User Manual

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ShapeMetriX

BlastMetriX

Field Procedures

User Manual
for Version 4.11
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CONTENTS

1 Introduction

This user manual addresses all topics for aerial and terrestrial imagery which corresponds to your *ShapeMetriX* or *BlastMetriX* system. It includes the required drone properties, field preparations and the guideline for surveying flights with drones. In addition, the specification for terrestrial applications with DSLR cameras is described for surface as well as for underground imaging. The captured images are directly transferred to the *SMX MultiPhoto,* which is the software component for 3D model generation from multiple, overlapping images or to the *SMX ReconstructionAssistant,* which is the software for 3D model generation from *Stereoscopic Image Pairs*.

Let us know if we can support you, and give us your valuable feedback. Only this way it remains possible to keep the system both, flexible enough for broad usage and sufficiently specific for your applications.

The Team of 3GSM

Graz, October 2024

2 Aerial imaging

2.1 Drone properties

For qualitative imaging of the area of interest following drone properties are recommended:

- Multi-copter preferred over fixed-wing UAV (see Figure 1)
  Allows the control over the picture orientation (parallel orientation or in-picture rotation)
- DSLR (digital single-lens reflex) system is preferred over built-in camera due to following quality demands:
  - picture quality
  - pixel size / senor size
  - senor and lens quality
- Camera MUST NOT frequently change focal length and focus
- Rotatable camera mount (gimbal) is recommended
- GPS-equipped drone is recommended

Figure 1: Multi-copter drone during recording

Check your drone / camera (mandatory information):

- EXIF (exchangeable image format) must be available for the individual images
- What information is required:
  - camera model
  - focal length
  - pixel size (pixel pitch)
  - number of pixels

Hint:
The EXIF information for individual is opened in Windows by following procedure: select the image / right mouse click / Properties / Details. See e.g. Figure 2.

EXIF Tag	Value
Filename	DJI_0435.JPG
ImageDescription	DCIM\100MEDIA\DJI_0435.JPG
Make	DJI
Model	FC6310
Orientation	Top left
XResolution	72
YResolution	72
ResolutionUnit	Inch
Software	v01.05.1577
DateTime	2020:03:18 11:21:54
YCbCrPositioning	Centered
ExifOffset	182
XPComment	Type=N, Mode=M, DE=None
XPKeywords	v01.05.1577;1.1.6;v1.0.0
ExposureTime	1/1000 seconds
FNumber	3.20
ExposureProgram	Manual control
ISOSpeedRatings	100
ExifVersion	0230
DateTimeOriginal	2020:03:18 11:21:54
DateTimeDigitized	2020:03:18 11:21:54
ComponentsConfiguration	CrCb
CompressedBitsPerPixel	3.25 (bits/pixel)
ShutterSpeedValue	1/999 seconds
ApertureValue	F 3.19
ExposureBiasValue	0.00

EXIF Tag	Value
Flash	No flash function
FocalLength	8.80 mm
FlashPixVersion	0010
ColorSpace	sRGB
ExifImageWidth	5472
ExifImageHeight	3078
InteroperabilityOffset	656
ExposureIndex	0.00/0.00
FileSource	DSC - Digital still camera
SceneType	A directly photographed image
CustomRendered	Normal process
ExposureMode	Auto
White Balance	Manual
DigitalZoomRatio	0.00/0.00 x
FocalLengthIn35mmFilm	24 mm
SceneCaptureType	Standard
GainControl	None
Contrast	Normal
Saturation	Normal
Sharpness	Normal
SubjectDistanceRange	Unknown
Serial Number	fb36a81fce851f84b002eee4a8a7
GPS information:	
GPSVersionID	2.3.0.0
GPSLatitudeRef	N

Figure 2: EXIF information

2.2 Preparation

What are the requirements of the project? Very often this step is omitted and results that images respectively the 3D models does not fit the project.

Important:
The smallest rock mass features or the smallest fragment to be measured determine the ground sample distance (GSD). All the flight planning and processing efforts relate to the GSD.

Ground sample distance

The GSD is the average size of a pixel on the ground and is measured in mm, cm, m etc.

$$GSD\ [m] = \frac{dimension\ (height, length, etc.)\ of\ an\ object\ [m]}{\#\ pixels\ along\ the\ dimension\ of\ the\ object\ [-]}$$

Example:

- Height of a rock slope: 50 m
- The rock slope covers 80% of the photo height (the rest is sky and floor)
- Camera sensor is portrait format has 3078 pixels

$$GSD\ [m] = \frac{50\ [m]}{3078\ pixels\ \cdot\ 0.8\ ct} = 0.0203\ m\ \triangleq\ 2.03\ cm$$

2.3 Nadir flights

Note:
Nadir is the direction pointing directly below a particular location, i.e. vertically downwards.

Nadir flights are a typically set-up for:

- Surveying operation to generate maps, etc.
- Fragmentation analysis of blasted muck piles in quarries and open pit mines

Hint:
Use grids; several overlapping flying paths (see Figure 4, Figure 3, and Chapter 2.4). The grids can be regular but also interactive that follow the tracks approximately.

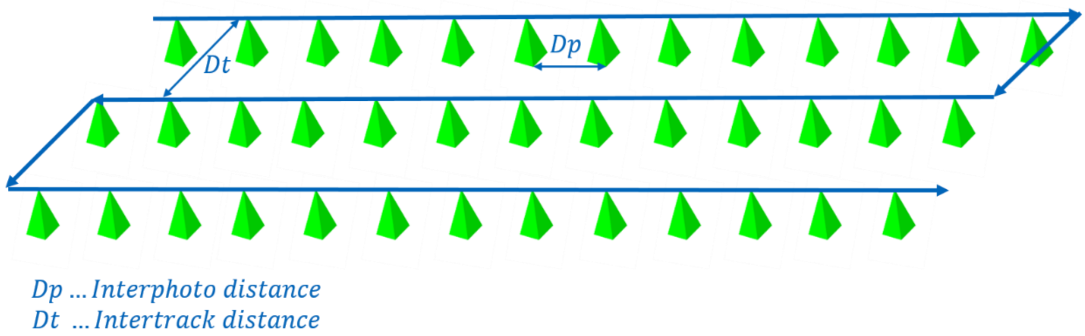


Figure 3: Flying grid

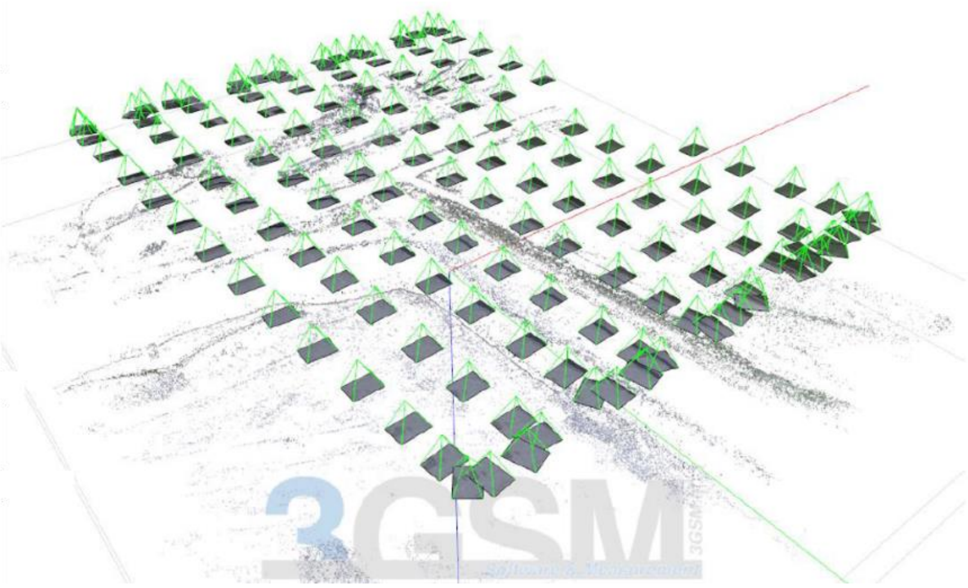


Figure 4: Example of a nadir flight with an almost regular grid. The green pyramids constitute camera positions at the drone during photo taking. At the end of the track one can notice the photo taken while the drone was turning.

2.4 Image overlap

The camera flies along a predefined meandering track while photos are taken (Figure 3). The distance between two adjacent photo taking positions is called *Interphoto* distance. The distance between two adjacent tracks of a meander is called *Intertrack* distance. Distances between subsequent photos should be:

- 80% in flight direction (*Interphoto* distance)
- 75 % lateral (*Intertrack* distance)

Interphoto distance:

Dp [m] ≤ 0.2 · *#pixels Y · GSD [m]*

Intertrack distance:

Dt [m] ≤ 0.25 · *#pixels X · GSD [m]*

Note:
The GSD is squared inside the covered area per photo (2 x GSD → 4 x area). GSD is of "squared" importance!

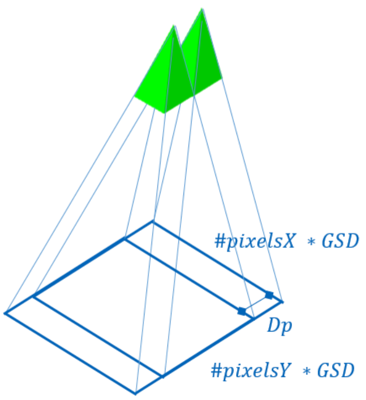


Figure 5: Schematic sketch of the Interphoto overlap

Example:

- Project requires a GSD of 10 mm
- Photo size 5472 x 3078 pixel

Dp ≤ 0.2 · 3078 *[px]* · 10 *[mm]*

Dt ≤ 0.25 · 5472 *[px]* · 10 *[mm]*

Dp [m] ≤ 6.2 *m* (20 *ft*)

Dt [m] ≤ 13.7 *m* (45 *ft)*

2.5 Flight altitude

Note:
The flight altitude determines the GSD and this is the basis for all other planning (see also Chapter 2.2).

Example:

- The smallest rock mass feature to be measured should be 1 cm
  Project requires a GSD of 10 mm/pixel (0.4 inch/pixel)
- EXIF information:
  - Camera FC6310 (helps to find specifications)
  - Focal length 8.8 mm
  - 5472 x 3078 pixel
- Camera specifications / pixel size: 0.0024 x 0.0024 mm

$$Altitude\ [m] = \frac{focal\ lenght\ [mm]\ \cdot\ GSD\ [mm]}{pixels\ size[mm]\ \cdot\ 1000}$$

$$37\ [m] = \frac{8.8\ [mm]\ \cdot\ 10\ [mm]}{0.0024\ [mm]\ \cdot\ 1000}$$

→ $Altitude\ 37\ m\ (120\ ft)$

2.6 Varying viewing angles

Inclined camera angles are required for rock slopes to have optimum view to the surface (perpendicular). Vertical or subvertical grids flight are typical for rock slopes and bench faces for blasting, very high muck piles, etc. In general, camera locations shall have (Figure 6):

- Perpendicular view to the objects surface
- Similar distance (i.e. constant image scale)

Note:
In case of changing orientation of the rock slope (or any other object) camera angles need to adjust to maintain the optimum view to the surface.

Fly instructions (Figure 7):

- Adapt drone´s altitude and viewing angle
- Keep angular changes < 30° for subsequent photos
- Obey the suggested overlaps (see Chapter 2.4)

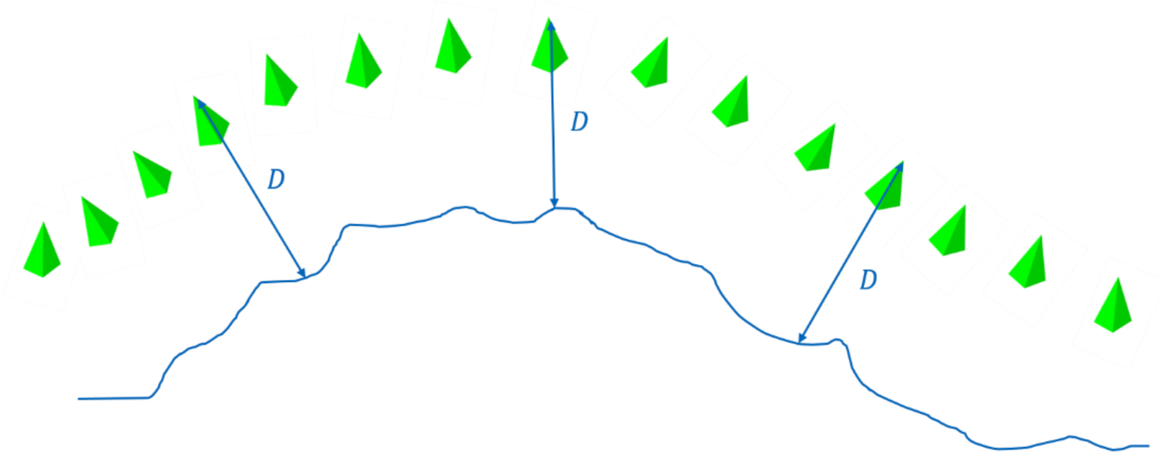


Figure 6: Setup for varying the viewing angle – constant distance

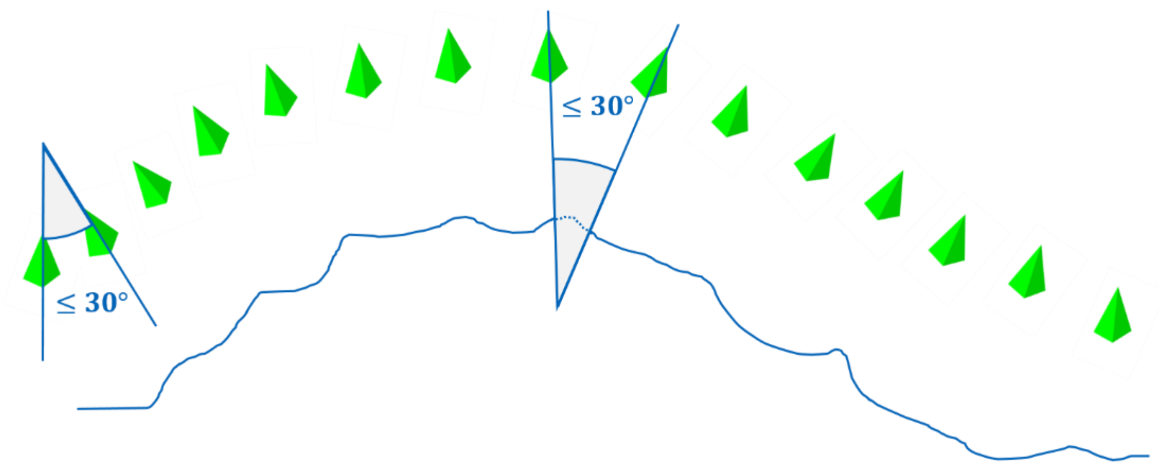


Figure 7: Setup for varying the viewing angle – angular changes

2.7 Fly instructions

Bench faces and crest (see Figure 8 to Figure 10)

1. Fly nadir (or nadir grid) - obey the suggested overlaps (see Chapter 2.4)
2. Tie in oblique views
    - fly frontal to the face
    - keep adjacent camera angles < 30° by using intermediate tracks
    - Obey the suggested overlaps

Note:
In the case it is not possible to take images beyond the limits of the region of interest, aerial images can be extended with terrestrial images by recording *Image Fans* (see Chapter 2.5).

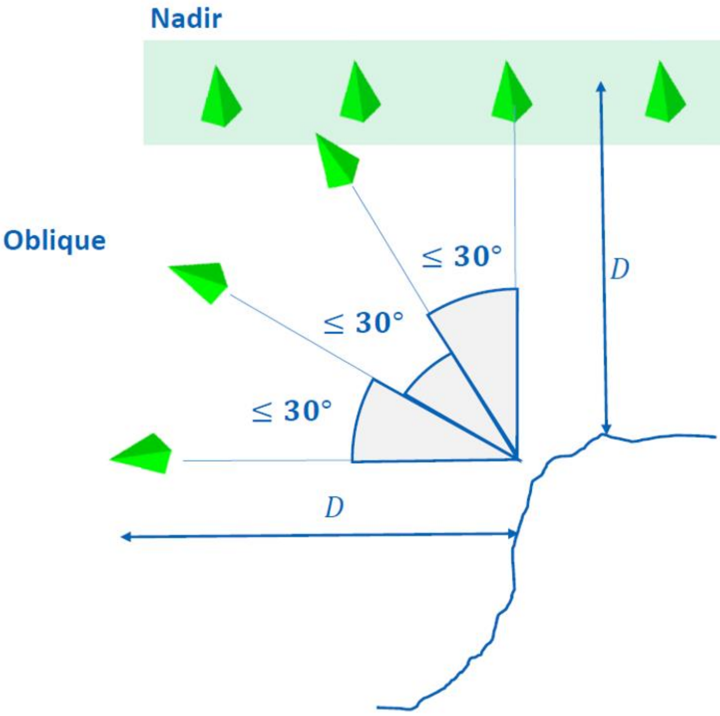


Figure 8: Setup for angular changes

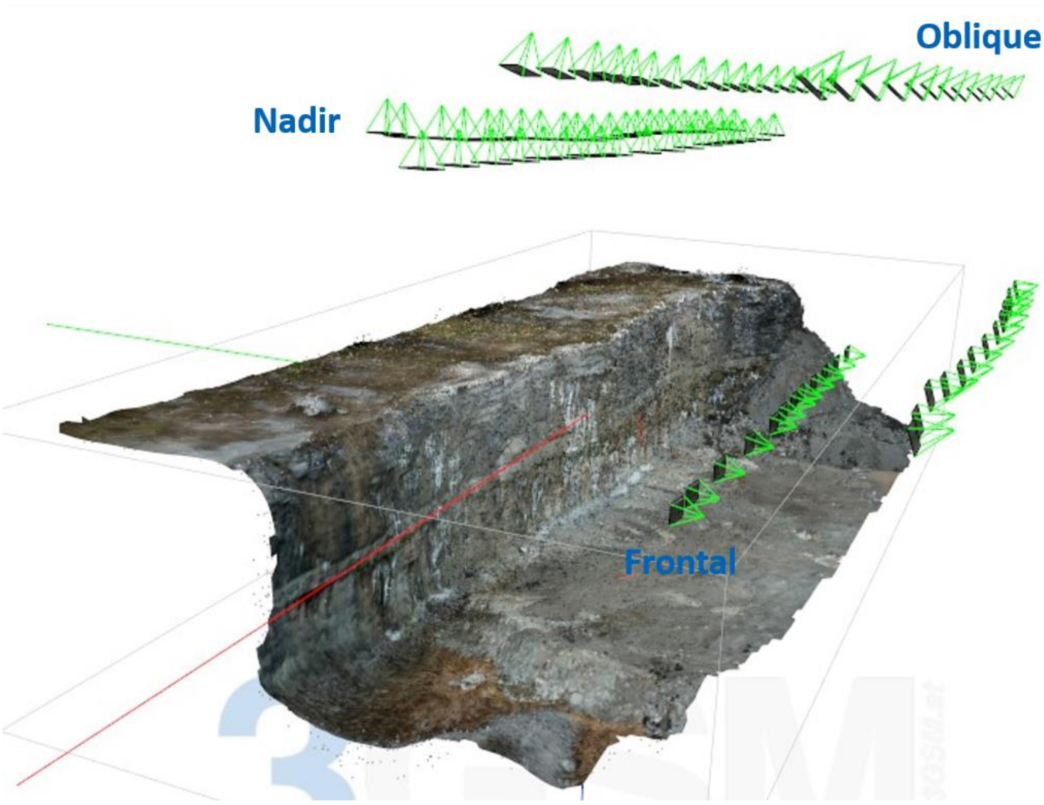


Figure 9: Example of a manual flight at the bench. The green pyramids constitute camera positions at the drone during photo taking. One nadir track and several oblique views to tie in the frontal view to the face.

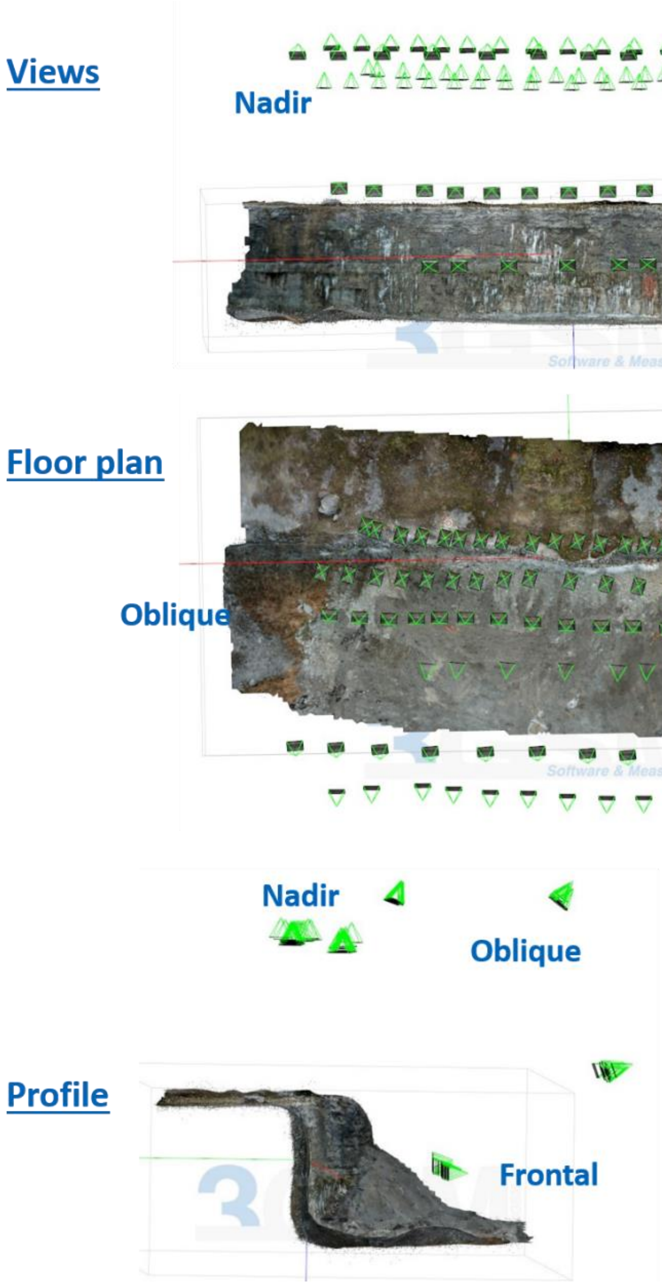


Figure 10: Detailed views of the flight plan shown in Figure 8

Very high muck piles (see Figure 7)

- Adapt drone´s altitude and viewing angle
- Keep angular changes < 30° for subsequent photos
- Obey the suggested overlaps (see Chapter 2.4)

Note:
The instructions (imaging setup) given in Chapter 2.6 may also be applied for high muck piles.

2.8 Scale changes

Changes in the imaging distance shall be smaller than a factor of 2 (Figure 11). Do not mix images with strong size changes (larger than factor 2).

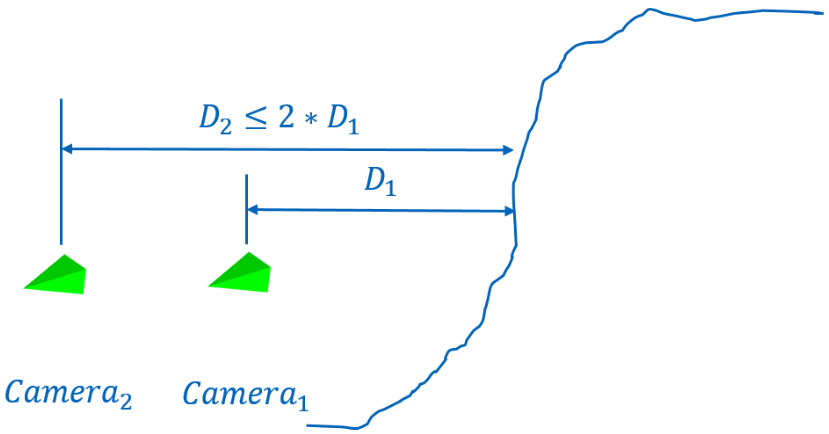


Figure 11: Setup for changing the imaging distances

2.9 Registration by drone GPS

Standard drone GPS provides good scale but not correct positioning. It is usually sufficient for 3D fragmentation analysis. For rock mass characterization as well a blast design where correct positioning is important, drones with RTK-GPS included are recommended. These drones determine the exact position at the time of photo taking and use this information for referencing.

At present, it is necessary to place one reference point on the ground for the work flow – *Single Point* mode in the *SMX MultiPhoto* software (see corresponding user manual).

3 Terrestrial surface imaging with DSLR camera

3.1 Imaging unit

The imaging unit is provided by 3GSM and includes following items:

- calibrated camera including battery and the standard zoom lens
- Wide angle zoom lens (optionally)
- Tripod (optionally)
- memory card inserted in the camera
- battery charger incl. cable
- USB transfer cable
- short instructions (behind foam of top cover)
- *Range Poles* with target disc (optionally)
- *Delimiters* with target disc (optionally / *BlastMetriX*)
- *TLS Markers* with target disc (optionally / *BlastMetriX*)

Note:
Camera calibration means determining the imaging behaviour of the camera lens pair. Each camera is uniquely calibrated making the camera measuring device.

Attention:
The number of items varies depending on the *ShapeMetriX/BlastMetriX* configuration.

3.2 Preparations

Before starting field work following issues should be checked:

- Optionally, check the *Range Pole* assemblage(s) for completeness and functionality (see Chapter 8)
- State of camera battery charge
  This can be checked through the LCD display on top of the camera body. The battery must be inserted and the camera switched on. In case of doubt, batteries should be charged with the provided battery charger. Further reading: Manual of the camera manufacturer.
- Camera settings
  Several camera settings are pre-set from 3GSM. Usually these settings remain unchanged. Check the camera settings from your camera settings sheet. If you don’t have your camera settings sheet available, contact 3GSM or your service partner.
- Memory capacity on camera
  The usual scope of supply includes a 32 GB memory card.

- Camera program selector (Figure 12)
  The wheel is set to "*P*", which activates automatic exposure control and focussing but prevents the built-in flash from working as its working range is just a few metres. Typical programmes used are "*P*" and "*A*".

- Shoot a test picture
  Switch the camera on by turning the "*On/Off*" switch, look through the view finder and push the trigger. The resulting picture is displayed instantly on the monitor at the camera's back.

- Camera use from tripod (Figure 13)
  In general it is not necessary to take images with a camera mounted on a tripod. Nevertheless, under low light conditions the use of a tripod might be advantageous by allowing increased exposure times and/or smaller apertures. The *ShapeMetriX/BlastMetriX* system in its configuration for tunnelling and underground application is by standard equipped with a tripod and a three-way camera head with a joystick for releasing and fixing the swivel head. This allows maximum flexibility even when using the camera from a tripod. Figure 13 shows the assembly of the camera with the tripod and the finally assembled camera.

1 Trigger
2 Focal length
3 *On/Off* switch with program selector

Figure 12: Camera program selector - Canon EOS 5D MARK III camera

1 Assembly of camera
2 Three way tripod
3 Camera
4 Assembly plate
5 Tripod head

Figure 13: Assembly of the camera on the tripod

Hint:
The monitor at the camera's back can be used as a view finder if the *Live View* mode is used For operating the camera in the *Live view* mode, please refer to the camera's user manual. Turn off the *Live View* mode after taking some photos to avoid heating of the camera sensor.

Hint:
It is recommended to use the extremal settings of the zoom lens (e.g. 10 mm or 20 mm for the Sigma lens or 17 mm or 50 mm for the Tamron lens). If the imaging conditions (distance to the bench face) do not vary much, the lens zoom can also be fixated by an adhesive tape.

3.3 Imaging

Terrestrial surface imaging with a SLR camera should follow up the same principles as aerial imaging (see Chapter 2 and Figure 14):

- overlap between adjacent photos 80%
- angular changes between adjacent photos < 30°
- scale changes < factor 2
- known camera properties

Attention:
In order to ensure optimal and robust processing of images it is recommended to provide the same camera settings for every imaging line. By switching off the *Autofocus* after focussing the camera settings are preserved. After taking the full set of photos of an image line, the Autofocus may be reactivated.

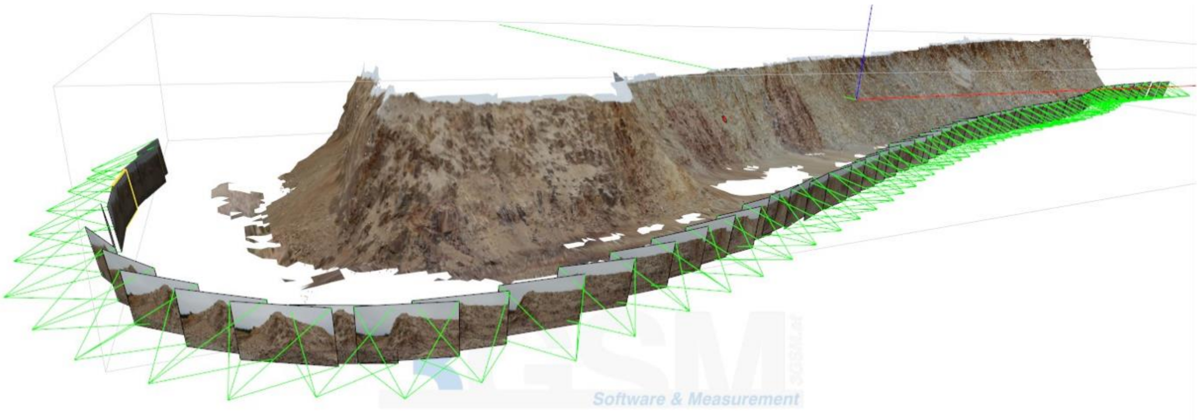


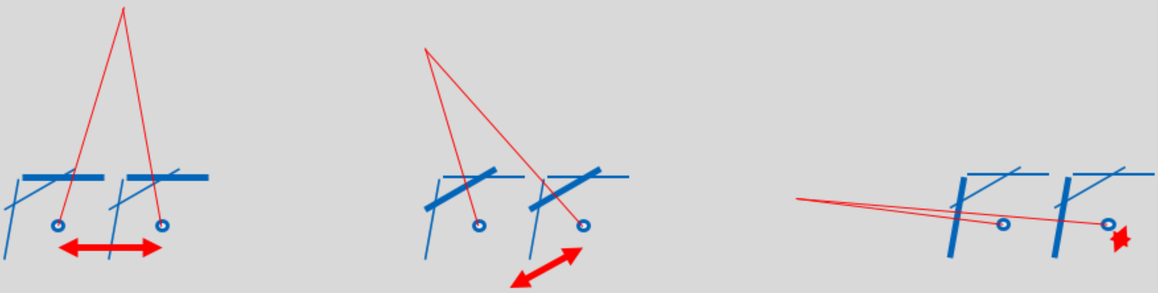
Figure 14: Example of a terrestrial imaging setup with a SLR camera

3.4 Image fans

In the case it is not possible to take images beyond the limits of the region of interest, *Image Fans* should be taken in order to completely capture the region of interest up to its boundaries (Figure 15). *Image Fans* are a series of photos taken from the same position but with different camera orientation (Figure 16). It is important to maintain a high overlap.

Attention:
A single image fan does not show a stereo base and a 3D model reconstruction is not possible firm a single image fan. Treat single images fans as if they were a single photo. For 3D reconstruction images three or more image fans from different positions are required such that each point appears in every fan.

Hint:
Take care to avoid vanishing baselines.



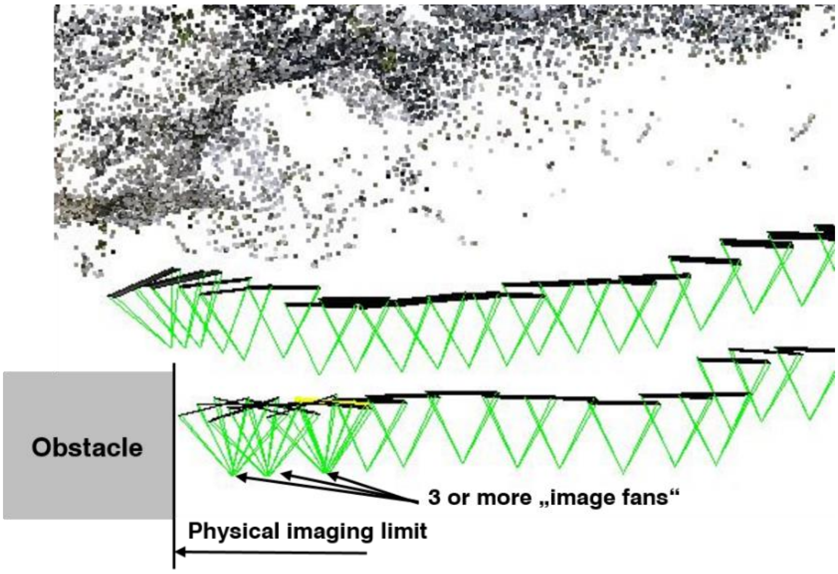


Figure 15: Terrestrial imaging of Image Fans

Figure 16: Image Fans: series of photos of the same location with different camera orientation

4 Underground application

The imaging setup in underground environment differ from surface imaging due to shortage of space and reduced lightning conditions. Imaging is typically performed with an imaging unit provided by 3GSM (see Chapter 3.1). Typically it includes a calibrated camera system and hardware element used for the geometric referencing of the imaging area (see Chapter 8.2).

Note:
The *ShapeMetriX/BlastMetriX* system in its configuration for tunnelling and underground application is by standard equipped with a tripod and a three-way camera head with a joystick for releasing and fixing the swivel head. This allows maximum flexibility even when using the camera from a tripod.

Attention:
In the following examples and imaging setup recommendations are given. They may not be generally applicable and have to be adapted in respect to the specific requirements of the project. Please contact 3GSM for your specific demands.

4.1 Lightning

A well illuminated surface is of major importance for the robust 3D model generation and subsequently for an accurate rock mass characterisation. Please notice following recommendations:

- flood light is preferred
- flash light should be avoided
- two are more light sources preferred
- avoid shadows while taking photos

Note:
When facing poor lightning conditions the camera should be mounted on a tripod to prevent a camera shake.

4.2 Field procedure

1. Activate the camera:
    - use the A-Setting (Aperture priority)
    - set *F-number* to *F8*
    - use minimum or maximum focal length if possible
    - use autofocus to focus the lens, then turn to manual focus for taking the images for one patch

2. Check lighting conditions

3. Surveyed *Ground Control Points (GCP)* or *Range Pole*(s) (see Chapter 5 and 8) should be well visible in the pictures
4. Check visibility - Take care that no obstacles are between the imaging locations and the tunnel face ore the sidewalls
5. Take the images
6. Switch off camera

Note:
Exposure time is chosen automatically and can take a few seconds depending on the available light.

4.3 Imaging – face only

Procedure;

1. Set up lightning - two flood lights left and right are recommended
2. Establish and survey reference points (*GCP*) **or** set up a *Range Pole* and take an azimuth measurement
3. Provide free view to the face
4. Set up and turn on camera
5. Choose a distance where the tunnel face is imaged almost maximal. The measuring area should fill the image tot maximum extent. A part of the tunnel wall shall be visible with the image. See Figure 17. The chosen distance depends on:
    - the target GSD
    - focal length
    - available space
6. Take four slightly converging photos from left to rights or vice versa (Figure 18):
    - distance between neighbouring photos should be about 10% of the face distance
    - the maximum distance between the photos should be about 30% of the face distance
    - Focus to image the imaging area
      Aim the imaging area and press the trigger slightly. If the camera focusses it gives a beep sound. Use phase auto focus (Quick mode).
    - Turn of the auto focus by changing the small switch on the lens from *AF* to *MF* in order to preserve the camera settings
    - Press the trigger, the camera should check for the rest. Image quality (brightness and crispness) can be checked instantly on the monitor at the camera back (viewing can be zoomed.

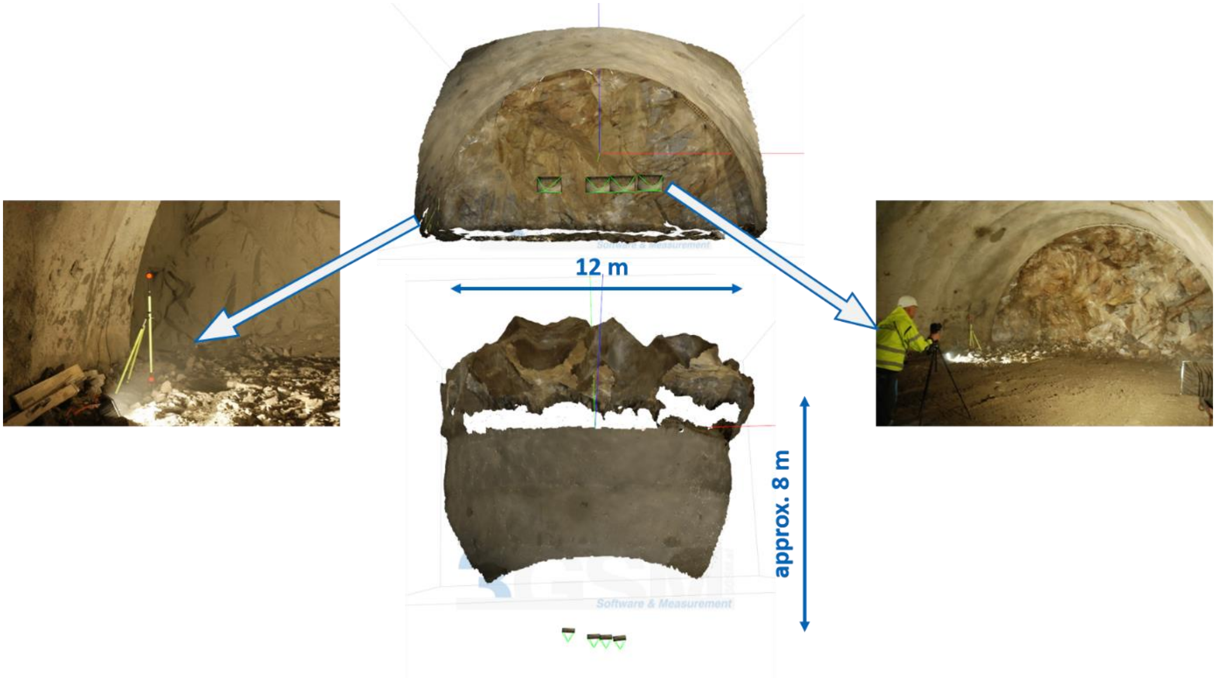


Figure 17: Example of imaging a tunnel face

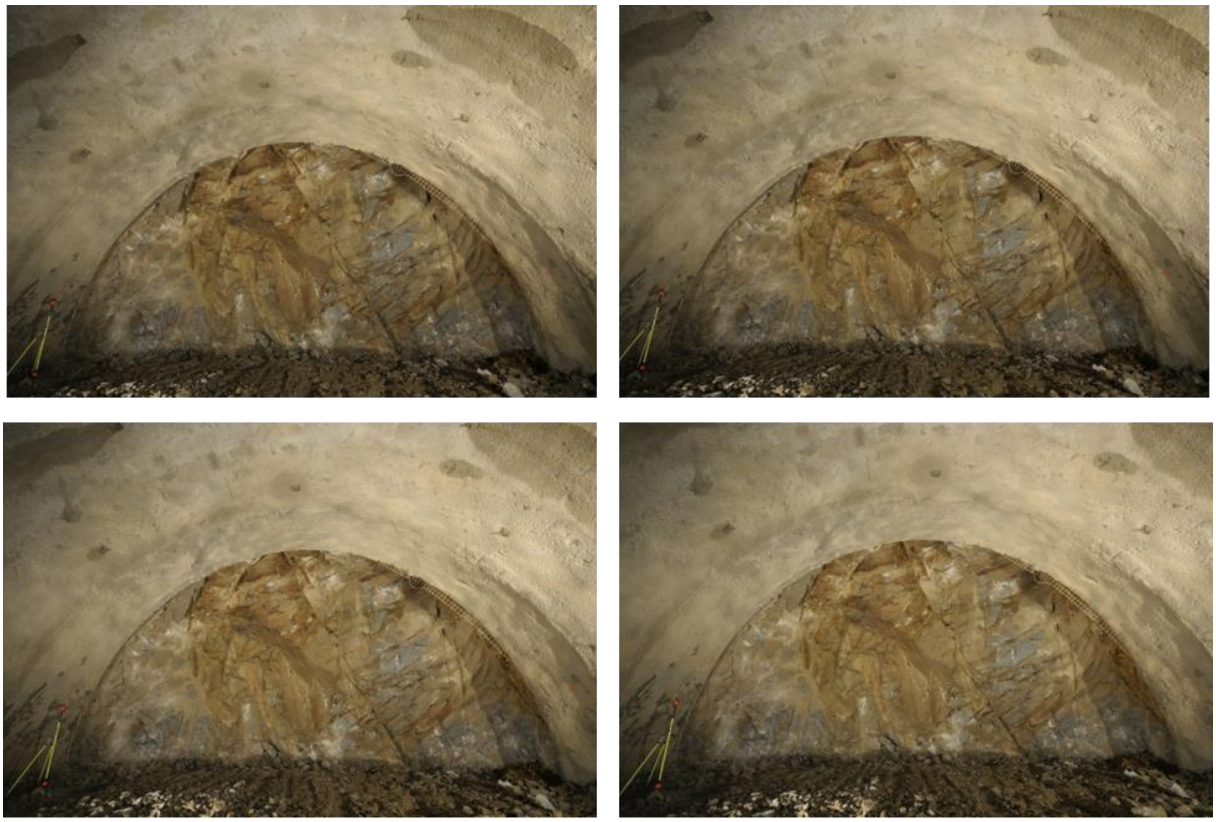


Figure 18: Four slightly converging photos from different positions

4.4 Imaging of face, sidewall and crown

Important:
Maintain an angle smaller than 30° between imaging lines and ensure an overlap of 80% between adjacent photos of different imaging lines.

Imaging of the tunnel face, sidewall and crown (Figure 19 to Figure 24, Figure 44):

1. Set up lightning - two flood lights left and right are recommended
2. Establish and survey reference points (*GCP*) **or** set up a *Range Pole* and take an azimuth measurement
3. Provide free view to the face
4. Set up and turn on camera
5. Choose a distance area of interest is imaged almost maximal. The measuring area should fill the image to the maximum extent. See Figure 17. The chosen distance depends on:
    - the target GSD
    - focal length
    - available space
6. Take four slightly converging photos from left to rights or vice versa **for each imaging line**
    - distance between neighbouring photos should be about 10% of the face distance
    - the maximum distance between the photos should be about 30% of the face distance
    - Focus to image the imaging area
      Aim the imaging area and press the trigger slightly. If the camera focusses it gives a beep sound. Use phase auto focus (Quick mode).
    - Turn of the auto focus by changing the small switch on the lens from *AF* to *MF* in order to preserve the camera settings
    - Press the trigger, the camera should check for the rest. Image quality (brightness and crispness) can be checked instantly on the monitor at the camera back (viewing can be zoomed.

Important:
Take transitory photos (intermediate tracks) to keep the angle between imaging lines < 30° (see Figure 8, Figure 25 and Figure 26).

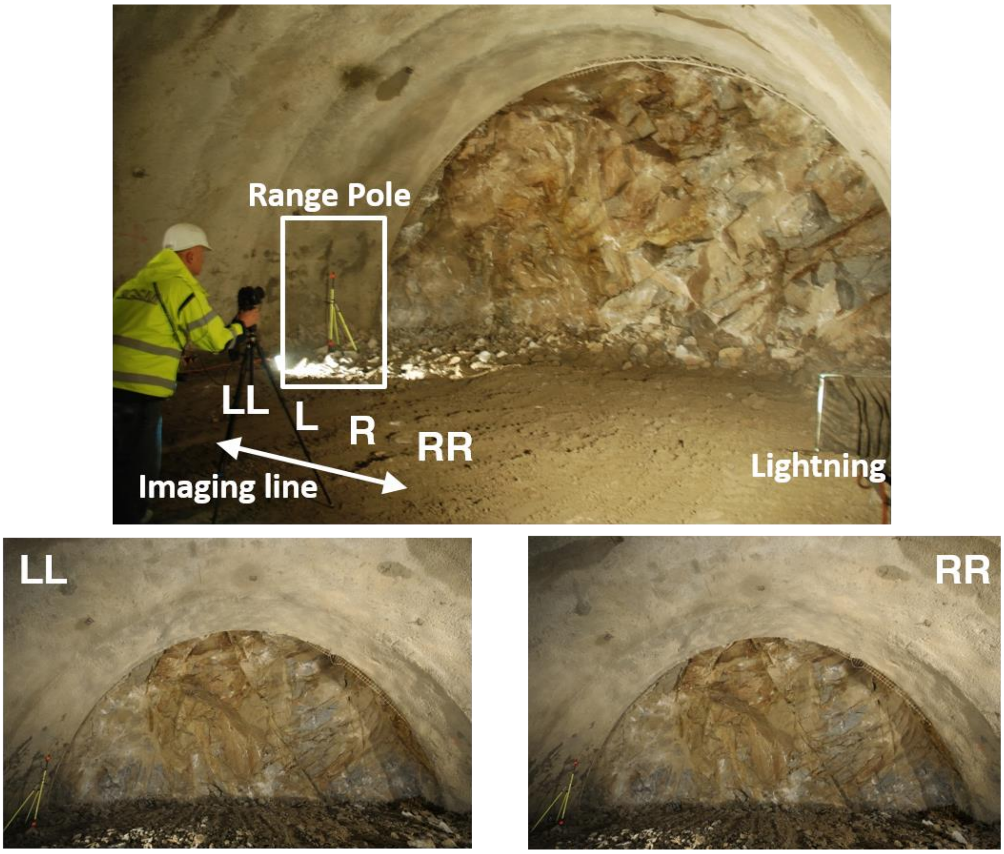


Figure 19: Example of imaging the tunnel face

Figure 20: Example of imaging the left sidewall

Figure 21: Example of imaging the left springline

Figure 22: Example of imaging the right springwall

Figure 23: Example of imaging the right sidewall

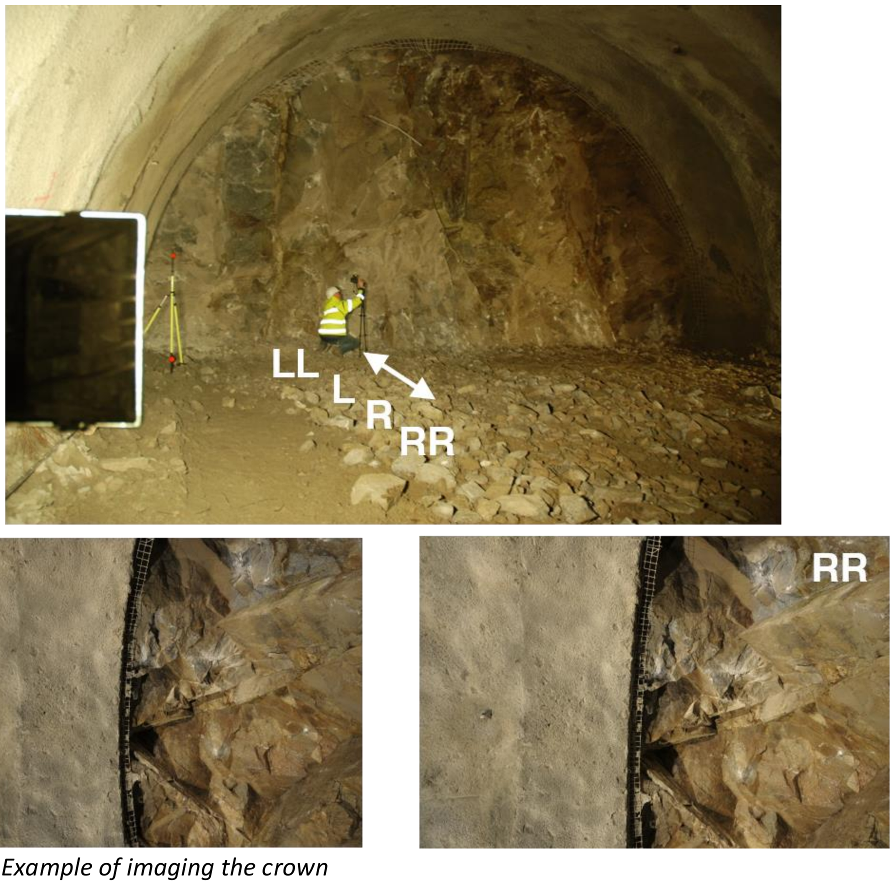


Figure 24: Example of imaging the crown

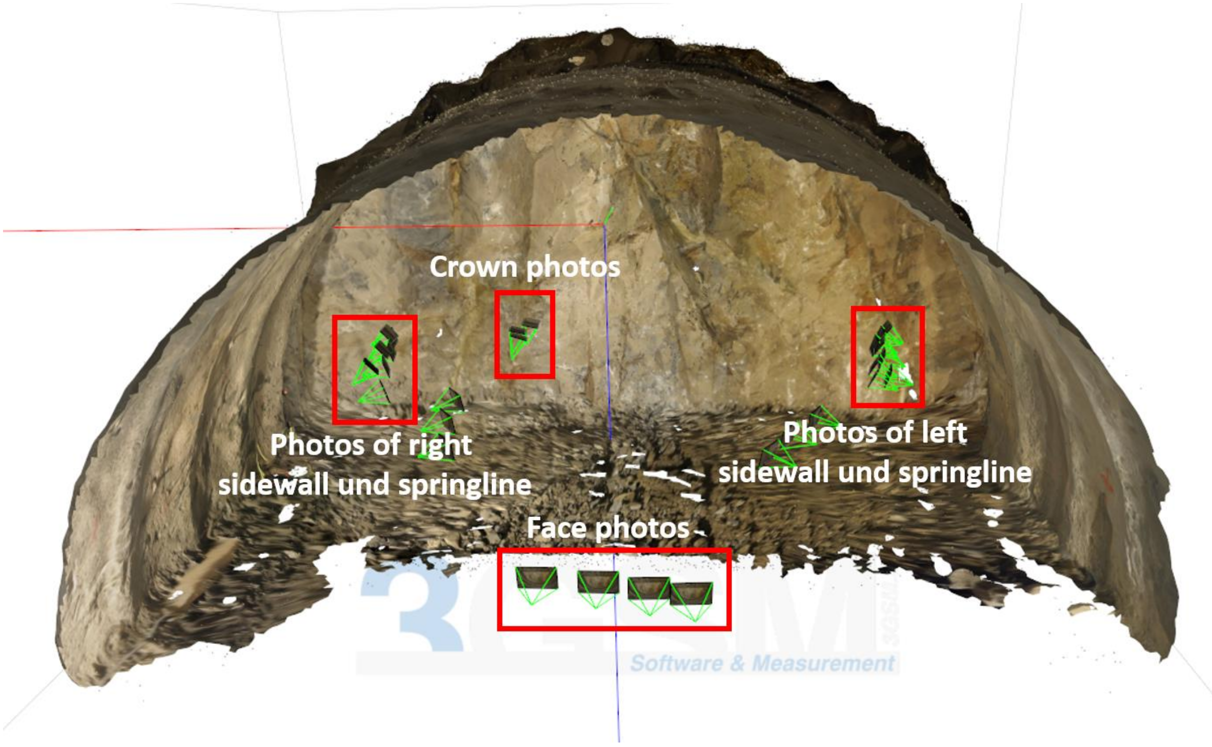


Figure 25: Example of image setup in tunnel – imaging the face, left and right sidewall and springwall and the crown – Part1

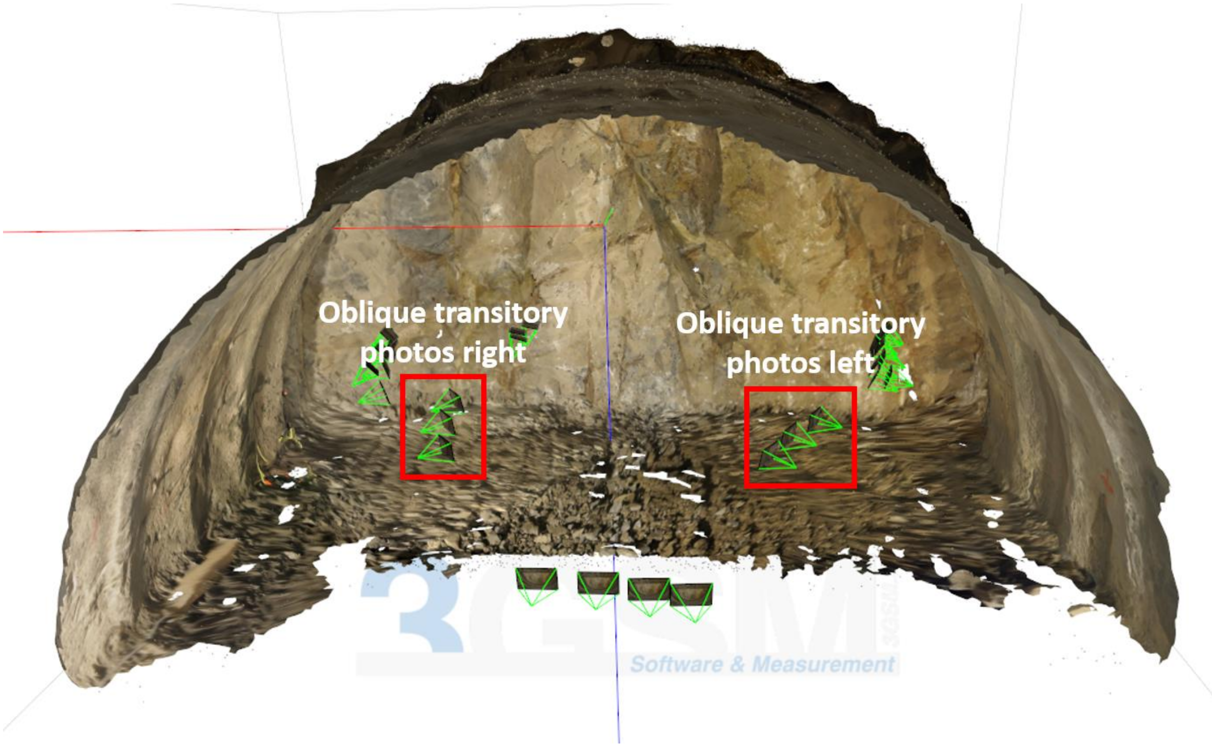


Figure 26: Example of image setup in tunnel – imaging of transitory photos – Part 2

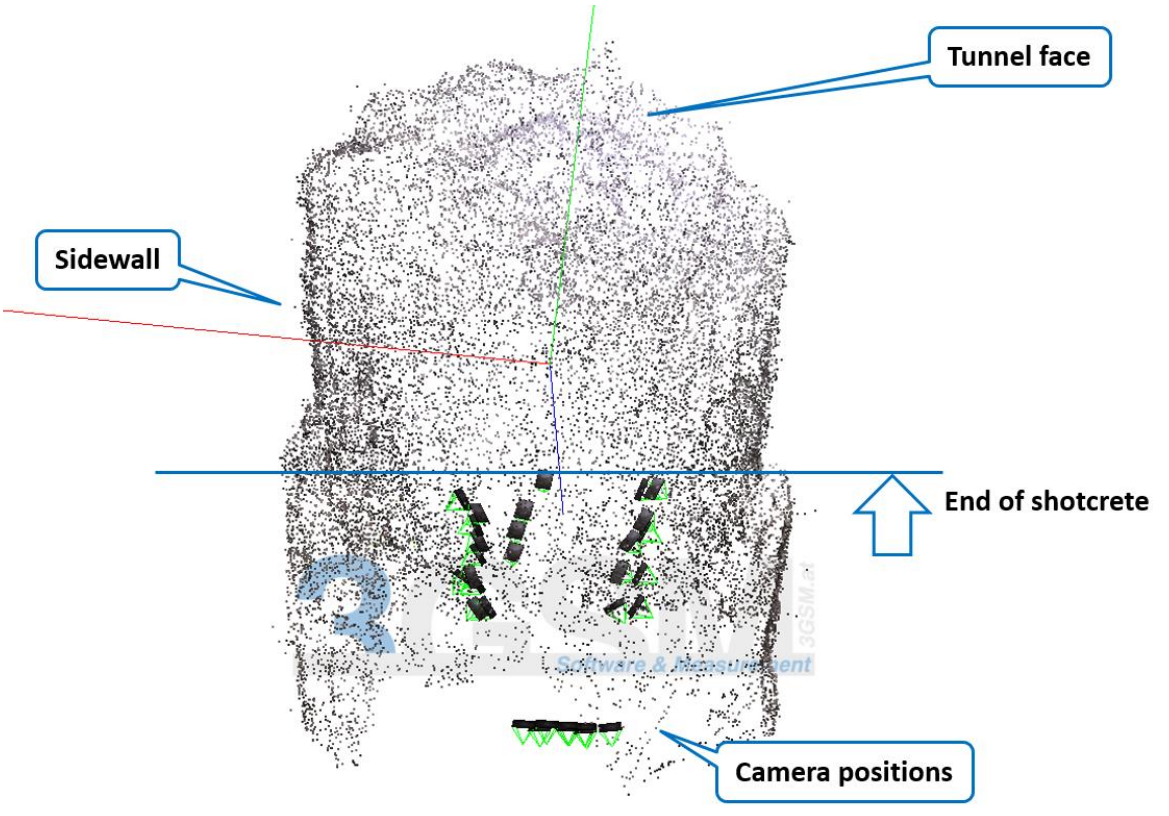


Figure 27: Exemplary setups of camera positions relative to a tunnel face

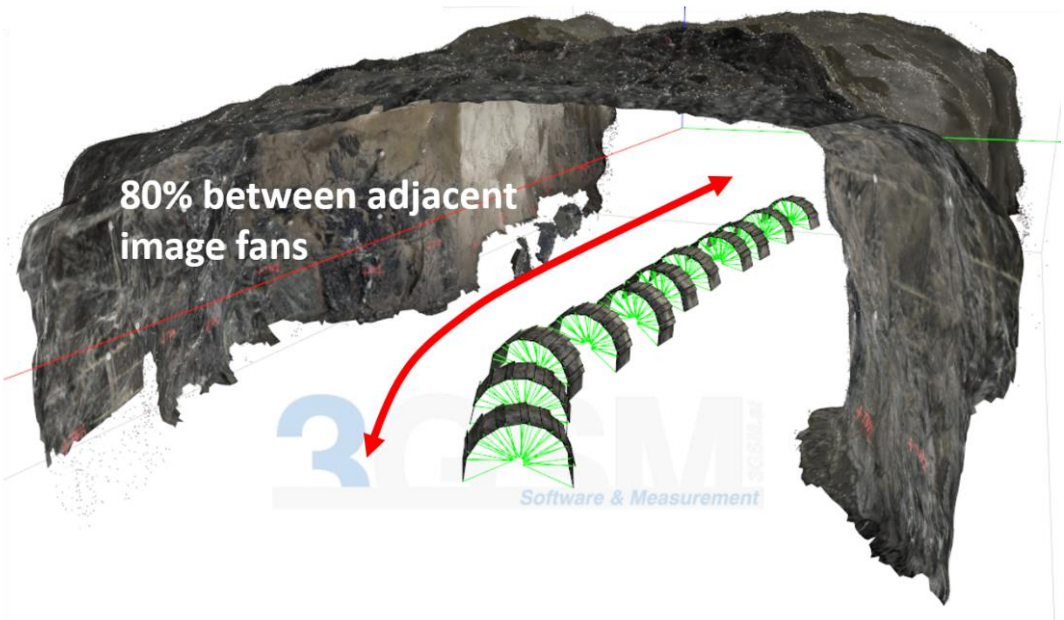


Figure 28: Exemplary setup for imaging the tunnel perimeter without the tunnel face

5 Data acquisition of Stereoscopic Image Pairs

5.1 Setup

From the *Stereoscopic Image Pair* a three-dimensional model is computed using the *SMX ReconstructionAssistant* software. For data acquisition on site, an off-the-shelf digital camera (single lens reflex – SLR) is used which is pre-calibrated by 3GSM. The operator takes two pictures of the bench face from different positions (*Stereoscopic Image Pair*). From the *Stereoscopic Image Pair* a three-dimensional model is computed using the *SMX ReconstructionAssistant* software.

Figure 29 and Figure 30 show the basic geometric arrangement for taking pictures of a rock slope and tunnel face, respectively. The base length (distance between the imaging positions) should be about 1/8 to 1/5 of the imaging distance (from imaging positions to the rock wall), i.e. having an imaging distance of about 10 m, the base length should be about 1,25 – 2 m.

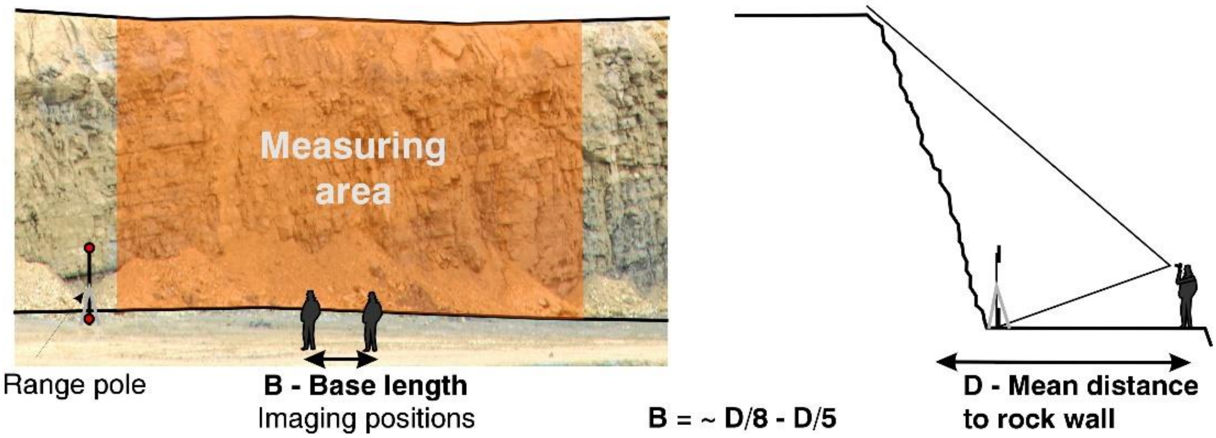


Figure 29: Principle geometric arrangement and position of Range Pole when acquiring a rock face

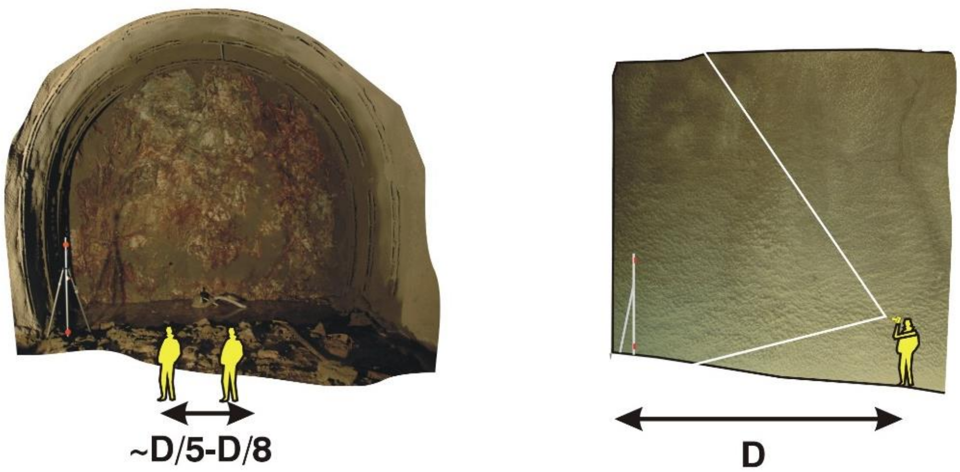


Figure 30: Principle geometric arrangement and position of Range Pole when acquiring a tunnel face

5.2 Imaging

Pictures of the bench face are taken from two different imaging positions using the calibrated SLR camera. Attention should be paid to:

- The imaging distance to the bench face depends on the area to image and the used lens (focal length).
- The base length (distance between the imaging positions) should be about 1/8 to 1/5 of the imaging distance (from imaging positions to the rock wall), i.e. having an imaging distance of about 10 m, the base length should be about 1,25 – 2 m. See also Figure 29 and Figure 30.
- Both imaging positions should have approximately the same imaging distance (distance between imaging position and rock wall).
- Both images show the bench face frontal. Images should be taken as parallel to the rock wall as possible.

Hint:
The 10 mm wide angle lens is used at constrained imaging conditions. Due to small imaging distances, perspective changes between the images up to occlusions occur more likely. If possible, the use of 17 mm (lower limit of Tamron lens) or 20 mm (upper limit of Sigma lens) is recommended.

Following steps should be noticed for imaging:

1. Select two imaging positions considering the following issues:
    a. Visibility of the imaging area
    b. Visibility of the target discs of the *Range Pole*
    c. Accessibility on site
    d. Used focal length, i.e. field of view of the lens
2. Take the first picture from the first imaging position as follows:
    a. Switch on the camera.
    b. Point to the region of interest using the view finder.
    c. Focus by slightly depressing the trigger – the camera should beep.
3. Change the camera mode from *Auto-Focus* to *Manual-Focus*:
    a. Change small switch on the lens from *AF* to *MF* or *M* (see Figure 31). This turns off auto-focussing and the camera settings remain constant for every image pair (recommended).
    b. Press the trigger firmly

Note:
The switch and its position on the lens for changing the focus, i.e. *Auto-Focus* and *Manual-Focus,* may differ from Figure 31 depending on your camera-lens system.

Important:
Use only focal lengths indicated at the lenses, i.e. extremal positions or those with a number. Do not use intermediate focal lengths.

Figure 31: Auto-Focus switch (Canon EOS 5D Mark III)

4. Take the second picture from the second imaging position:
    a. Point to the region of interest using the view finder and press the trigger firmly.
    b. Do not change the focal length of the lens between left and right image.
5. Dismount *Range Pole.*

Hint:
Write down image number and comments on it in the sequence of acquisition

Hint:
If you use a lens not supplied by 3GSM according calibration information will not be available. In such case measurement accuracy deteriorates significantly. If you need additional lenses (e.g. a telephoto lens for large imaging distances), please contact your service partner or 3GSM.

Hint:
Pay attention on hints on taking pictures in Chapter 6.

5.3 Hints on taking images

Good image

Figure 32: Good image: Area of interest stretches across image; Proper contrast; No sun flares.

Area of interest too small within photo

Figure 33: What to do: Change focal length; Change viewpoint (get closer)

Range Pole in front of area of interest

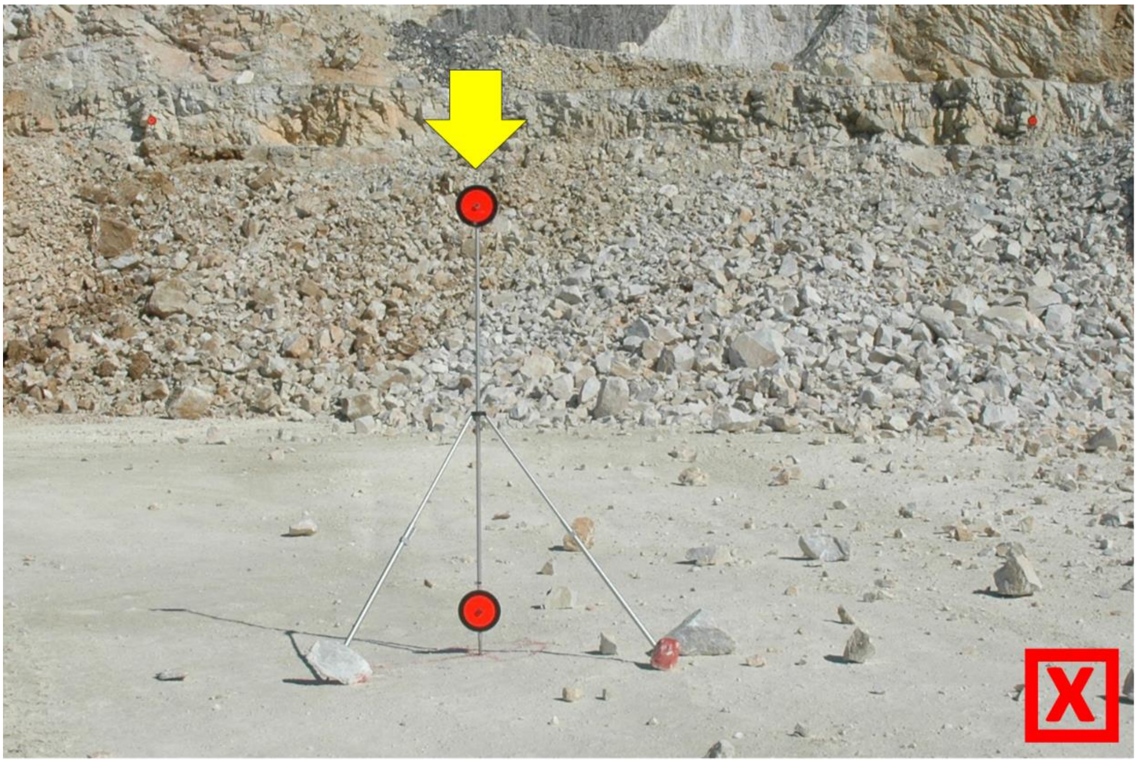


Figure 34: What to do: Change position of Range Pole laterally

Range Pole too close to camera

Figure 35: What to do: Place Range Pole closer to the bench face wall

Target disc partially occluded

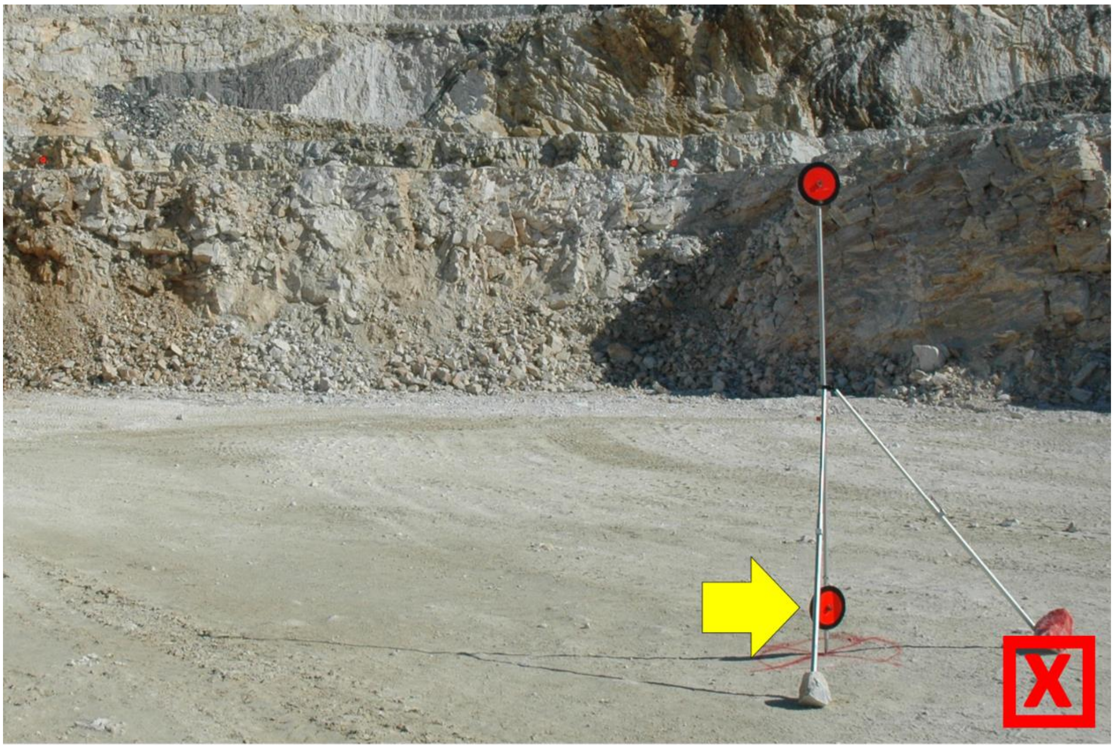


Figure 36: What to do: Place tripod legs behind on opposite side; Remove obstacle in front of target; Change viewpoint; Assemble Range Pole in alternative configuration.

Sunflares

Figure 37: What to do: Change viewpoint; Use sunscreen or hand to prevent sunlight hitting the front lens directly.

Still usable but not optimal: Dark areas

Figure 38: What to do: Change viewpoint; Ensure the camera to adapt exposure time according to the dark area; Overexpose image to enhance contrast in shadow areas.

6 Image quality

Note:
Image quality is of prime importance. Main reason for unsatisfying results is poor image quality.

General hints:

- Lower drone speed may increase image quality
- <u>Don´t process images for good looking!</u>
- If images are processed, ensure that the EXIF data remains
- <u>Switch of any auto-calibration!</u>
    - This changes the geometry of the photos
    - The auto-calibration in the software feature does the better job as it calibrates the camera according to your project instead of generically
- Brightness (Figure 39 left) → decrease f-stop number
- Shadows (Figure 39 right) → fly drone on shadow areas (if possible)

Figure 39: Examples of images. Left: Image is too bright. Right: Image with shadow areas.

For an optimal result of the data acquisition certain boundary conditions during taking the photos should be kept in mind. Below possible causes for later problems during image processing are given (see Figure 32 up to Figure 38).

7 Referencing using GCP

7.1 General

Standard applications with *ShapeMetriX/BlastMetriX* lead to a metric 3D model with no reference to a given co-ordinate system and no reference to north. However, variants allow for accurate geo-referencing using surveyed *Ground Control Points* and coarse (geo-)referencing to north using a manual compass reading (see Chapter 8).

Attention:
Surveying of *GCP* in the field is crucial for the absolute metric accuracy of the 3D model and thus should be performed carefully.

7.2 Requirements and setup

Ground Control points (GCP) are used for a proper alignment and referencing of a 3D model. The points are positioned in the field before imaging and shall comply with the following requirements:

- Surveyed GCP should be well visible in the pictures
- Surveying grade accuracy: better than 5cm or according to the project
    - Total station
    - RTK GPS / Differential GPS
- Minimum 3 GCP are required
    - Recommended more than 5 GCP
- Evenly distributed over surveying area
- Avoid collinearity of GCP in any circumstance

Surveyed GCPs can be (see e.g. Figure 42):

- Spray-painted marks
- Fiducial markers
- Aerial target
- Rock mass features
- …

Hint:
Spray the name of the target at the side. This eases assigning coordinates in the office.

Figure 40 and Figure 41 show arrangements of *GCP* set in surface terrains and underground environment. Referencing of 3D models is directly performed in the *SMX MultiPhoto* (see corresponding user manual).

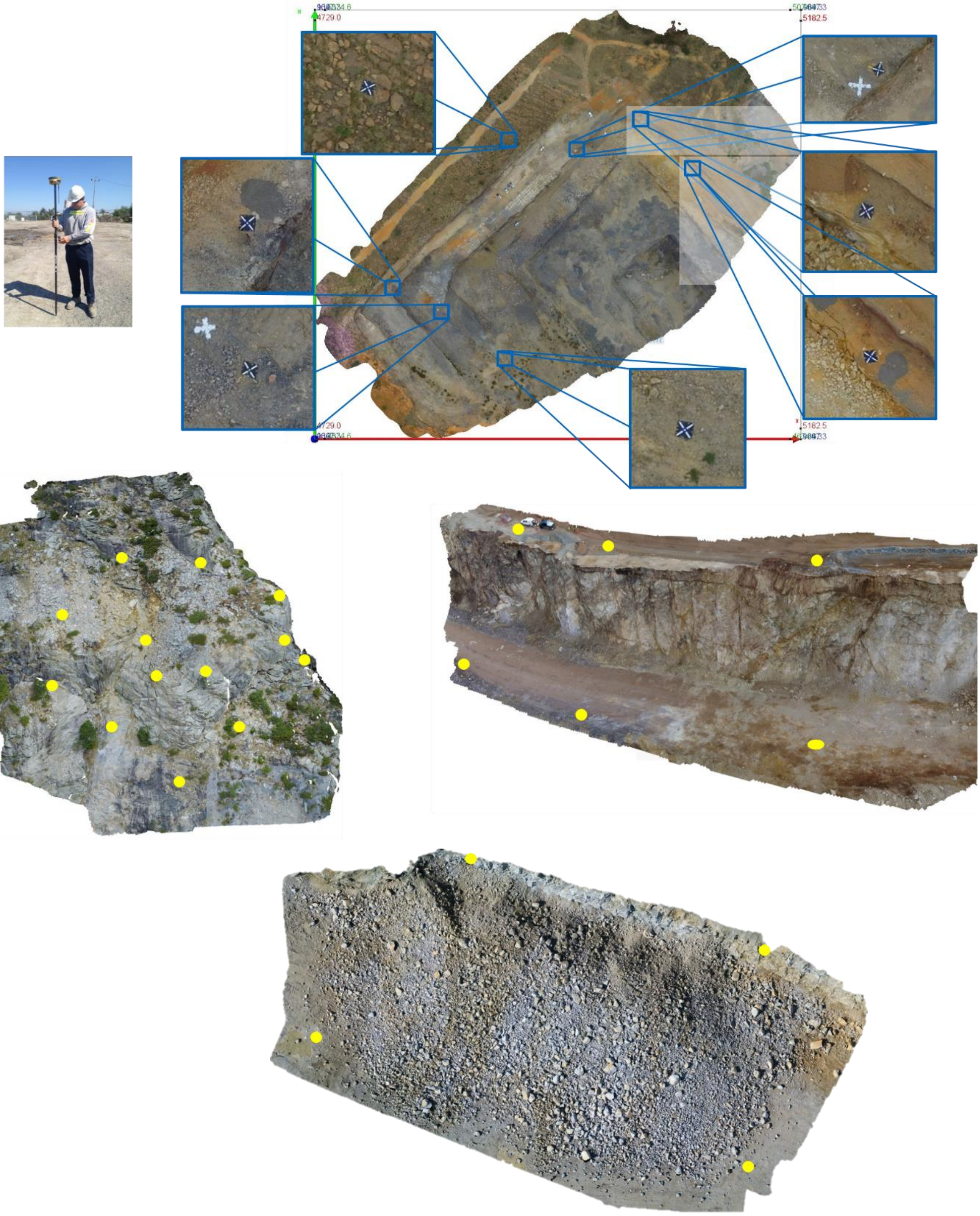


Figure 40: Examples of GCP (yellow spots) setups in surface environment

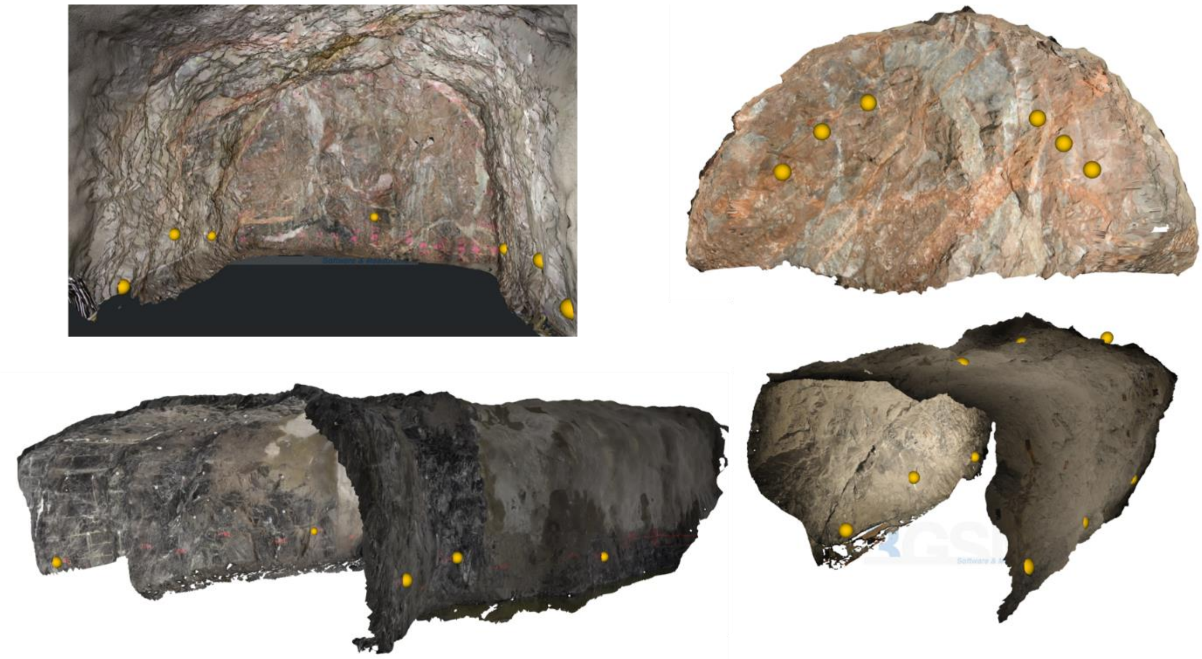


Figure 41: Examples of GCP (yellow spots) setups in underground environment

Figure 42: Examples of GCP

8 Registration using Range Poles

It is possible to register your 3D model in a local system based on 3GSM supplied targets (*Range Poles*). The survey is then in a local co-ordinate system. Typically this registration is applied to underground applications but can be used for terrestrial applications too.

Range Poles are hardware element used for the geometric referencing of the imaging area. They are typically part of the imaging unit for terrestrial applications. Please refer to the user manual of *ShapeMetriX/BlastMetriX Guideline* for further information.

8.1 General

Two different *Range Pole* assemblages are possible:

- Target distance 235 cm (recommended standard configuration):
  The distance between the target discs is 235 cm (7.710 ft) and the height of the lower disc from bottom is 26.5 cm (0.869 ft). See Figure 43.
- Target distance 135 cm (alternative):
  The alternative assembly is used if uneven surface prevents sight on the lower target disc when assembled in the recommended standard configuration. The distance between the target discs is 135 cm (4.429 ft) and the height of the lower disc from bottom is 126.5 cm (4.150 ft). See Figure 44.

Note:
For larger bench faces, the standard configuration shown in Figure 43 is recommended.

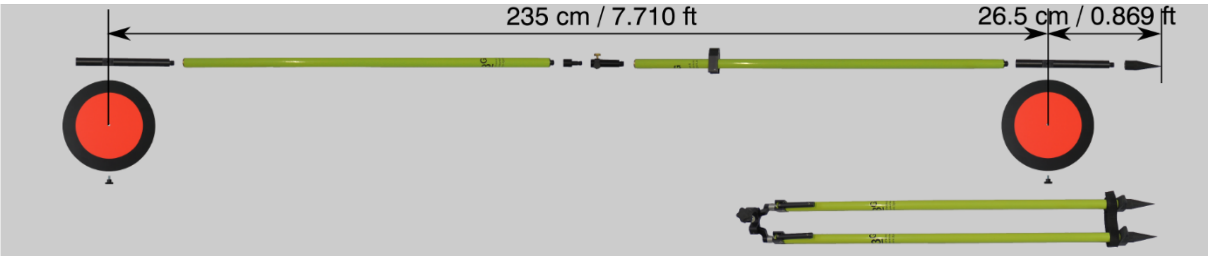


Figure 43: Standard configuration of the Range Pole with a target distance of 235 cm (7.710 ft)

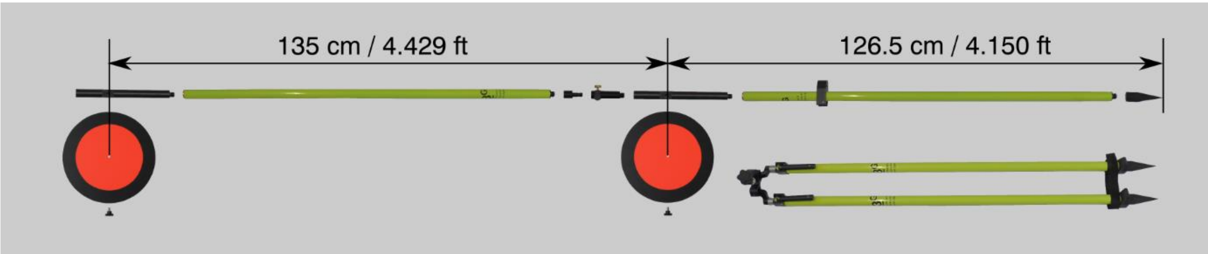


Figure 44: Alternative configuration of the Range Pole with a target distance of 135 cm (4.429 ft)

8.2 Range Poles in underground environment

For tunnelling and underground works a smaller version of the *Range Pole* is available (Figure 45). The targets are smaller (diameter 8 cm) and disuses the extension pole. This involves a face height smaller than 15 m. Figure 46 shows a *Range Pole* installed in front of a tunnel face. The *Range Pole* shall be located in a way that minimum occlusion of the face behind occurs. However, it can be placed either in the middle of the face or at the side walls. It shall be not too close to the imaging positions.

Figure 45: Parts of a Range Pole as they have to be joined together for tunnelling application. Good for tunnel faces up to 15 m.

Figure 46: Range Pole installed in front of a tunnel face. The Range Pole should be located leading to <u>minimum occlusion</u> of the face behind. It can be placed in the <u>middle</u>, at the <u>sides</u> or at any position visible in both images but not too close to the camera locations.

8.3 Setting up the Range Pole

The *Range Poles* are assembled by joining several single parts. Please note following steps:

1. Choose the location where you place the *Range Pole* (see Figure 47).

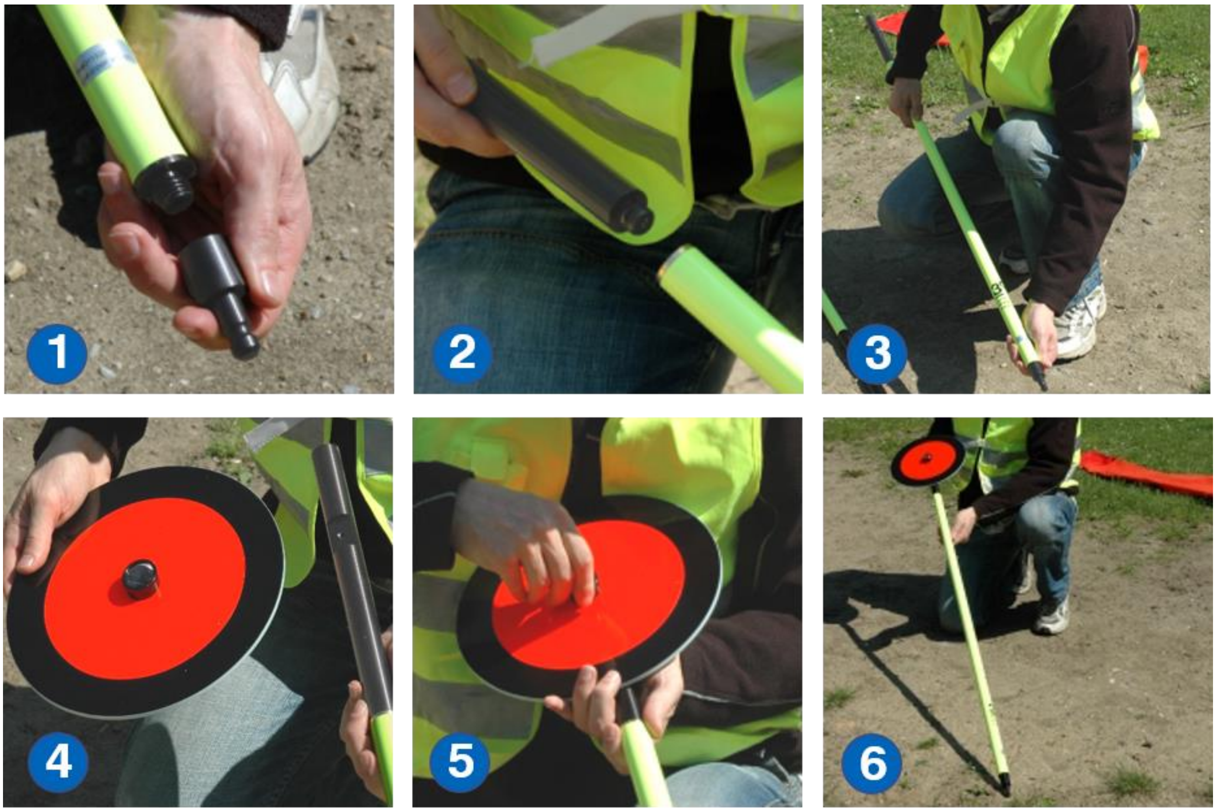
Hint:
The setup locations must be chosen in a way that both target discs are visible from the planned imaging locations. Use the configuration with larger distance between the target discs if possible (see following description).

2. Join the target mount at the lower end of the centre pole with attached spirit level (see Figure 47).
3. Join the spike with the joined target mount (see Figure 47).
4. Mount the first target disc (25 cm) on the target mount (see Figure 47).
5. Join the alignment part (lower piece) at the upper end of the centre pole with attached spirit level (see Figure 47).
6. Join the alignment part (upper piece) at the lower end of the extension pole (see Figure 48).
7. Join the target mount at the upper end of the extension pole (see Figure 48).
8. Mount the second target disc (25 cm) on the target mount (see Figure 48).
9. Insert the centre pole into the eye of the stand piece and fixate it with the clamping bolt (see Figure 49).
10. Set up the lower part of the *Range Pole* by unfolding the legs and align it coarsely vertical by using the hand gear for changing the length of the telescopic legs (see Figure 49).
11. Join the extension pole and the centre pole (see Figure 49).
12. Align the target discs to each other by using the alignment part (see Figure 50).
13. Release the clamping bolt and turn the target discs so that they are looking towards the planned imaging locations.
14. Set up the *Range Pole* vertically by changing the length of the telescopic legs. Verticality is checked with the spirit level (see Figure 50).
15. If it is windy, the *Range Pole* should be established such that the foldable legs are looking downwind. Additionally the *Range Pole* can be secured using a rope spanned from the eye of the stand piece.

Note:
Fixing of the target disc on the target mount is provided with a target prism in older versions or with simple screws in newer versions, respectively.

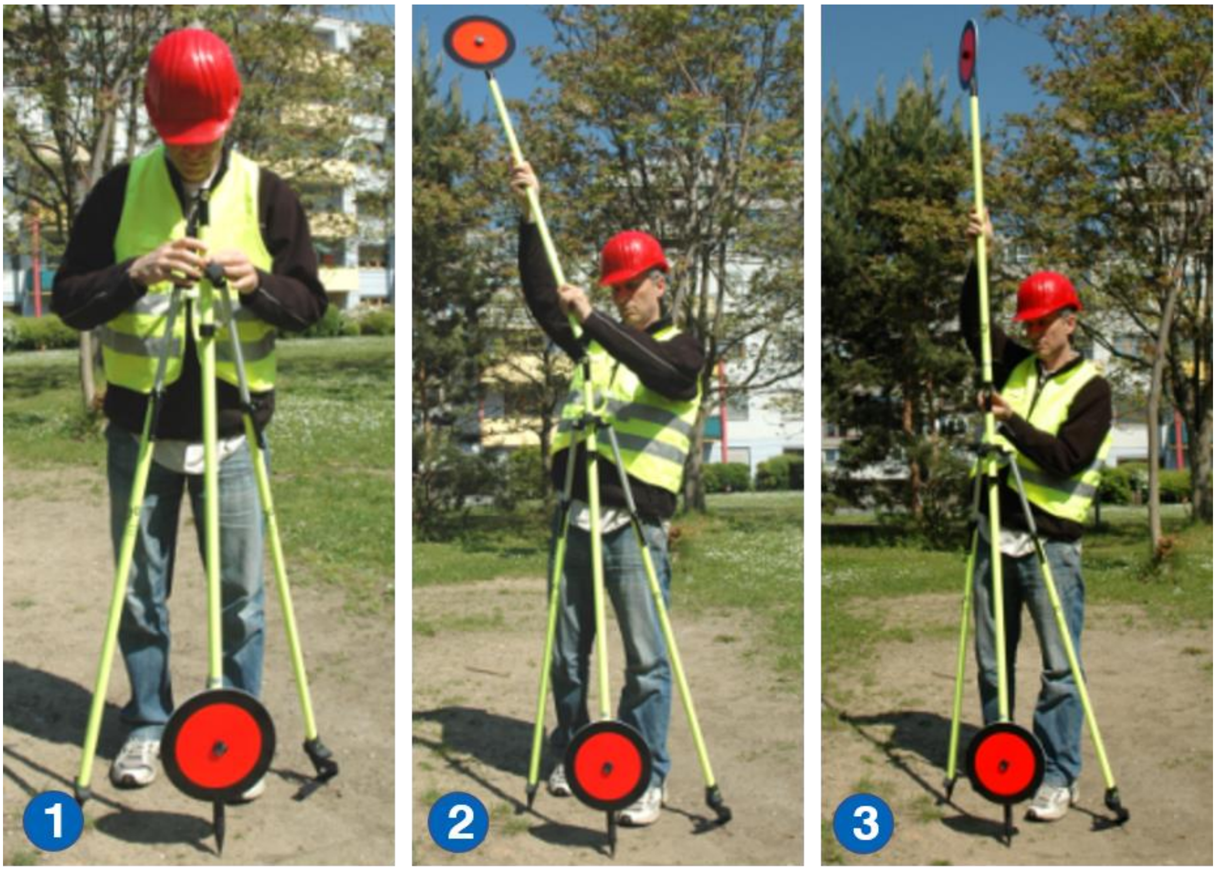
1 Joining the center pole with the target mount
2 Joining the spike to the target mount
3 Target disc and connected center pole with target mount
4 Mounting the target disc on the target mount
5 Joining the alignment piece (lower part) at the center pole
6 Lower part of the assembled *Range Pole*

Figure 47: Mounting of the lower Range Pole part



1 Joining the alignment part (upper piece) with the extension pole
2 Joining the target mount at the upper end of the extension pole
3 Upper center pole with alignment part with target mount
4 Target disc and connected center pole and target mount
5 Mounting the target disc and the target mount
6 Upper part of the assembled *Range Pole*

Figure 48: Mounting of the upper Range Pole part



1 Clamping the center pole in the eye of the stand piece and unfolding the telescopic legs
2 Joining the extension pole and the center pole
3 *Range Pole* (non-aligned)

Figure 49: Setting-up of the Range Pole

1 Aligning the target discs by releasing the screw and pushing the button at the alignment piece, rotating the upper part of the pole, releasing the button and fixating the screw again

2 Spirit level to check the verticality

3 Changing the length of the telescopic legs (depress the appropriate hand gear) to set the *Range Pole* vertically

Figure 50: Alignment of the Range Pole

Range Poles in windy environment

Wind might topple the *Range Pole*. Support the legs and tauten the centre pole to ground in such case. Stones or filled sand bags are convenient. Figure 51 shows the installation of a *Range Pole* in windy environment. The legs are supported by stones. Additionally, the centre pole is tautened by a cord to ground to give tensile support and to secure it from falling. Ideally, three cords in different directions are applied.

Figure 51: Correctly installed Range Pole. Legs are supported by stones. The centre pole is tautened by cords to ground. Ideally, three cords in different directions should be applied.

8.4 Registration alternatives

Local co-ordinates

Local measurements allow the determination of the rock wall geometry, parameters such as joint spacing, and relative dipping to the rock face. The procedure comprises the steps as described in Chapter 8.3:

1. Set up the *Range Pole*
2. Take the images ensuring that the *Range Pole* is visible in at least two images

Local co-ordinates with reference to north

If the bench face orientation against north is an issue, the scaled model can be orientated by two options:

- Establish a *Reference Line*
- Measure the orientation of a significant large, planar area

The orientation *Reference Line* or the area can be measured e.g. by compass reading. The value can be introduced during image processing. Please refer to the user manual of the *SMX Normalizer* and *SMX SurfaceTrimmer* for further information.

Attention:
North orientation can be an issue when using the 3D model also for geological mapping with *JMX Analyst*, or when working with borehole deviation probes. Do not rely on orientation measurements with a magnetic compass if the rock mass contains magnetic rocks. Sometimes it is also necessary to consider the deviation between the magnetic north and the geographic north, for instance, when integrating the compass-measurement into a geo-referenced system / model.

The procedure comprises the steps as described in Chapter 8.3:

1. Set up the *Range Pole*
2. Establish north reference (two options):
    a. Establish a *Reference Line* with the end points visible in both images (for instance, from the *Range Pole* to another marked point) and Measure the azimuth of the *Reference Line* from the left point to the right point, **OR**
    b. Measure the orientation of a significant large, planar area in the imaging area visible in both images
3. Take the images ensuring that the *Range Pole* and the north reference is visible in at least two images

Note:
For *BlastMetriX*: The *Reference Line* is determined by a straight line between the base points of the two *Delimiters* (see Figure 52 and Figure 53).

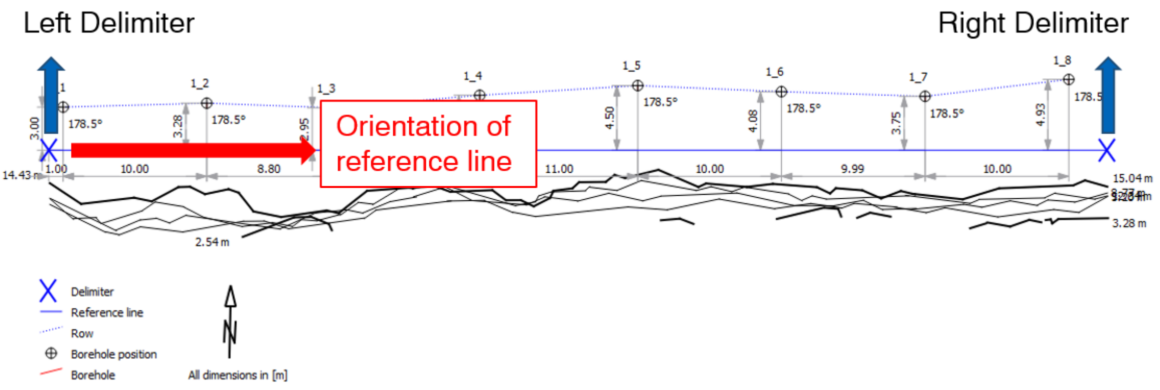


Figure 52: Definition of the Reference Line: it is defined pointing from the left to the Right (when looking at the bench face). The example shows an azimuth of about 80°.

Figure 53: Determining the azimuth from left to right Delimiter using a compass

Local co-ordinates with reference to north - Approximation of global co-ordinates

The procedure comprises the steps as described in Chapter 8 and 8.3:

1. Set up the *Range Pole*
2. Establish north reference (two options):
    a. Establish a *Reference Line* with the end points visible in both images (for instance, from the *Range Pole* to another marked point) and Measure the azimuth of the *Reference Line* from the left point to the right point, **OR**
    b. Measure the orientation of a significantly large, planar area in the imaging area visible in both images
3. Measure the co-ordinates of one point (marked or well distinguishing) using GPS or total station
4. Take the images ensuring that the *Range Pole* and the north reference is visible in in at least two images

9 Scaling of 3D models in a local co-ordinate system

The *Sample Mode*, available in *SMX MultiPhoto and SMX Normalizer,* is used to scale the 3D model in a local co-ordinate system with a horizontal reference plane. It is especially suitable for underground environment. The mode requires defining three points, two points provide scale and orientation of the x-axis while the third point defines the xy plane.

The *Sample Mode* is based in a right handed co-ordinate system and requires the definition of three points; i.e. *First Point*, *Second Point* and *Plane Point*. The local co-ordinate system is defined as follows:

- The x-axis points from the *Second Point* to the *First Point*
- The *Plane Point* defines the orientation of the xy-plane by fixing the orientation around the x-axis
- The y-axis points from the *Plane Point* into the direction of the x-axis
- The z-direction is either to the observer or away from the observer, respectively, depending from orientation of the other axis

In addition, the *Sample Mode* requires the input of the point distance between the *First* and the *Second Point*. According to the setup of the three points, four scenarios of co-ordinate system are possible (see Figure 54).

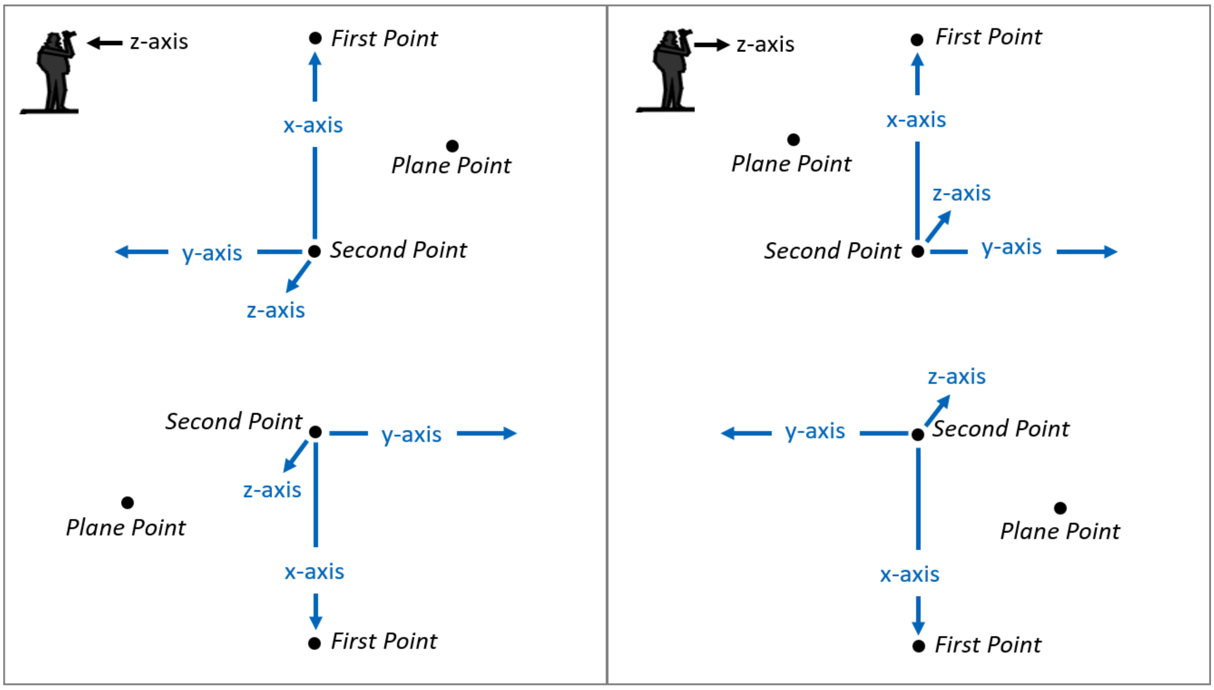


Figure 54: Orientation possibilities of the Sample Mode as a result of the marker setup

11 Blast design – Marker geometry

Blast planning in the *BMX BlastPlanner* requires reference elements to define the geometry of the *Blast Site*. In subject to the dimension and geometry of the bench face as well as the imaging setup (terrestrial or aerial), different marker geometries are necessary for the accurate generation of the *Blast Site*.

11.1 Aerial imaging

Following markers are required to define the geometry of the *Blast Site* (see Figure 55):

Left Delimiter	The position of the *Left Delimiter* on the top of the bench limits the geometry of the *Blast Site* on the left.
Right Delimiter	The position of the *Right Delimiter* on the top of the bench limits the geometry of the *Blast Site* on the right.
Left Floor Level Marker	The position of the *Left Floor Level Marker*, i.e. toe point of the quarry on the left side, limits the geometry of the *Blast Site* at its bottom.
Right Floor Level Marker	The position of the *Right Floor Level Marker*, i.e. toe point of the quarry on the right side, limits the geometry of the *Blast Site* at its bottom.
Crest Polygon	The *Crest Polygon* defines the upper boundary of the quarry face with a polygon
Toe Polygon	The *Toe Polygon* defines the lower boundary of the quarry face with a polygon

A detailed descriptions of elements defining the *Blast Site* is found in the user manual *BMX BlastPlanner*.

Note:
The Crest and the Toe Polygon are defined directly on the 3D model in the BMX BlastSitgeGenerator3D. There are no specific markers in the field needed. Please refer to the user manual of the *BMX BlastSiteGenerator3D* for further information.

Attention:
Surveyed markers should be well visible in the pictures.

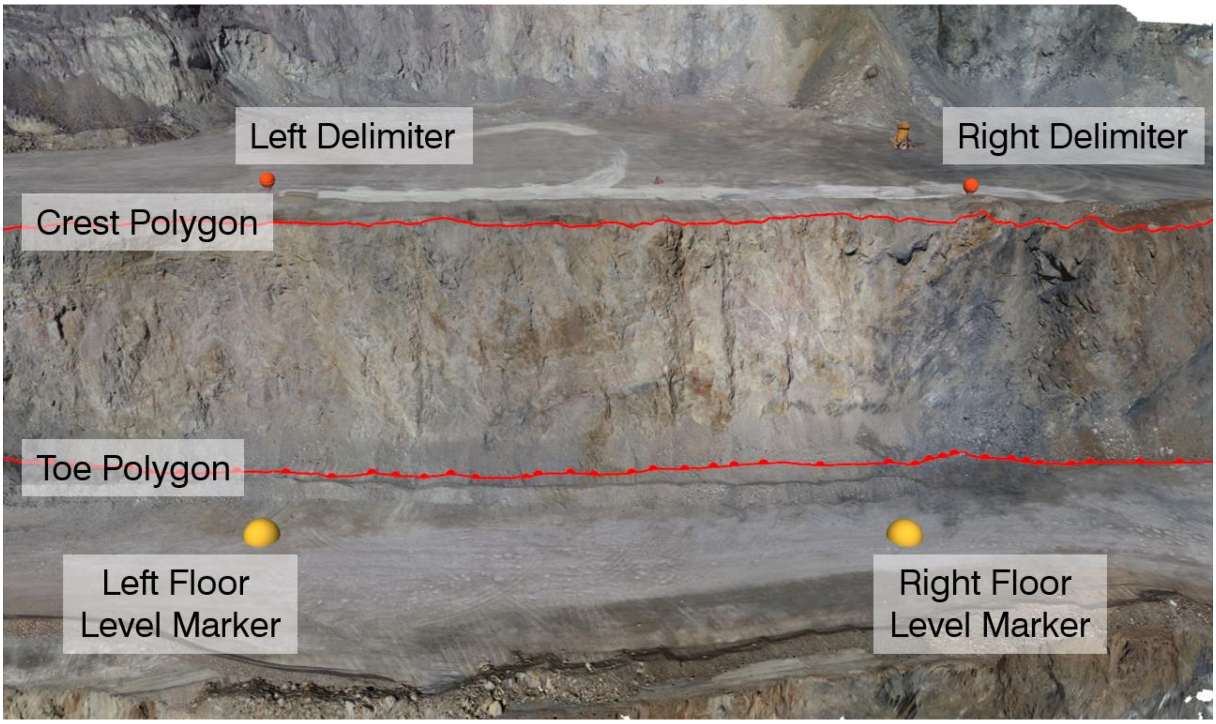


Figure 55: Example of a blast site geometry

11.2 Terrestrial imaging

In subject to the dimension and geometry of the bench face, different marker geometries are necessary for the accurate generation of the *Blast Site*. In the following standard setups are describes. If your bench face requires a particular marker geometry, please contact 3GSM.

Two Range Poles & Two Delimiters

This is the recommended standard configuration for blasts with one main face (see Figure 56). The configuration can be applied regardless of using single or merged 3D models generated from Stereoscopic Image Pairs (see Chapter 11.4) or using 3D models generated from multiple overlapping images (see Chapter 3). With single 3D models the limits stated is shown in Figure 56, with merged 3D models the width of a blast can be increased (Figure 57).

The configurations comprises the following mandatory markers:

- 2 *Range Poles* at the floor level
- 2 *Delimiters* at the top level
- 2 *Floor Level Markers*

The *Left* and *Right Delimiter* define the *Reference Line*. The *Range Poles* are used to scale and orientate the 3D model. The *Floor Lever Markers* define the *Floor Level Plane*. The *Top Level Plane* is defined by the toe points of the *Delimiters*. Additional *TLS Markers* can be used optionally at an arbitrary number.

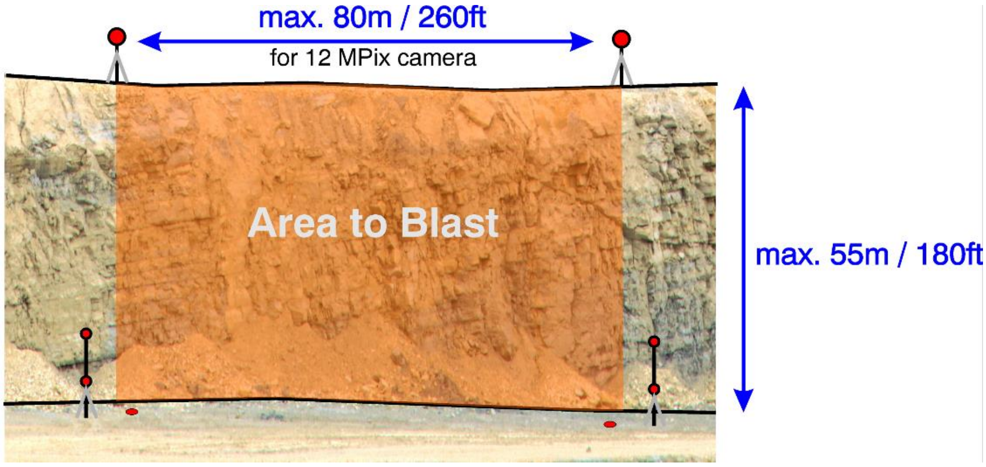


Figure 56: Maximum range for one 3D model in standard configurations of the system (target size and camera model)

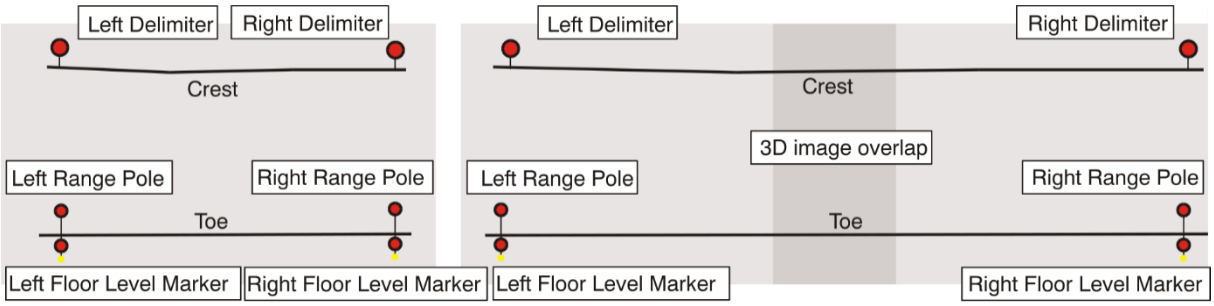


Figure 57: Configuration with single (left) and merged (right) 3D models: 2 Range Poles at the toe, 2 Delimiters at the crest and two Floor Level Markers at the toe.

Two Range Poles & additional Delimiter (optionally Top Level Surface Marker)

This configuration is used only if the blast has a free end (open corner). The configuration comprises the following mandatory markers (see Figure 58):

- 2 *Range Poles* at the floor level
- 3 *Delimiters* at the top level
- 3 *Floor Lever Markers*

The *Left* and *Right Delimiter* along the main face plane define the *Reference Line*. The *Range Poles* are used to scale and orientate the 3D model. The *Floor Level Markers* define the *Floor Level Plane*. Additional *Floor Level Marker* allows for inclined *Floor Level Planes* at open corners. The *Top Level Plane* is defined by the toe points of the three *Delimiters*. This allows for inclined *Top Level Planes* at open corners. Additional *TLS Markers* can be used optionally at an arbitrary number.

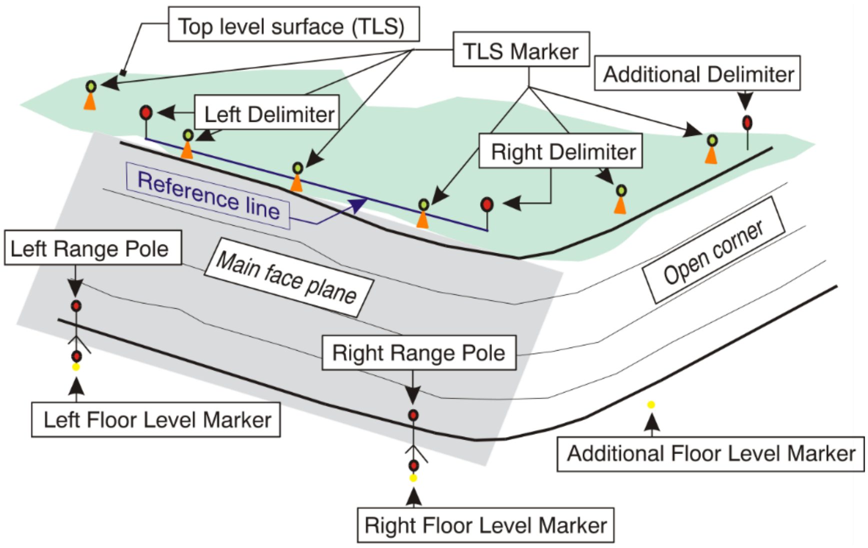


Figure 58: Configuration at an open corner. 2 Range Poles at the toe, three Delimiters at the crest and three Floor Level Markers at the toe. Additional TLS Markers can be applied along the crest at an arbitrary number.

Top Level Surface (TLS) Marker

The *Top Level Surface* is part of the blast site borders and used to model an uneven crest. The *Top Level Surface* contains the toe points of the *Delimiter*, *TLS* Markers and optionally point of borehole collars (*Collar Markers*). *Top Level Surface Markers* and *Collar Markers* are defined along the bench face's crest. They are defined either directly at the surface (natural point) by manual placement or using targets with a known height offset by automatic placement. The *Top Level Surface* finally contains the toe points of the markers. *TLS Markers* shall be established along the crest and describe the shape of the crest properly (Figure 59). For instance, they shall be placed at edges rather than at planar areas.

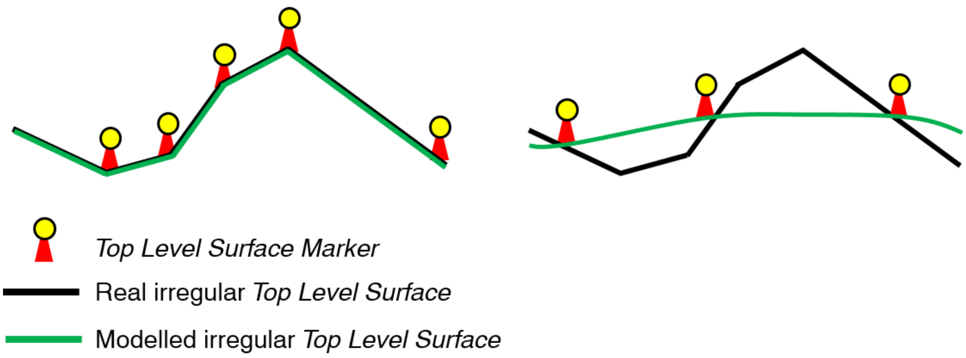


Figure 59: Established TLS Markers. Left: TLS Markers describe the crest properly. Right: TLS Markers do not lead to a proper representations of the Top Level Surface.

11.3 Setting up markers

Attention:
Please refer to Chapter 8.3 for the description how to setup the Range Poles.

Setting up Delimiters

Two *Delimiters* are placed on top of the bench face enclosing the area to blast. The *Delimiters* must be located in a way that the target discs are fully visible from the intended imaging locations. *Delimiters* do not need to stand directly at the crest line or on the planned borehole line. The standard *Delimiter* with the target disc at 126.5 cm is shown in Figure 60.

A *Delimiter* with a target disc at 226.5 cm is provided for *Highwall* applications (Figure 61). The configuration might facilitate the recording of pictures in special cases e.g. the area at the crest where is *Delimiter* should be positioned is blocked by mug pile and/or a proper position to take pictures is not accessible due to security reasons etc. If the geometry of your quarry for any reason requires a specific setup of *Delimiters*, please contact 3GSM or your support partner for further information.

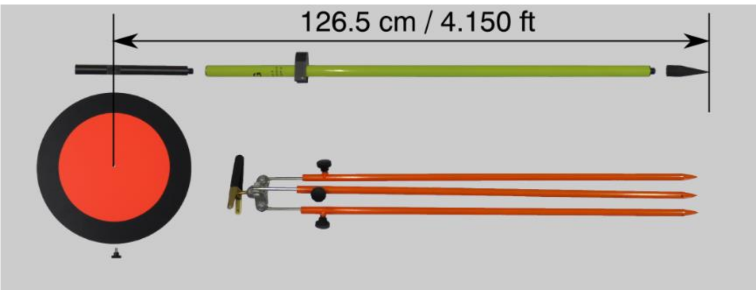


Figure 60: Components of a Delimiter as they have to be assembled. The target disc is at 126.5 cm (4.15 ft) height.

Figure 61: Components of a Highwall Delimiter as they have to be assembled. The target disc is at 226.5 cm (4.15 ft) height.

The *Delimiters* are assembled by joining several single parts (see Figure 60). Please note following steps for establishing the *Delimiters*:

1. Choose the setup location

Hint:
The setup locations must be chosen in a way that the target discs are visible from the planned imaging locations (check by looking back down). In case of doubt enlist the assistance of someone for checking visibility.

2. Join the spike with the centre pole (with attached spirit level) (see Figure 62)
3. Join the target mount with the centre pole (see Figure 62)
4. Mount the target disc on the target mount (see Figure 62)
5. Setup centre pole using the tripod. The centre pole must be established carefully vertically (use the spirit level). See Figure 63

Hint:
In order to ensure stability of the *Delimiter* during data gathering the legs of the tripod shall be extended as long as possible. Take care to tauten the *Delimiter* with cords (similar to Figure 51). **Place the *Delimiter* at a position where in case of toppling falling over the face is avoided.**

Hint:
At windy conditions the clamp of the tripod can be supported using sticky tape preventing the target disc from being rotated.

6. Mark the *Delimiter's* position, e.g. by colour spray

1 Joining the spike at the lower end of the center pole (with attached spirit level)
2 Joining the target mount at the upper part of the center pole
3 Target disk and connected center pole with target mount
4 Mounting the target disc at the target mount
5 Assembled *Delimiter*

Figure 62: Mounting of the Delimiter

1 Connecting the tripod to the Delimiter
2 Check verticality using the attached spirit level
3 Assembled *Delimiter* with tripod

Figure 63: Setting-up the Delimiter using a tripod

Marking the Floor Plane (optionally)

Note:
Marking the *Floor Plane* is **only** required if the *Range Poles* are **not** located on the bottom level.

The *Floor Plane* is marked with two points defining the lower border of the bench face (from this plane the subdrilling is counted). Using a distinctive colour spray two locations on the left and right end of the planned blast site are marked (see Figure 64). It is important that the markers can be identified within the images by the user later when doing the blast planning on the computer. The size of the markers should correspond with the size of the target discs. Points or crosses can be applied.

Attention:
Be sure that the markers can be seen from both planned imaging locations.

Recommendation:
The markers should be placed at the lateral borders of the blast site which eases to take the pictures containing the whole area of interest.

Figure 64: View of a bench face part with marked bottom level.

Setting up Top Level Surface Markers (optionally)

The *Top Level Surface Markers* are placed along the bench face's crest (see Chapter 11.2). They are defined either directly at the surface (natural point) by manual placement or using targets with a known height offset by automatic placement. *TLS Markers* included in *BlastMetriX 3D* system (see Figure 65) have a standard height of 75 cm (2.461 ft).

Figure 65: Top Level Surface Marker

11.4 Data acquisition of Stereoscopic Image Pairs

From the *Stereoscopic Image Pair* a three-dimensional model is computed using the *SMX ReconstructionAssistant* software. Figure 29 shows the basic geometric arrangement for taking pictures of a rock slope. The base length (distance between the imaging positions) should be about 1/8 to 1/5 of the imaging distance (from imaging positions to the rock wall), i.e. having an imaging distance of about 10 m, the base length should be about 1,25 – 2 m.

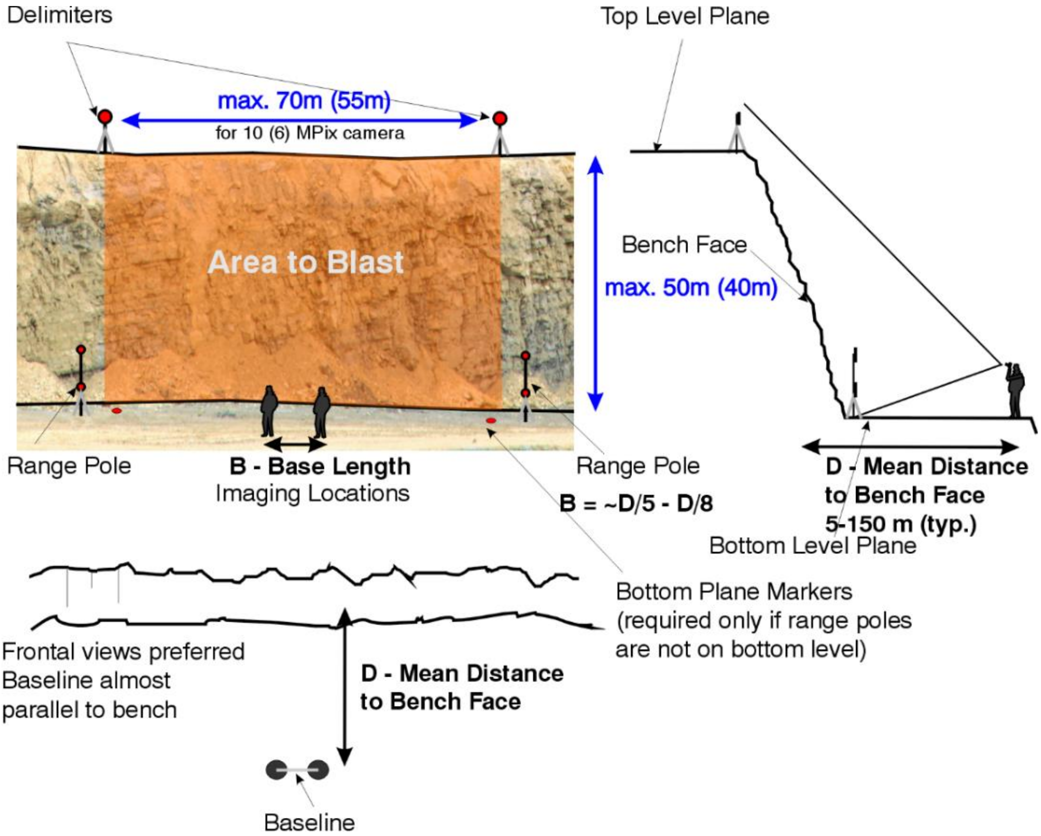


Figure 66: Principle geometric arrangement and position of Range Pole when acquiring a rock face

Note:
Please refer to Chapter 5.2 for the detailed description of the imaging procedure.