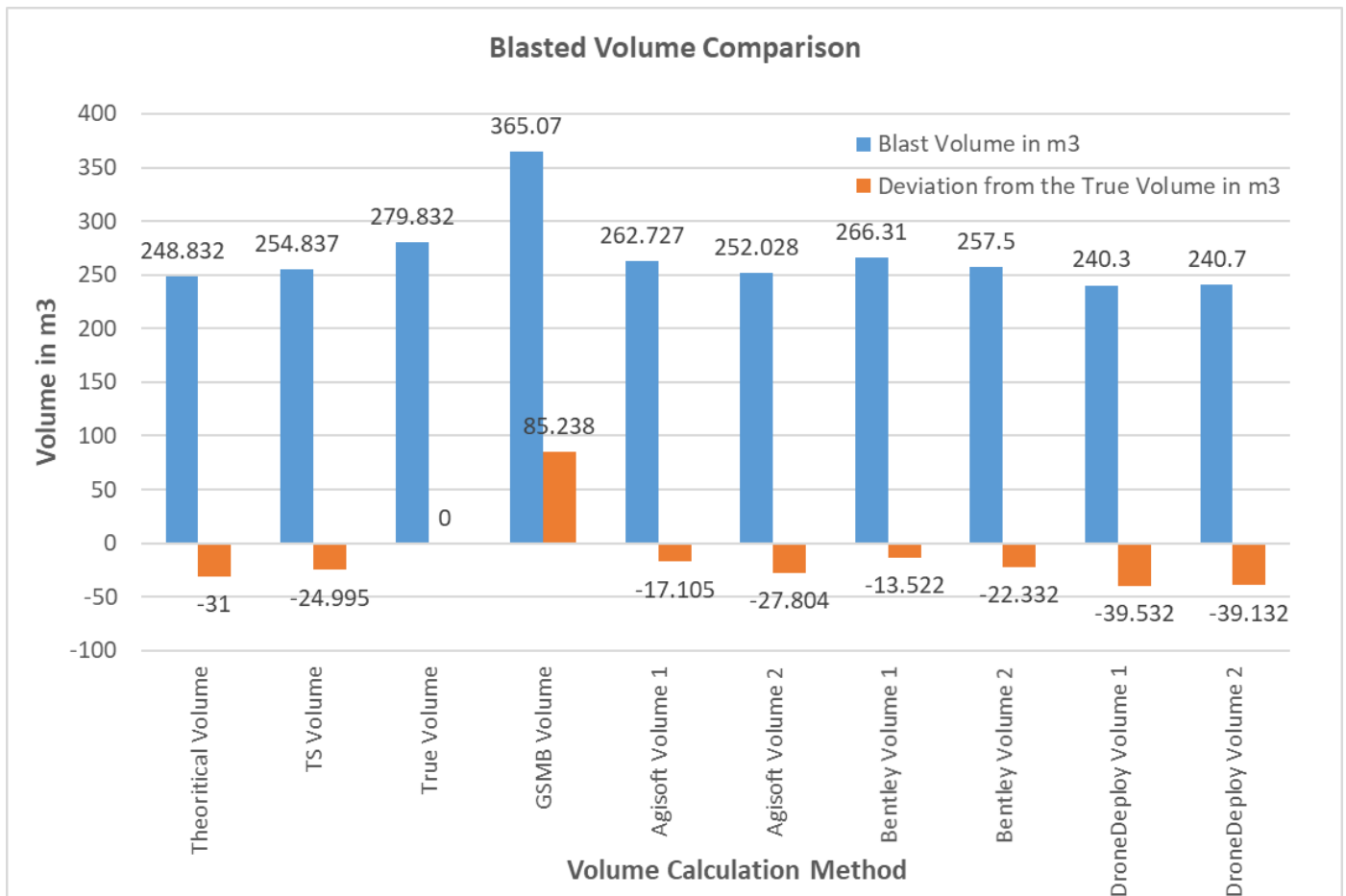
Figure 5-1: Blasted Volume Comparison

In this chart, vertical axis represents the in-situ volume of blasted the rock in m^3 and the horizontal axis represents volume calculation method. As we can clearly see in the graph, GSMB volume is deviating drastically from the true volume. Therefore, that method shouldn't have used to calculate the mining royalty.

From the methods that we have occupied to calculate the blasted volume, the values that we have obtained from Bentley ContextCapture shows the least deviation from the true volume. Which implies that it is the most suitable software to obtain volume measurements using photogrammetric 3D modelling.

Anyway it shows a deviation of -13.5 m^3 and -22.3 m^3 from the true value. This maybe because we had to calculate the volume above an inclined plane. This inclined plane was not a uniform one. It was consisted of small holes and terrains. If we took the volume reading above a flat surface, then this volume will be very close to the true value.

Volume measurement using Agisoft PhotoScan also shows a 17-27 m^3 deviation while DroneDeploy shows the highest deviation among softwares which is 39 m^3. Here we have used a 14-day trial version which is freely available on internet. They have restricted the accuracy of the volume measurement as this is a free version. When it comes to commercial versions, they might have a better accuracy.

5.2 Effect and Errors of Total Station Survey

There are some external factors affecting accuracy of this method. Total station used laser beam to the focus the survey points. Type and color of the reflecting surface will affect for the energy of the reflection of the laser beam. It leads to increase the error in measuring the slope distance. So when use the prism mode in high terrain level, the surface of the quarry rock is sharp or rough then the reflection point can be changed in the sunny time. It can effect for the 3D model. If we can increase the number of point measured, it can generate a high accuracy model.

Total Station is remained frequently used instruments for conducting topographic surveys in heritage recording projects. Although the point coordinate measurements are very accurate, data collection is time consuming and we can't map the original surface of bench using TS. Because of the when the constructing the 3D modeling, we had to assume that bench faces are even but natural case they are uneven. It will be a huge error for the volume calculation.

5.3   Polarization Effect of the Drone Images

We have used a polarizer for our DJI Phantom 4 Pro drone. Now a day's polarizer used in the many times in the drone imagining. Polarizer filter is most often used to,

- Dark white clouds in the sky
- Control the reflection from natural objects (tree leaves) and shiny surface in the ground
- Reduce the glare effect from the surface of water bodies (lake, ocean, stream)

The polarizer filter will block the unclean light. Those lights are bouncing and reflecting into various direction with the glare. Then filter works as the controller of the lights. The lights coming into a filter and it was filtered and it converted from bidirectional light rays to one direction rays.
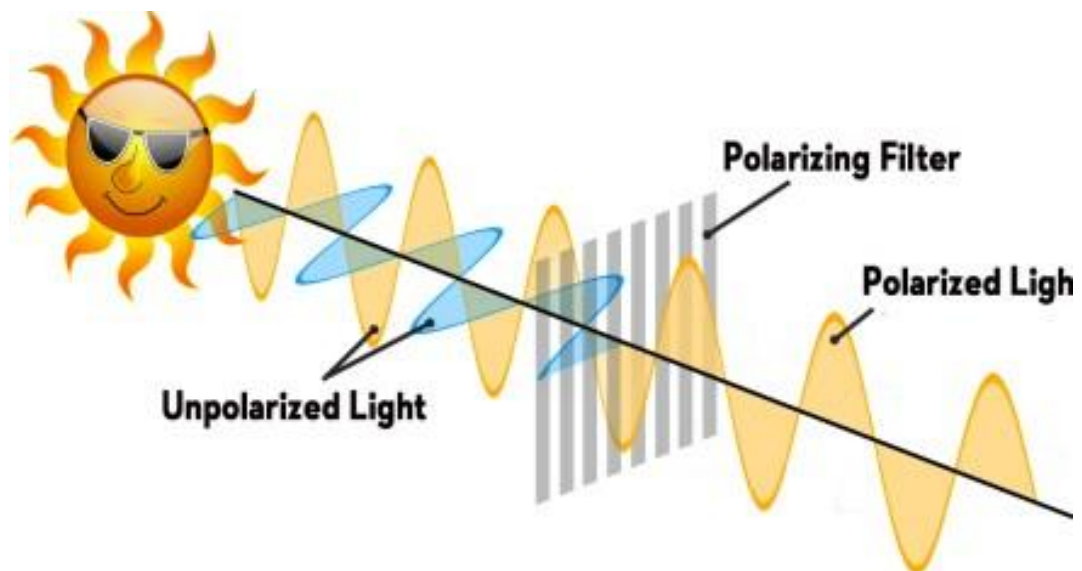
Figure 5-2: Polarization Effect

In our case, we used the DJI Phantom 4 Pro drone with a polarizer. It gives huge advantages for our quarry surveying. Because it controls the shiny effect of the quarry faces. Surveying is carried out on a sunny day at the time between 10.00 am to 1.00 pm. If not used the polarizer definitely shiny effect can occur and reduce the degree of quality. Finally, it directly affects the quality of the drone images and processed models. Our observed model has very good quality with high appearance.

6   CONCLUSIONS & RECOMMENDATIONS

6.1   New suggestion for Drone

DJI group announced latest drone technology for survey. DJI phantom 4 RTK is frequently releases new drone model in this year. It has huge leap forward and mainly focused on aerial mapping. Because of quadcopter built with Real Time Kinematic (RTK) capabilities. It gives highly accurate drone data for mapping. Phantom 4 RTK produces high resolution drone maps with 20MP sensor and 3D measurement. That are accurate within a few centimeters without using ground control points (GCP). Accuracy measurement are 1-3 cm in X and Y direction and 5cm in Z direction of position. Real time kinematic system integrated directly into the drone which is supply most efficient aerial GCPs. Phantom 4 RTK can achieve a ground sample distance (GSD) of 2.74cm at 100-meter flight altitude.

RTK model combined with several coordinate systems such as GPS L1 L2, GLONASS L1 L2, Galileie Esa, BeiDow B1 B2. In areas with lack to RTK coverage, DJI phantom 4 RTK allows for the use of Post Processed Kinematic (PPK) for the processing. Retail price of the DJI phantom 4 RTK is $6472.

7 REFERENCES

- Anon, (2018). [online] Available at:
  https://www.researchgate.net/publication/286511007_Topographic_Survey_at_S
  mall-scale_Open-pit_Mines_using_a_Popular_Rotary-
  wing_Unmanned_Aerial_Vehicle_Drone [Accessed 4 June. 2018]

- Pix4D. 2018. Drone-mapping streamlines surveys in mineral production operations.
  [ONLINE] Available at: https://pix4d.com/drone-mapping-streamlines-surveys-in-
  mineral-production-operations/. [Accessed 04 June 2018].

- Hathcock, L. and MacNeille, R. (2016). [online] Gri.msstate.edu. Available at:
  http://www.gri.msstate.edu/publications/docs/2016/03/15021Mosaic_Software_V
  5.pdf [Accessed 1 Nov. 2018].

- Mineral Processing & Metallurgy. (2015). How to Find and Determine the
  Specific Gravity of a Rock. [online] Available at:
  https://www.911metallurgist.com/blog/how-to-find-and-determine-specific-
  gravity-of-rocks [Accessed 16 Nov. 2018].

- DJI Official. (2018). The Phantom 4 RTK. [online] Available at:
  https://www.dji.com/newsroom/news/dji-launches-the-phantom-4-rtk-globally
  [Accessed 24 Nov. 2018].

- Dronedeploy.com. (2018). Powerful Drone & UAV Mapping Software |
  DroneDeploy. [online] Available at: https://www.dronedeploy.com/ [Accessed 6
  Nov. 2018].

- Cdn2.hubspot.net. (2018). DroneDeploy's 2017 Drone Buyer's Guide. [online]
  Available at: https://cdn2.hubspot.net/hubfs/530284/DroneDeploy-Drone-Buyers-
  Guide-V1.0%20(1).pdf?__hstc&__hssc&hsCtaTracking=46e71ea8-f14d-4448-
  8d9f-78b375ddd7d7%7C9bdcf295-8c3b-40d7-ae69-c1438d59eb3d [Accessed 7
  Nov. 2018].

- Prismic-io.s3.amazonaws.com. (2018). Price of the software. [online] Available
  at: https://prismic-io.s3.amazonaws.com/dronedeploy-www%2F0fac4d0d-769c-
  4faa-8e45-7a3c96b50f78_dronedeploy_pricing-11_2018.pdf [Accessed 5 Nov.
  2018].

- Stockpile base plane. (2018). [image] Available at:
  https://files.readme.io/f33097c-stockpile_base_plane.png [Accessed 1 Nov. 2018].

- Amazon.com. (2018). Polarize of Drone camera. [online] Available at: https://www.amazon.com/Drone-Fans-Professional-Polarized-Graduated/dp/B01INAY6EY [Accessed 13 Nov. 2018].

- FORUM, D. (2018). How to use Polarizing filter. [online] Forum.dji.com. Available at: https://forum.dji.com/thread-132110-1-1.html [Accessed 6 Nov. 2018].

- Polerizer filters for DJI drone. (2018). [image] Available at: https://www.google.lk/url?sa=i&source=images&cd=&cad=rja&uact=8&ved=2ah UKEwjY_9uS4uzeAhXQyIUKHRpXDi0QjRx6BAgBEAU&url=https%3A%2F %2Fdjiphotoacademy.com%2Fpolarizer-filter-drone-photography%2F&psig=AOvVaw0WKOm2DORoQrKoBVuwQPcM&ust=15431 39 Spike's Calculations. (2018). Bulking/Swell Factors for Various Excavated/Mined Materials. [online] Available at: https://www.spikevm.com/calculators/excavation/bulking-swell-factors.php [Accessed 5 Nov. 2018].873057727 [Accessed 7 Nov. 2018].

- COMPARISON BETWEEN MULTICOPTER UAV AND TOTAL STATION FOR ESTIMATING STOCKPILE VOLUMES. (2015). [ebook] https://www.sciencedirect.com/. Available at: https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-1-W4/131/2015/isprsarchives-XL-1-W4-131-2015.pdf [Accessed 11 Nov. 2018].

- Kršák, B., Blišťan, P., Pauliková, A., Puškárová, P., Kovanič, Ľ., Palková, J. and Zelizňaková, V. (2016). Use of low-cost UAV photogrammetry to analyze the accuracy of a digital elevation model in a case study. Measurement, [online] 91, pp.276-287. Available at: https://www.sciencedirect.com/science/article/pii/S0263224116301749 [Accessed 3 Nov. 2018].

- Pflipsen, b. (2006). Volume Computation - A Comparison of Total Station Versus Laser Scanner and Different Software. 1st edition. Department of Technology and Built Environment - University of Gavle.

Pre Blast Face

Agisoft PhotoScan - Processing Report

08 November 2018
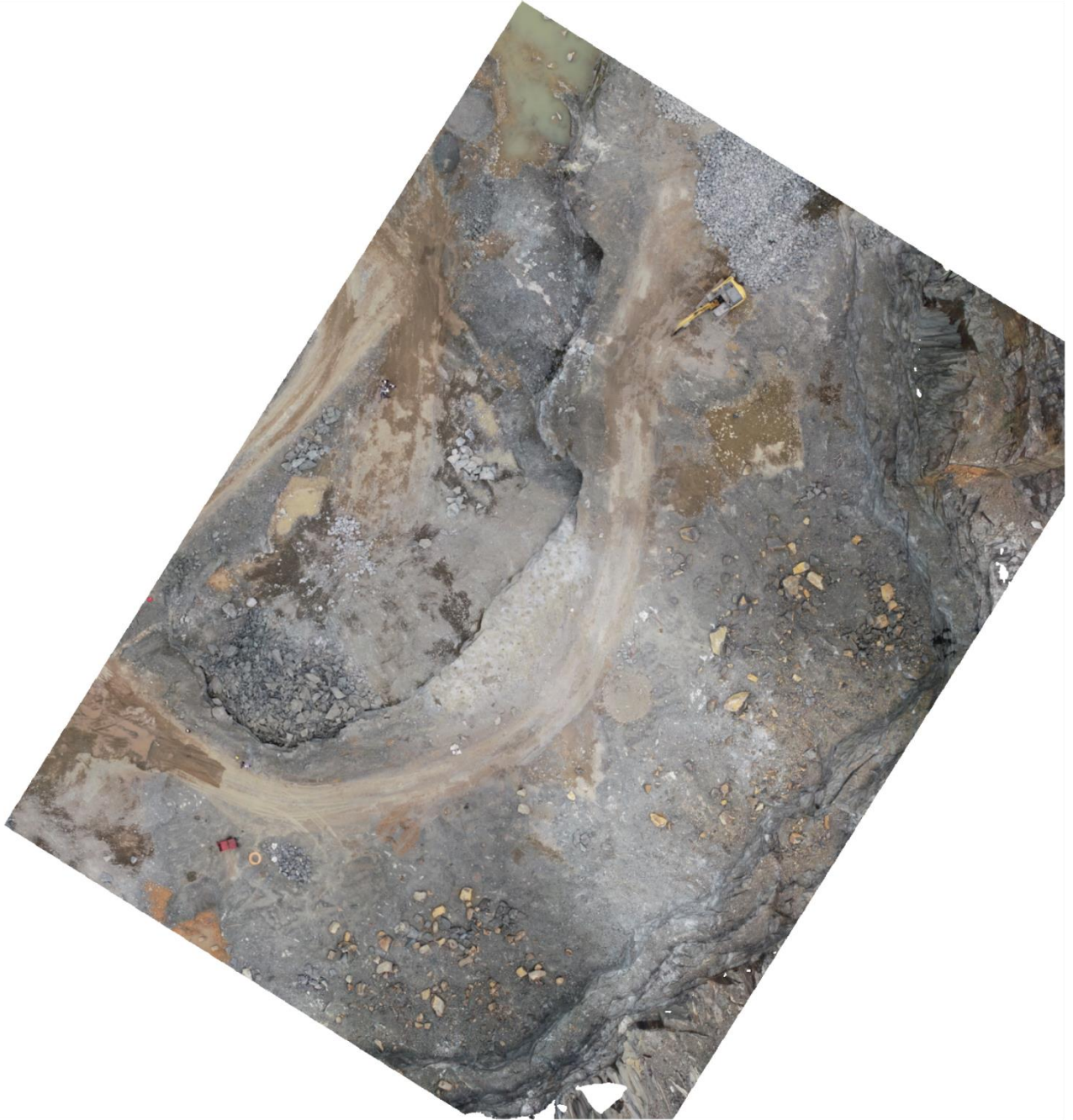
Survey Data
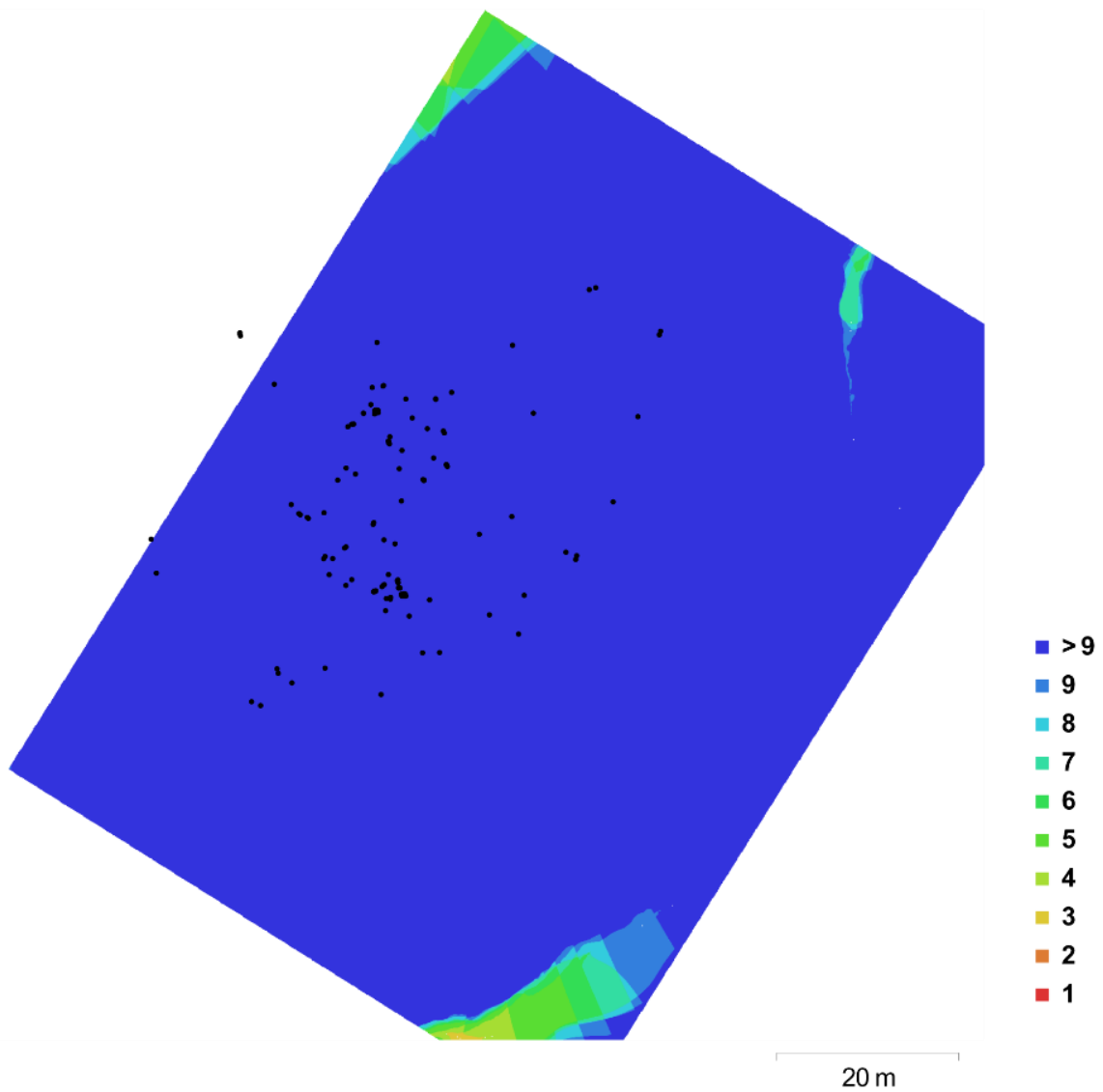
Fig. 1. Camera locations and image overlap.

Number of images:	139	Camera stations:	139
Flying altitude:	28.7 m	Tie points:	69,952
Ground resolution:	7.16 mm/pix	Projections:	492,142
Coverage area:	7.06e+03 sq m	Reprojection error:	1.41 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
FC6310 (8.8 mm)	5472 x 3078	8.8 mm	2.53 x 2.53 um	No

Table 1. Cameras.

Camera Calibration

1 pix

Fig. 2. Image residuals for FC6310 (8.8 mm).

FC6310 (8.8 mm)

139 images

Resolution	Focal Length	Pixel Size	Precalibrated
5472 x 3078	**8.8 mm**	**2.53 x 2.53 um**	**No**

Type:	Frame	Skew:	0
Fx:	3647.59	Cx:	2727.39
Fy:	3647.59	Cy:	1563.84
K1:	-0.00033257	P1:	0.000982489
K2:	-0.016343	P2:	0.000641353
K3:	0.0168726	P3:	0
K4:	0	P4:	0

Camera Locations
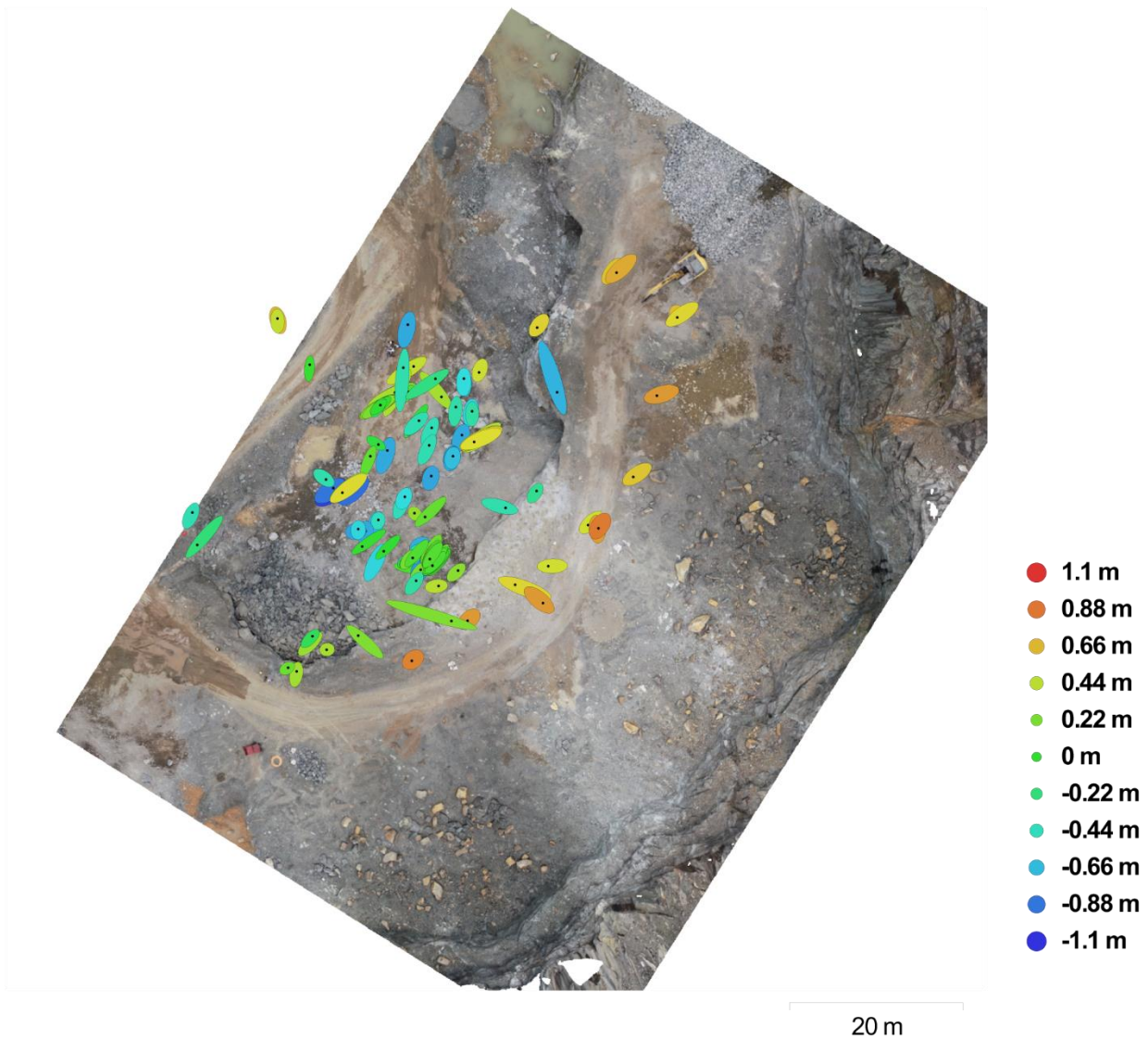
Fig. 3. Camera locations and error estimates.
Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	XY error (m)	Z error (m)	Total error (m)
0.919216	0.881532	1.2736	0.438529	1.34698

Table 2. Average camera location error.

Digital Elevation Model
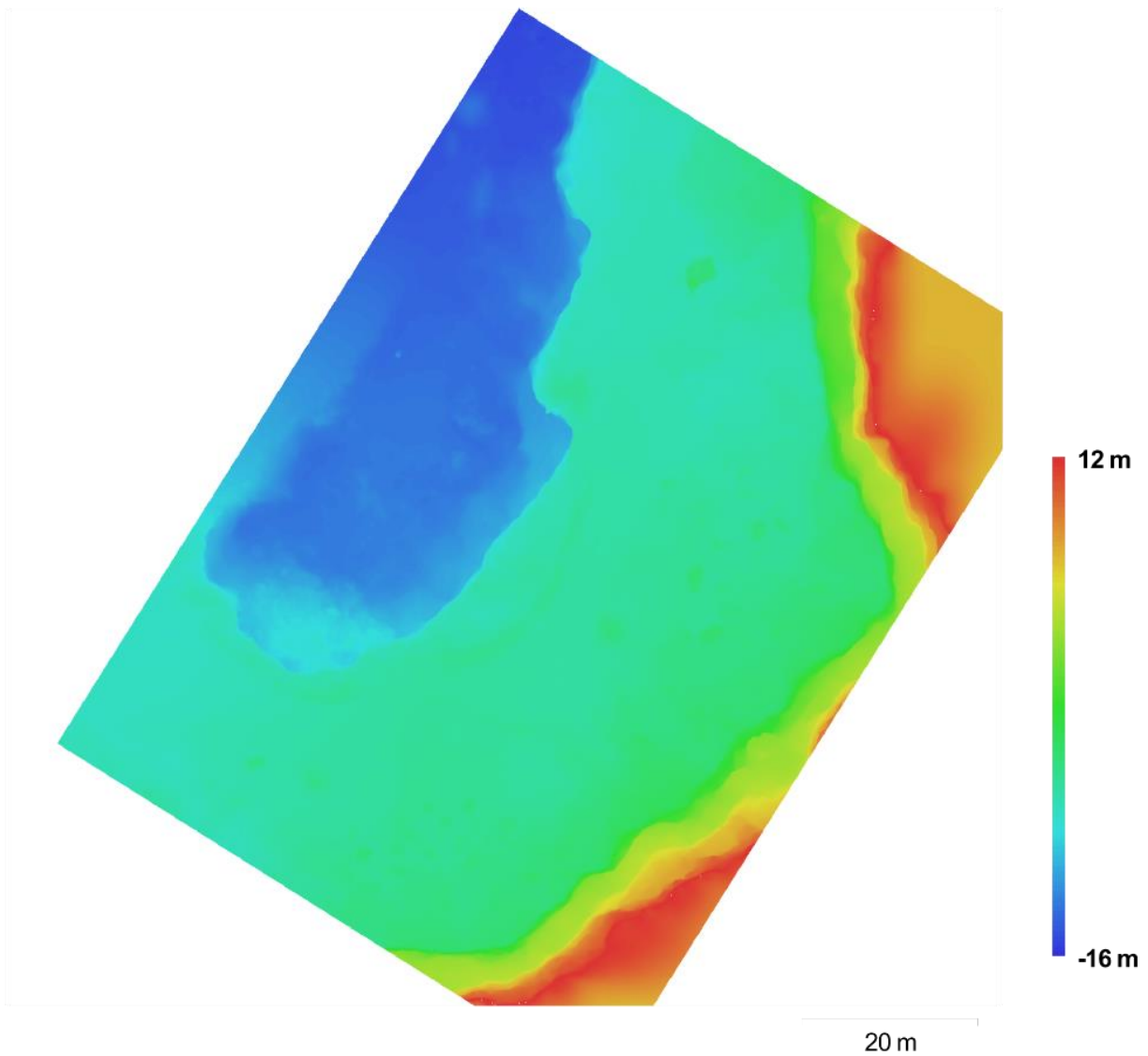
Fig. 4. Reconstructed digital elevation model.

Resolution: 2.86 cm/pix
Point density: 1218.47 points per sq m

Processing Parameters

General

Cameras	139
Aligned cameras	139
Coordinate system	WGS 84 (EPSG::4326)

Point Cloud

Points	69,952 of 86,492
RMS reprojection error	0.181228 (1.41286 pix)
Max reprojection error	0.709401 (46.0768 pix)
Mean key point size	6.80881 pix
Effective overlap	8.29047

Alignment parameters

Accuracy	Medium
Pair preselection	Disabled
Key point limit	40,000
Tie point limit	4,000
Constrain features by mask	No
Matching time	1 days 3 hours
Alignment time	1 minutes 47 seconds

Optimization parameters

Parameters	f, cx, cy, k1-k3, p1, p2
Optimization time	5 seconds

Dense Point Cloud

Points	11,904,895

Reconstruction parameters

Quality	Medium
Depth filtering	Aggressive
Processing time	45 minutes 33 seconds

Model

Faces	793,633
Vertices	399,296
Texture	4,096 x 4,096, uint8

Reconstruction parameters

Surface type	Arbitrary
Source data	Dense
Interpolation	Enabled
Quality	Medium
Depth filtering	Aggressive
Face count	793,633
Processing time	1 days 8 hours

Texturing parameters

Mapping mode	Generic
Blending mode	Mosaic
Texture size	4,096 x 4,096
UV mapping time	2 minutes 30 seconds
Blending time	1 minutes 1 seconds

DEM

Size	3,995 x 4,274
Coordinate system	WGS 84 (EPSG::4326)

Reconstruction parameters

Source data	Mesh
Interpolation	Enabled

Orthomosaic

Size	15,980 x 17,096
Coordinate system	WGS 84 (EPSG::4326)
Channels	3, uint8
Blending mode	Mosaic

Post Blast Full Quarry

**Agisoft PhotoScan - Processing Report**
08 November 2018
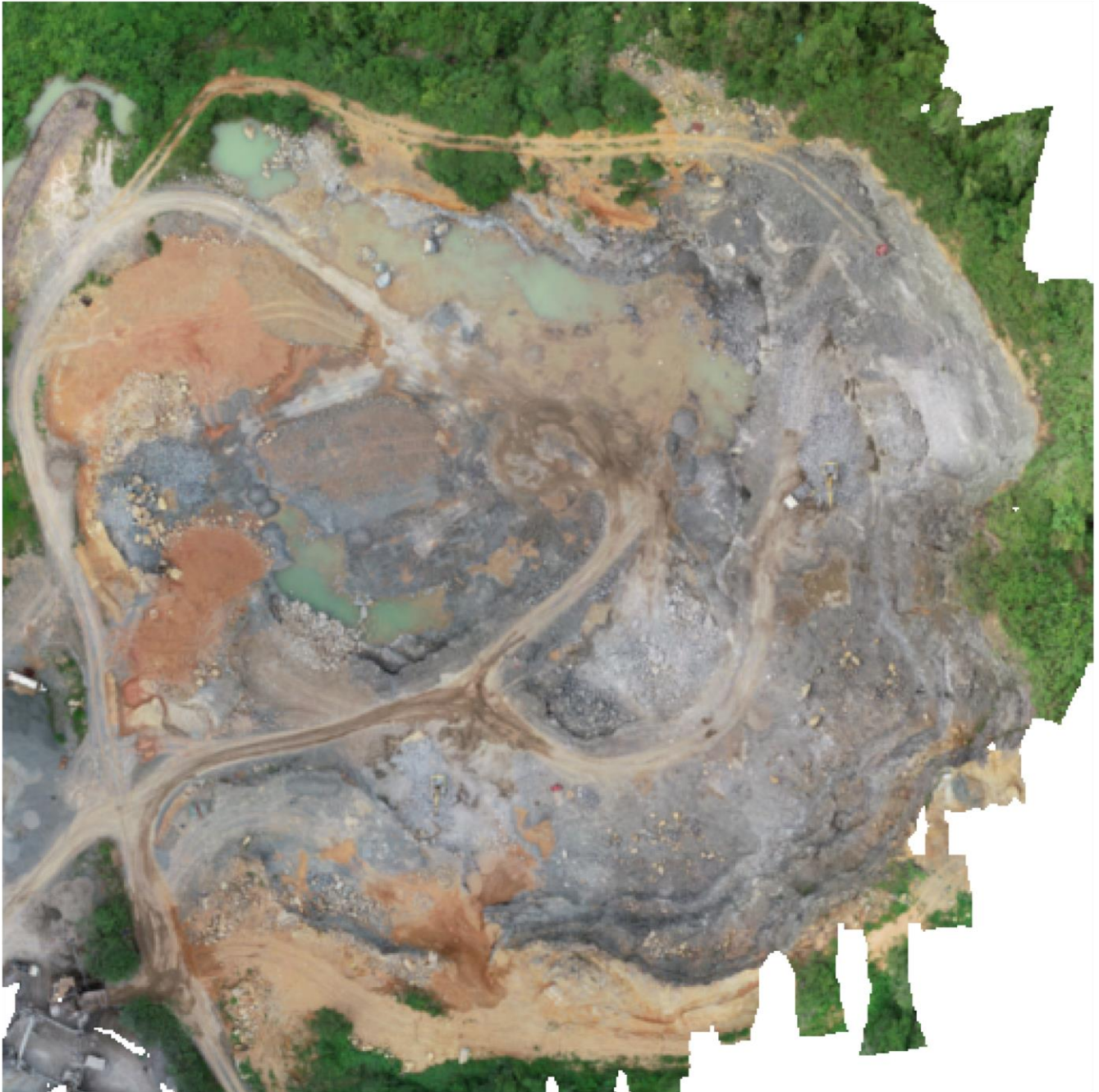
Survey Data
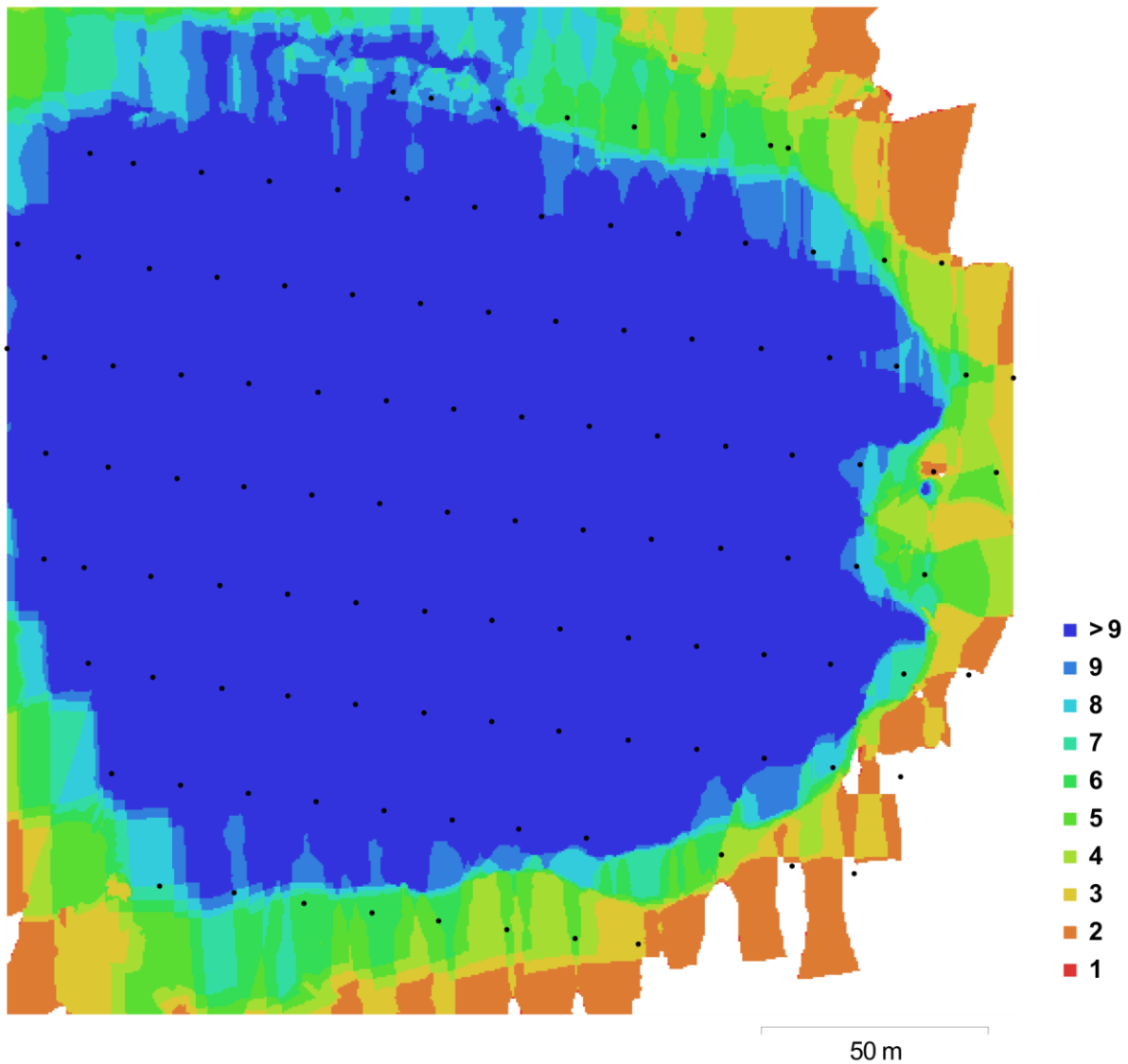
Fig. 1. Camera locations and image overlap.

Number of images:	118	Camera stations:	115
Flying altitude:	73.3 m	Tie points:	65,568
Ground resolution:	1.84 cm/pix	Projections:	362,181
Coverage area:	4.5e+04 sq m	Reprojection error:	1.06 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
FC6310 (8.8 mm)	5472 x 3078	8.8 mm	2.53 x 2.53 um	No

Table 1. Cameras.

Camera Calibration

1 pix
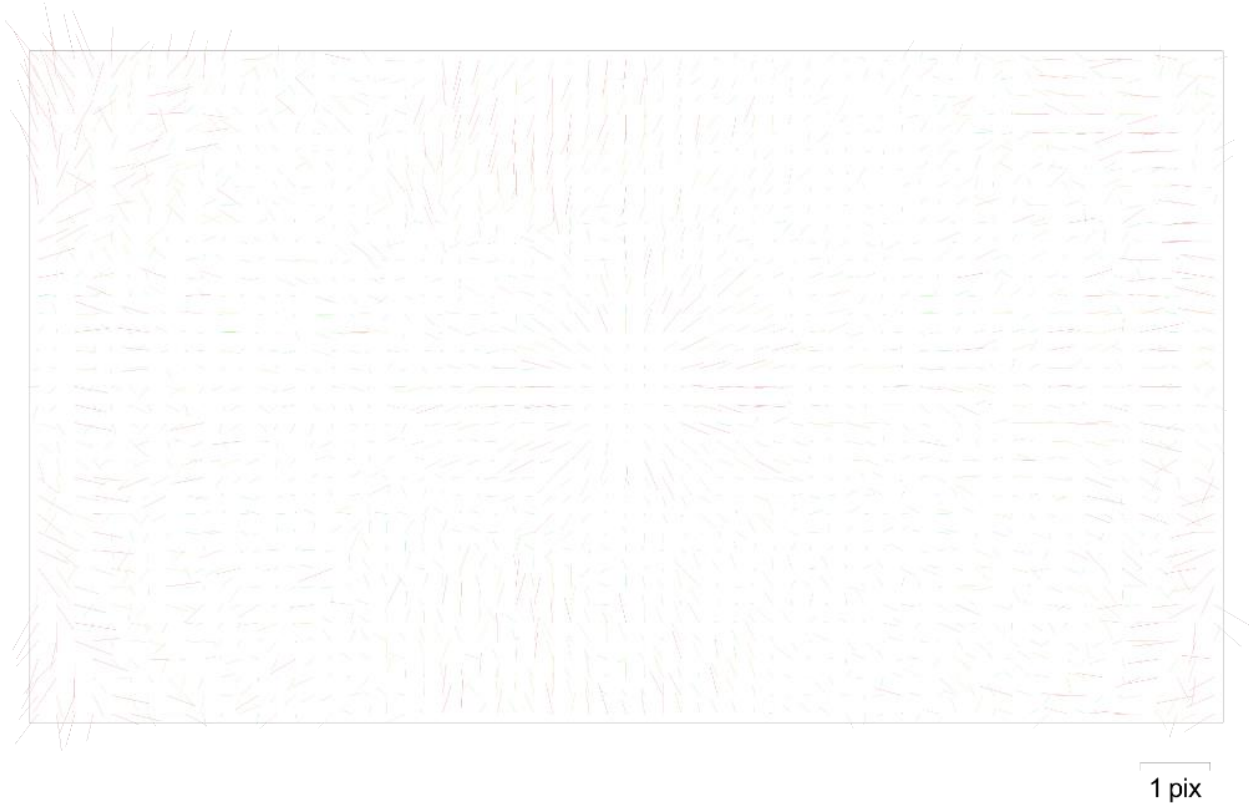
Fig. 2. Image residuals for FC6310 (8.8 mm).

FC6310 (8.8 mm)

118 images

Resolution	Focal Length	Pixel Size	Precalibrated
5472 x 3078	**8.8 mm**	**2.53 x 2.53 um**	**No**

Type:	Frame	Skew:	0
Fx:	3641.51	Cx:	2728.59
Fy:	3641.51	Cy:	1565.17
K1:	-0.00223112	P1:	0.000881173
K2:	-0.0152951	P2:	0.000790376
K3:	0.0153662	P3:	0
K4:	0	P4:	0

Camera Locations
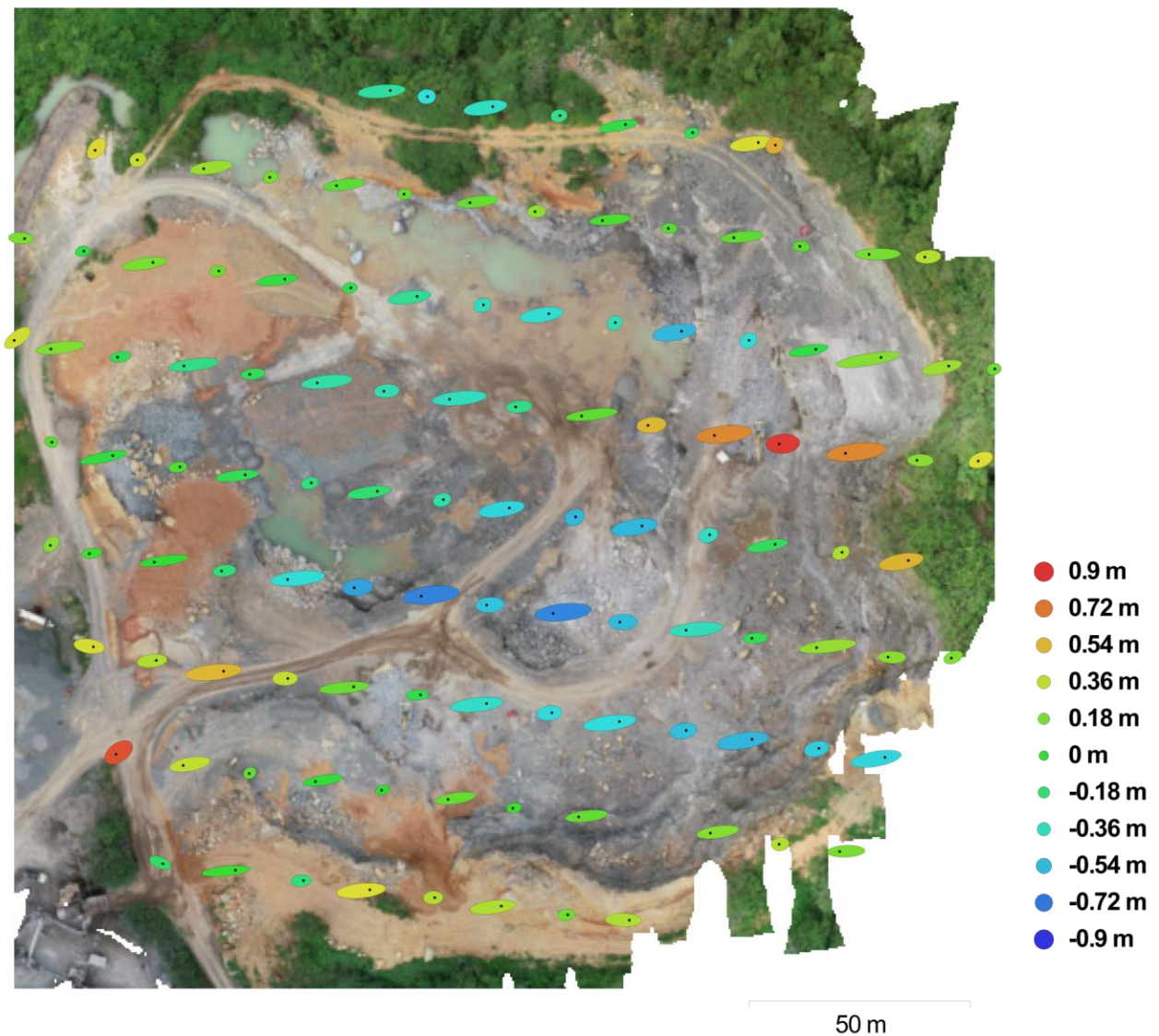
Fig. 3. Camera locations and error estimates.
Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	XY error (m)	Z error (m)	Total error (m)
2.77035	0.407925	2.80022	0.349371	2.82193

Table 2. Average camera location error.

Digital Elevation Model

Fig. 4. Reconstructed digital elevation model.

Resolution: 7.35 cm/pix

Point density: 184.872 points per sq m

Processing Parameters

General

Cameras	118
Aligned cameras	115
Coordinate system	WGS 84 (EPSG::4326)

Point Cloud

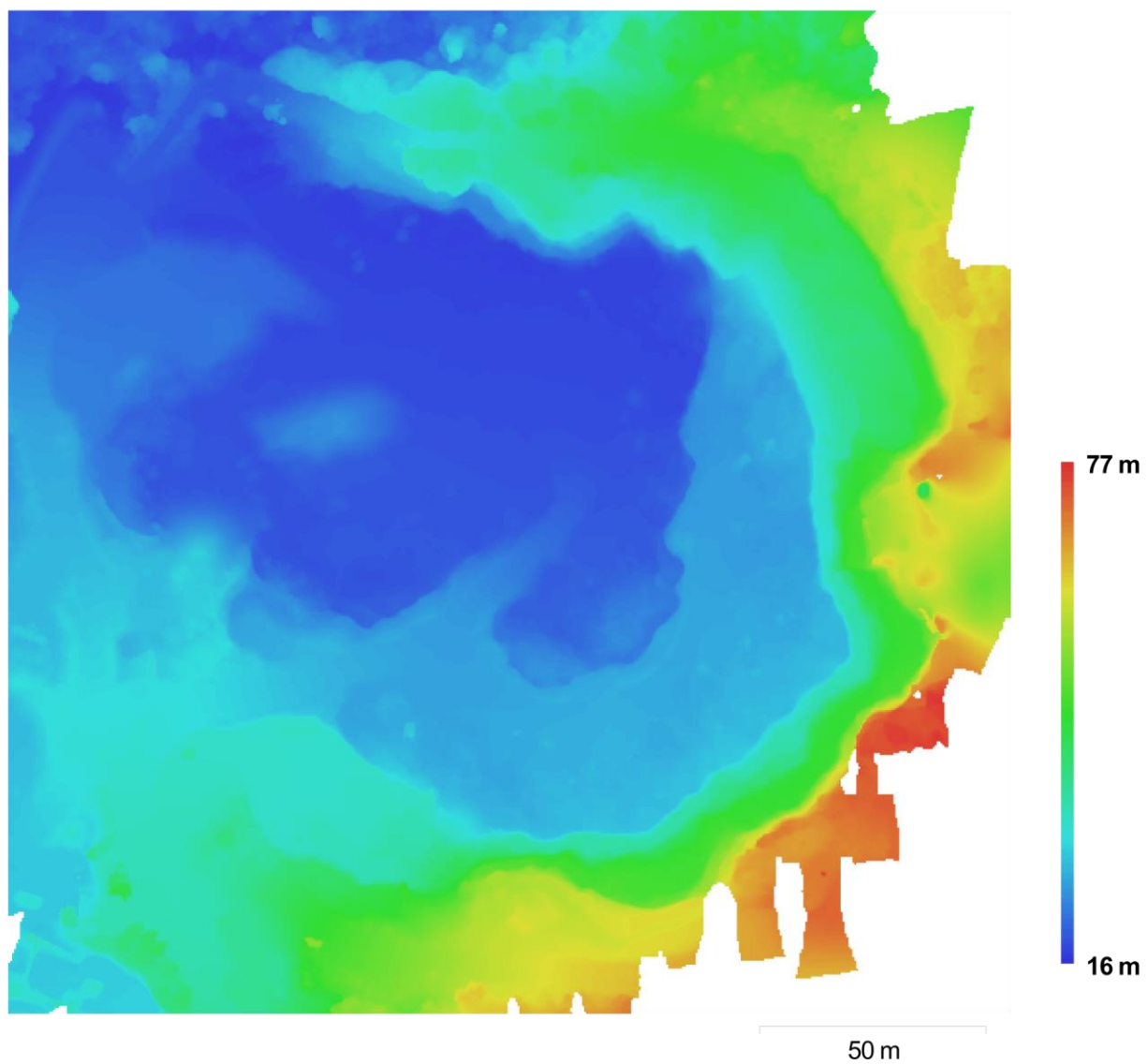|	
Points	65,568 of 75,685
RMS reprojection error	0.155486 (1.06199 pix)
Max reprojection error	0.468607 (29.7918 pix)
Mean key point size	6.38797 pix
Effective overlap	5.9944

Alignment parameters

Accuracy	Medium
Pair preselection	Disabled
Key point limit	40,000
Tie point limit	4,000
Constrain features by mask	No
Matching time	10 minutes 6 seconds
Alignment time	34 seconds

Dense Point Cloud

Points	13,866,376

Reconstruction parameters

Quality	Medium
Depth filtering	Aggressive
Processing time	3 minutes 8 seconds

DEM

Size	4,721 x 4,924
Coordinate system	WGS 84 (EPSG::4326)

Reconstruction parameters

Source data	Mesh
Interpolation	Enabled

Orthomosaic

Size	15,208 x 15,488
Coordinate system	WGS 84 (EPSG::4326)
Channels	3, uint8
Blending mode	Mosaic

Reconstruction parameters

Surface	DEM
Enable color correction	No

Appendix 03: DJI Phantom 4 Pro - Drone Specifications

Aircraft:

Weight (Battery & Propellers Included)	1388 g
Diagonal Size (Propellers Excluded)	350 mm
Max Ascent Speed	S-mode: 6 m/s P-mode: 5 m/s
Max Descent Speed	S-mode: 4 m/s P-mode: 3 m/s
Max Speed	S-mode: 45 mph (72 kph) A-mode: 36 mph (58 kph) P-mode: 31 mph (50 kph)
Max Tilt Angle	S-mode: 42° A-mode: 35° P-mode: 25°
Max Angular Speed	S-mode: 250°/s A-mode: 150°/s
Max Service Ceiling Above Sea Level	19685 feet (6000 m)
Max Wind Speed Resistance	10 m/s
Max Flight Time	Approx. 30 minutes
Operating Temperature Range	32° to 104°F (0° to 40°C)
Satellite Positioning Systems	GPS/GLONASS
Hover Accuracy Range	Vertical: ±0.1 m (with Vision Positioning) ±0.5 m (with GPS Positioning) Horizontal: ±0.3 m (with Vision Positioning) ±1.5 m (with GPS Positioning)

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 - ∞
ISO Range	Video: 100 - 3200 (Auto) 100 - 6400 (Manual) Photo: 100 - 3200 (Auto) 100- 12800 (Manual)
Mechanical Shutter Speed	8 - 1/2000 s
Electronic Shutter Speed	8 - 1/8000 s
Image Size	3:2 Aspect Ratio: 5472×3648 4:3 Aspect Ratio: 4864×3648 16:9 Aspect Ratio: 5472×3078
PIV Image Size	4096×2160(4096×2160 24/25/30/48/50p) 3840×2160(3840×2160 24/25/30/48/50/60p) 2720×1530(2720×1530 24/25/30/48/50/60p) 1920×1080(1920×1080 24/25/30/48/50/60/120p) 1280×720(1280×720 24/25/30/48/50/60/120p)
Still Photography Modes	Single Shot Burst Shooting: 3/5/7/10/14 frames Auto Exposure Bracketing (AEB): 3/5 bracketed frames at 0.7 EV Bias Interval: 2/3/5/7/10/15/20/30/60 s