GEOLOGIC STRUCTURE MAPPING
using digital photogrammetry

Digital photogrammetry provides a cost effective remote means of documenting a mapped rock face while allowing structural mapping to be conducted from the photographs.

Digital photogrammetry allows structural geologic mapping to be conducted on rock faces that were, and are, essentially inaccessible for conventional mapping. It also allows, and provides, aerial coverage of faces that is difficult, if not impossible, to obtain conventionally. In addition, the DTM (digital terrain model) created from the photogrammetric data reduction process can be directly utilized for geotechnical stability and volumetric analyses.

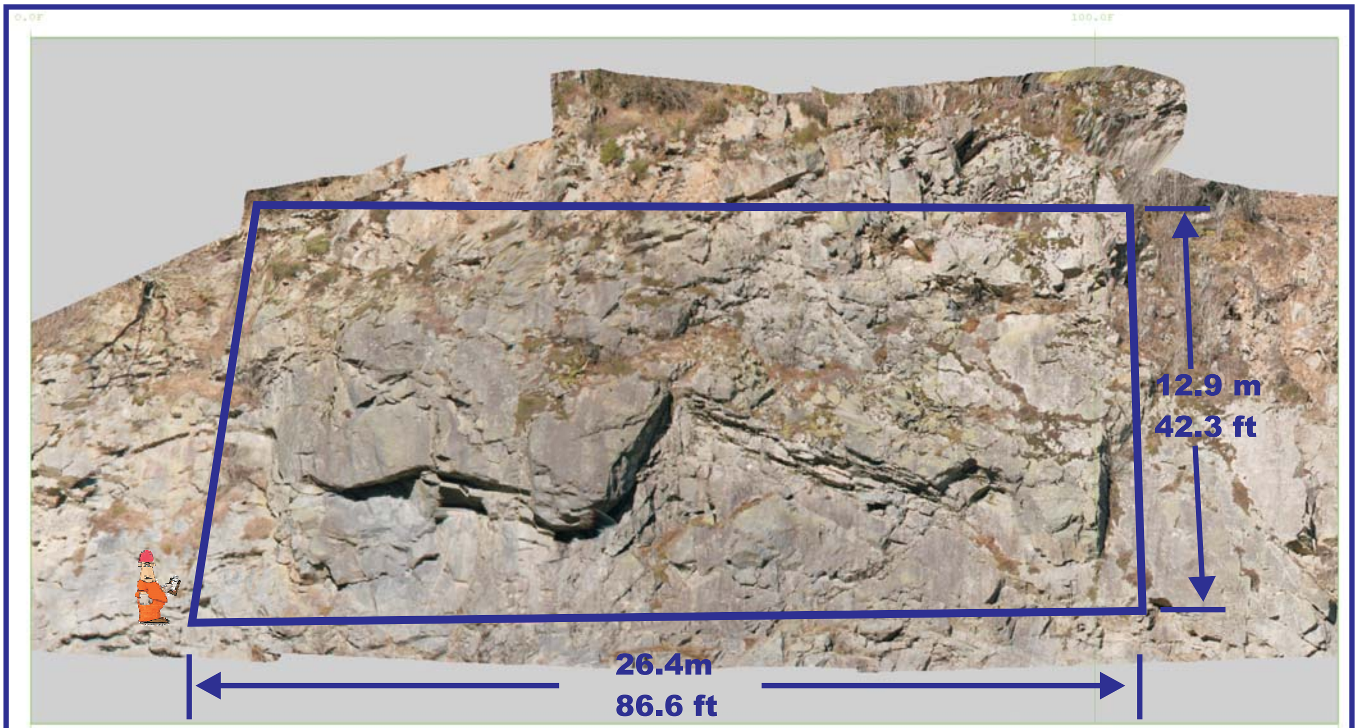

Image: Canon EOS 20D, 24mm objective Data reduction: ADAM Technology, 3DM Analyst, ver. 2.2

Highway cut - mapping window

A slope excavated for a highway rock cut is provided as an example in the image above. Aerial dimensions are as illustrated with the graphic image of the geologist in the lower left hand corner shown to scale. As is obvious, ground based mapping would be difficult. The geologist not only has a large area to cover, but is hindered in his ability to observe, or access, the geologic structure on the cut slope.

Present field techniques would require that the geologist/geotechnical engineer rappel over the face in a sling and on a rope to map the geologic structure. Another person would be assigned "on belay" or ensuring the rope is tied off and the mapper is safe at all times. This is both dangerous and time consuming work.

In addition, for this highway case, traffic flow may need to be interrupted at times. If this is the case, traffic control may be required.

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Let's compare this to the digital photogrammetry case in terms of manpower required for the mapping job.

Highway cut - estimated mapping time comparison

Standard geologic mapping			Digital photogrammetric mapping		
Men required	**task**	**Time required**	**Men required**	**task**	**Time required**
1 geologist	mapping	8	1 professional	photography	1
1 assistant	notes/rope	8	1 professional	photogrammetry	1
2 flaggers	traffic control	8	1 professional	digital mapping	1.5
1 geologist	data entry	4	1 professional	data entry	0
Total estimated time		**28 hours**	**Total estimated time**		**3.5 hours**

Using digital photogrammetric techniques, this rock face was photographed, and the data digitally reduced to a computer mappable DTM in two hours.

Another 1.5 hours of work resulted in the detailed structural mapping shown below, and subsequently reduced to stereographic projections and discontinuity model parameters on the following page.

Aside from the obvious safety, speed, and aerial coverage advantages of digital photogrammetry, the system provides an additional bonus in that the mapped data is already in the computer. The three dimensional location of the geologic structure, orientation, trace length, and any other observable parameters from the photographs are assigned digitally when the structure is mapped. This not only avoids data transcription errors, but further reduces the time required for data reduction.

The key to the mapping process, as well as to proper rock mechanics engineering, is the ability to accurately describe the myriad of discontinuities, collectively called "rock fabric", in the rock mass and couple these with any observable and quantified larger geologic structures such as faults or shear. The latter is readily achievable using photographic mapping, as the major structures can be observed as to effects and relationships to local fabric.

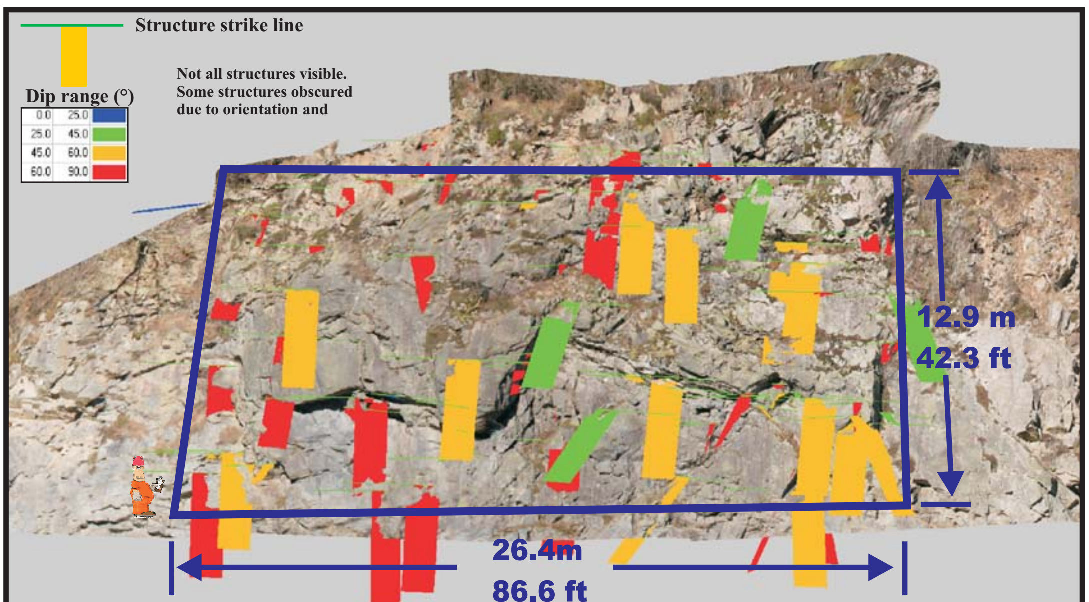

Image: Canon EOS 20D, 24mm objective Data reduction: ADAM Technology, 3DM Analyst, ver. 2.2 Beta; Vulcan ver. 6

Highway cut - digitally mapped structures

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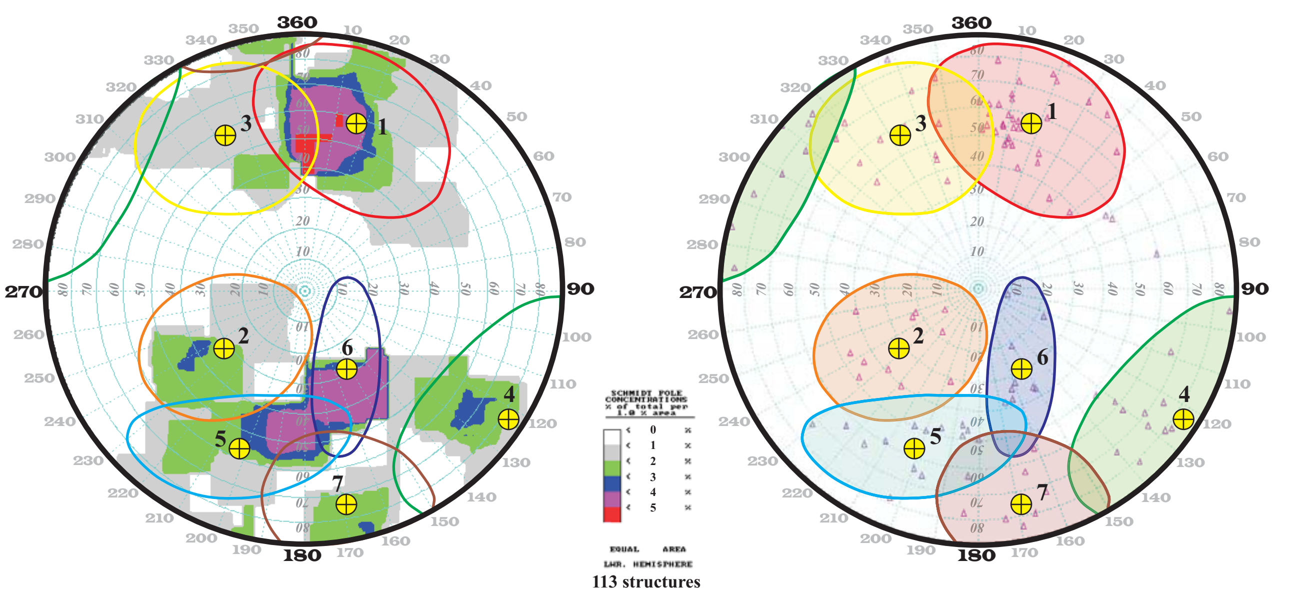
Rock engineering requires a robust, verifiable, structural fabric model from a well designed structural mapping program. This fabric model can be utilized directly to describe discontinuities in the rock mass for engineering design of excavations. Design methodologies are similar for both mining and civil structures and excavations. However, mining generally has a greater acknowledgment, and assessment, of risk incorporated in design.

Zostrich Geotechnical's mapping and data reduction techniques and programs have been developed, utilized, and verified in primarily in operating open pit and underground mines around the world. The collected statistical structural fabric data has been utilized for rock support design for engineering the dimensions and required rock support for tunnels, mining stopes, and pillars, bench face, interramp and overall slope angles for open pit mines, fragmentation analyses (blasting, cave, and inherent), dam abutment stability analysis (thrust load), and many other directed goals. These developed techniques and methodologies can be implemented directly on civil excavations (highways, dams, and other rock excavations) as the subsequent examples illustrate.



Set No.	Dip Direction	Dip	No.	Sigma Max	Sigma Min	Omega	Joint length		Joint center density	
							Mean	St. Dev.	Mean	St. Dev.
1	197.079	56.738	37	2.144E-01	1.613E-01	47.952	6.278	N.A.	0.028	N.A.
2	54.047	32.381	11	1.217E-01	8.634E-02	169.147	0.755	N.A.	0.030	N.A.
3	152.69	56.889	12	1.878E-01	1.561E-01	23.469	6.335	N.A.	0.006	N.A.
4	302.933	83.011	19	2.729E-01	2.220E-01	43.968	2.262	N.A.	0.024	N.A.
5	22.408	56.847	14	2.290E-01	1.055E-01	126.794	4.489	N.A.	0.014	N.A.
6	333.086	28.799	9	1.098E-01	3.593E-02	151.516	0.948	N.A.	0.022	N.A.
7	349.323	74.443	9	2.115E-01	1.462E-01	15.248	3.572	N.A.	0.012	N.A.

Data reduction: Zostrich Geotechnical proprietary programs

Highway cut - stereographic projections and spatial characteristics

The stereonets depicted above have been constructed utilizing the digital photogrammetric mapping data from the highway road cut example. Note that as this was conducted as an example, complete fabric mapping was not conducted. Many of the smaller joints were not characterized for the sake of expediency in this example. This will affect the fabric statistics by reporting and enhanced mean lengths and a reduced joint center density as compared to a complete uncensored sampled. This did not substantially affect the results of the engineering analysis conducted herein. Note the level of detail is likely similar to what would normally be obtained from rope based face mapping.

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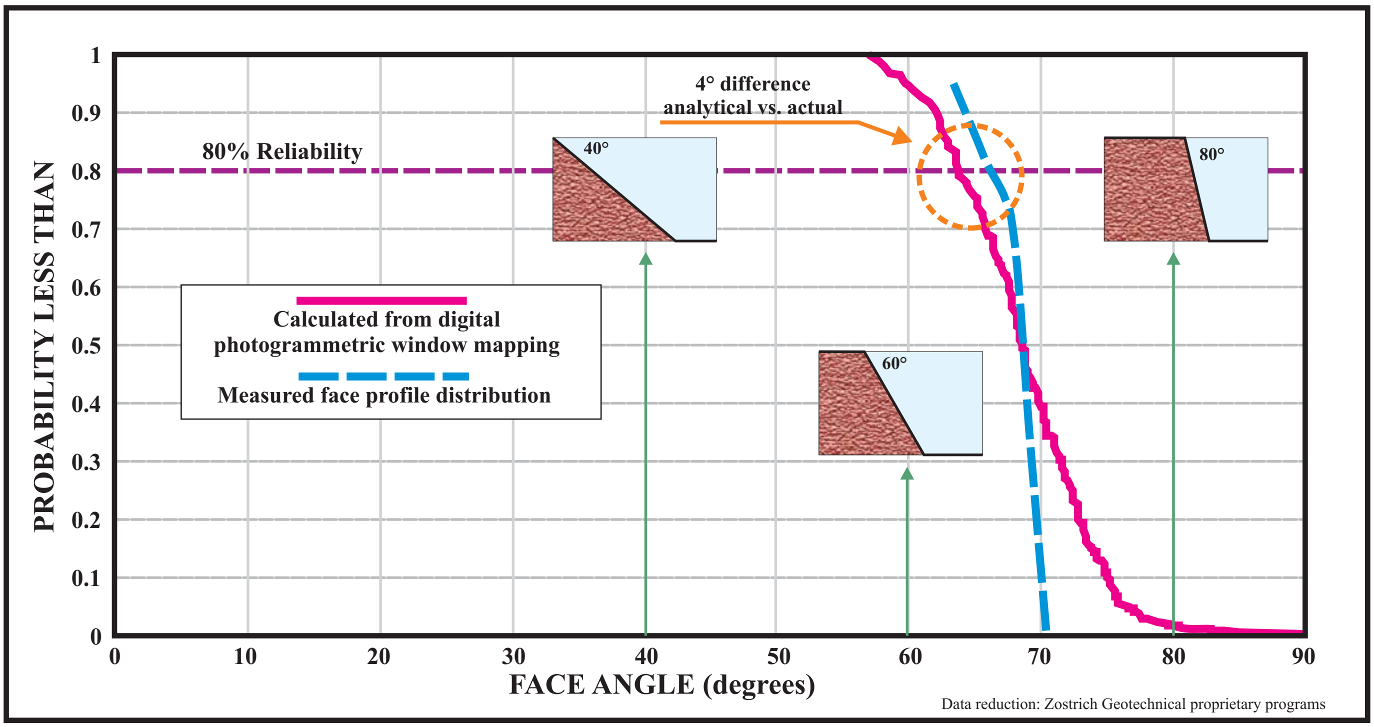
To illustrate the logical geotechnical completion of the analytical process, the calculated rock fabric statistics shown on the previous page were utilized to construct a fabric model of the rock mass. This fabric model was then analyzed to determine the theoretical face angle obtainable in the mapped orientation, for the example rock mass.

In order to conduct a face stability analysis for the rock face, a discontinuity shear strength was required. This was provided by utilizing a generic shear strength distribution, obtained from laboratory testing, for similar volcanic rock. The resulting kinematic block stability analysis was conducted on a 13m high vertical face as was examined in the field.

The field face angle distribution was obtained from toe and crest contours of the field obtained (photogrammetric) DTM, with a face height of 13m. Note that the actual face angle distribution will be slightly shallower than shown, as the crest contour was below the actual face crest.

The field and analytical results are shown graphically as a probability distribution below. Most designs are conducted at the 80% reliability level of maintaining the face angle. This insures that the face is not oversteepened compared to the geologic structure and a catch bench can be maintained. As can be seen below, highlighted by the orange dashed circle, the difference between the actual and measured face angle at the 80% reliability level is about 4°. This is excellent, especially given the small design length (26m) of the rock face available for comparison.

Note that the comparison in the graph below is of probabilities of the slope angle occurring. It is not a slope profile.



Highway cut - theoretical vs. actual bench face angle comparison

For more information on bench face design and analysis, please see the web course located at:
http://www.edumine.com/xutility/html/menu.asp?category=xcourse&course=Xbench

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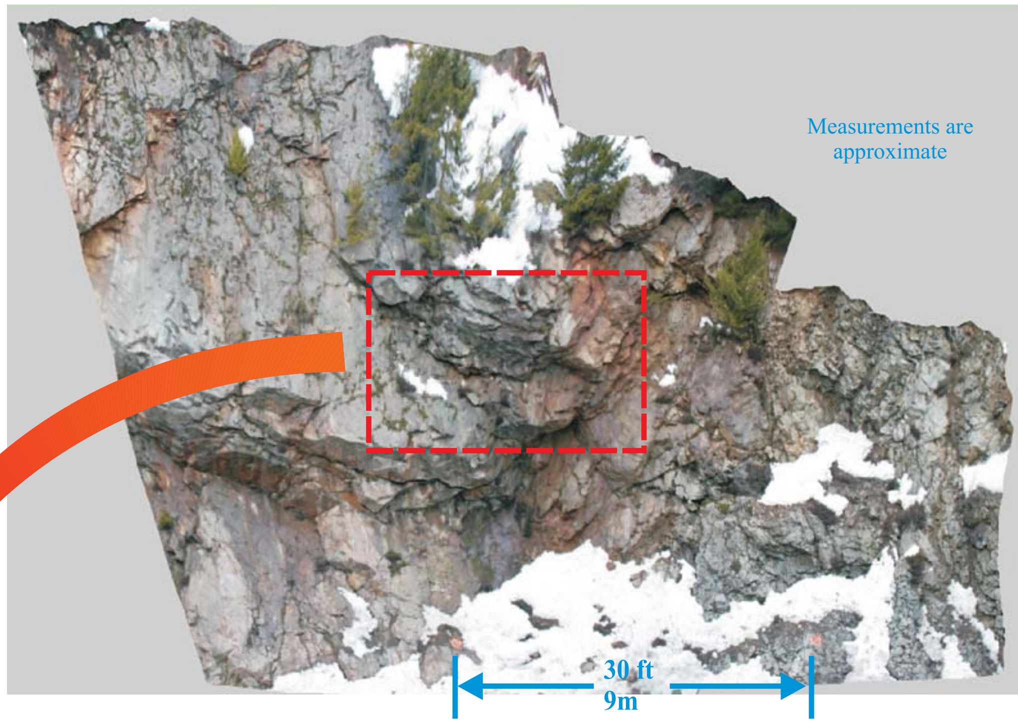
Rock structural mapping using photogrammetry and imaging techniques may also be utilized for directly analyzing existing geotechnical situations as well, as illustrated below.

Image: Canon EOS 20D, 24mm objective Data reduction: ADAM Technology, 3DM Analyst, ver. 2.2 Beta; Vulcan ver. 6



Highway cut - discrete block analysis - raw image

Highway cut - close-up of undercut potential failure block

The engineer can safely examine the potential failure area in great detail from a multitude of angles. It is possible to literally "fly" around and above potential rock failure blocks, even those in active failure. At times, one can even fly "under" the failure blocks as can be seen in the adjacent photograph, and the undercutting of the leading edge of the block (close-up, adjacent) is obvious.

While physical examination of the block may be required at some point, this method allows for detailed examination and analysis of the situation without the rock scaling and rope work normally required to assess the situation.

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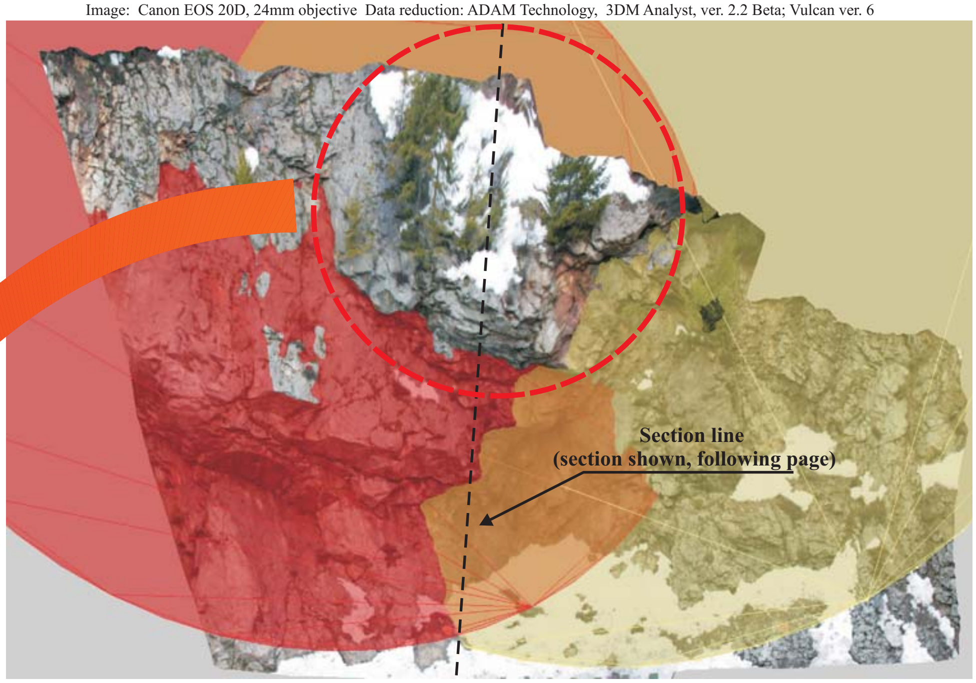
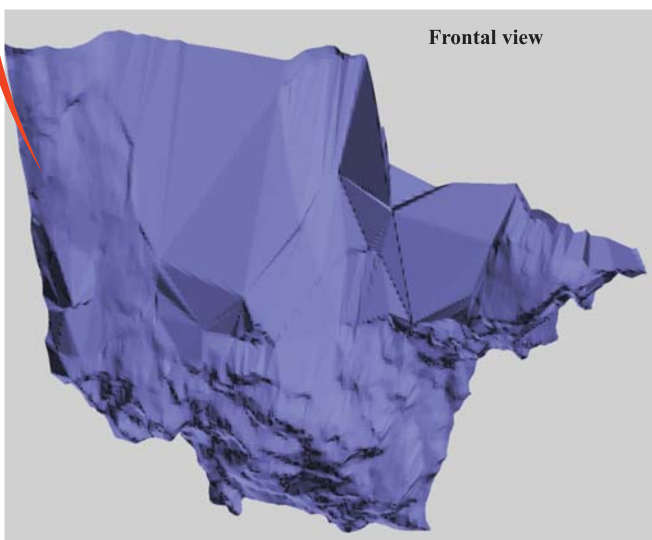
Structural "halos" are defined that approximate the local geologic structures that define the failure block. As this was an example, the work was conducted using general (planar) instead of specific (detailed, digitized) surfaces.

Image: Canon EOS 20D, 24mm objective Data reduction: ADAM Technology, 3DM Analyst, ver. 2.2 Beta; Vulcan ver. 6



Highway cut - discrete block analysis - failure block defined

The DTM model of the slope can be cut by the constructed halos, resulting in a three dimensional solid model of the potential failure block. This is useful for driving force calculations for rock support design.



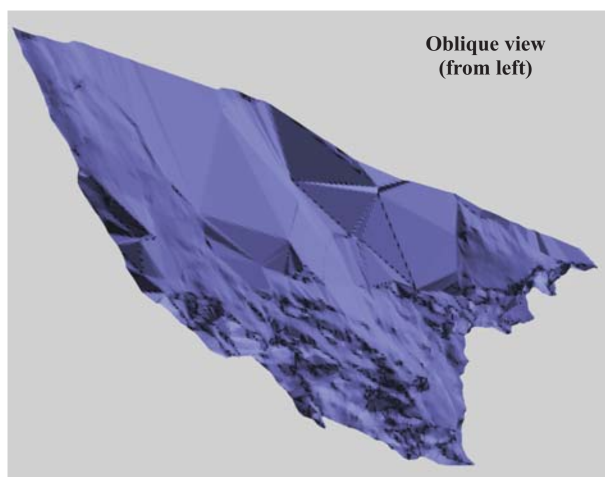


Image: Vulcan ver. 6 DTM, Boolean truncated solid
from ADAM Technology, 3DM Analyst, ver. 2.2 Beta

Highway cut - discrete block analysis - failure block solid

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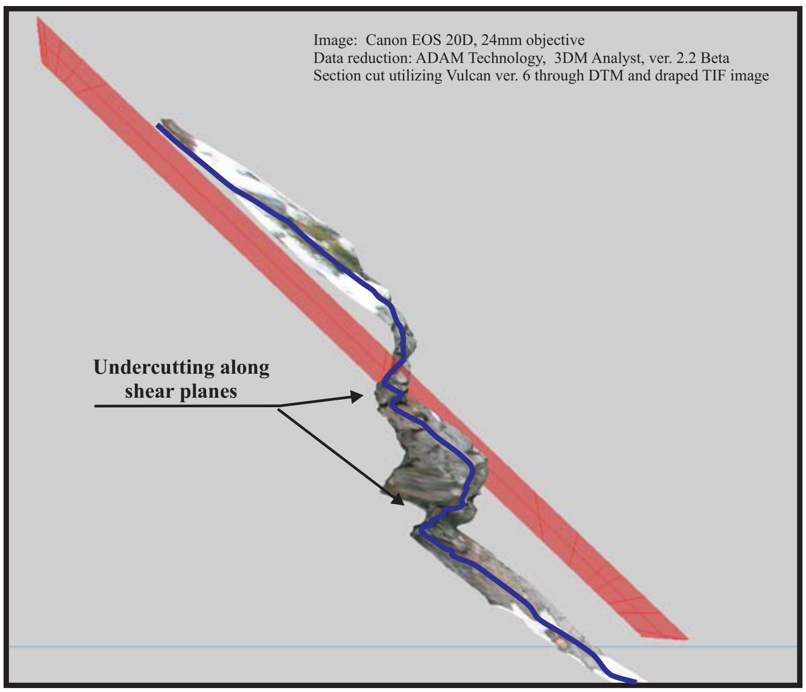
Sections can be cut through the photographed surface, and underlying DTM as shown below, for aid in visualization and design. These sections, as well as the DTM, are scale correct. The accuracy of the DTM is an engineered parameter, and is normally within 1-4 centimeters (0.5 to 2 inches) for rock work.

In this case, the estimated volume of the potential failure block, as shown by the DTM solids on the previous page, is approximately 1600 cubic feet, or 45 cubic meters. This equates to a potential rock failure mass of 130 tons (100 tonnes).

Rock support could easily be designed for this potential failure block, with the size, and the location of the reinforcement easily located on the DTM and/or photographic images and generated sections. Given the quantity and quality of detailed geotechnical information available, design and location of the appropriate rock support is estimated to require less than an hour of engineering time.

Digital photogrammetry, and associated rock analysis with the associated DTM's and images increase the efficiency, and accuracy of any rock design where large or poorly accessible areas must be mapped, great geologic detail is required, or where dangerous mapping situations exist.



Highway cut - vertical section through potential failure block

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The methodology can be readily applied to mining situations as well. In the example below, adverse geologic structures became apparent upon excavation of the pit wall. The area was targeted, and photographed, in approximately one day. Mapping was conducted on screen the following day, when weather conditions were such that it was impossible to map outdoors.

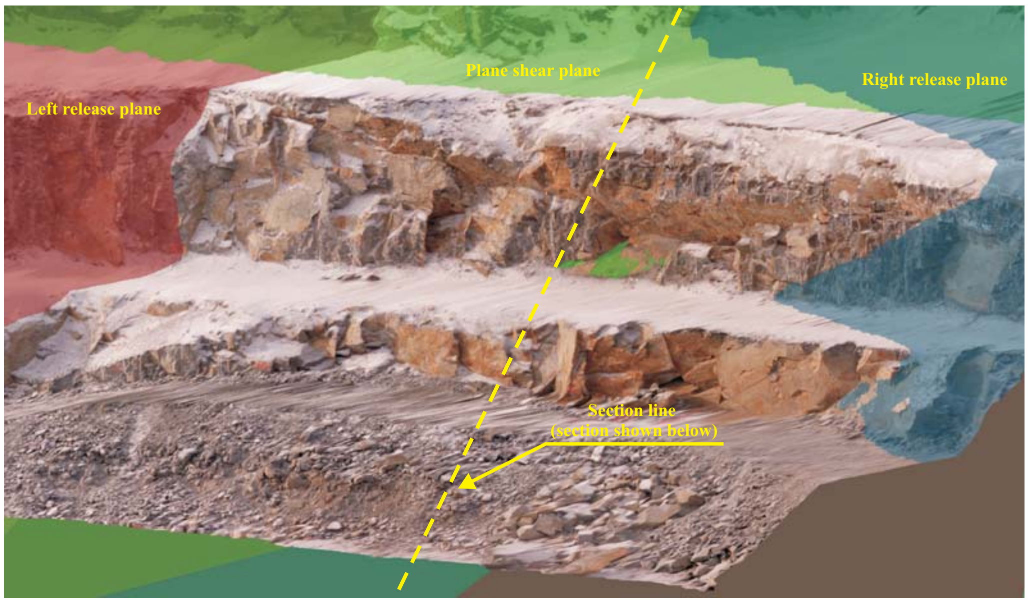
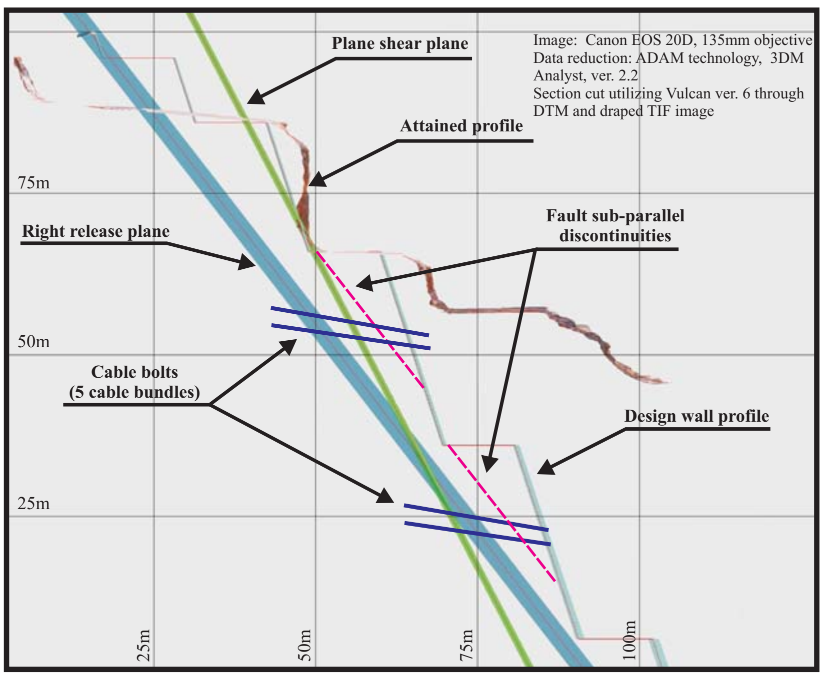


Image: Canon EOS 20D, 135mm objective Data reduction: ADAM Technology, 3DM Analyst, ver. 2.2 Beta; Vulcan ver. 6

Pit wall imaging showing potential failure bounding discontinuities



Design section - pit wall

Sections were cut through the DTM photogrammetric model, the failure controlling faults, and the design pit wall utilizing Vulcan. The result is shown in the adjacent diagram.

A cable bolt design was constructed based on the observed major structures as well as the stereonets for the mapped joints (not shown).

The result was a cable bolt design with bolt locations noted on a high resolution photographic image for field markup.

As the wall was scaled, and additional material removed, additional photographs were taken to update the design in terms of bolt loading, as well as bolt placement.

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