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Äspö Hard Rock Laboratory

**Laser scanning combined with
digital photography**

**Tunnel TASQ and niche NASQ0036A
at Äspö HRL**

Rolf Berlin
Advanced Technical Solutions AB (ATS)

Carljohan Hardenby
Vattenfall Power Consultant AB

June 2008

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00



**Äspö Hard Rock
Laboratory**

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Author
Rolf Berlin
Carljohan Hardenby
Checked by
Johan Berglund
Approved
Mats Ohlsson

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Keywords: Laser scanning, Digital photography, Colour laser scan image, Geological mapping, Underground mapping, Volume calculations, Cross sections, TASQ

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

Abstract

Laser scanning in combination with digital colour photography was performed in the TASQ-tunnel at the -450 m level of the Äspö Hard Rock Laboratory in 2006. The scanning and photography was done at three occasions; the first one before the niche NASQ0036A was excavated, the second after excavation and the third one when the niche had been reinforced. On the last occasion the whole tunnel was scanned and photographed. The first two included only the niche section.

A Faro 3D laser scanner 880HE40 was used on all three occasions. On the first scanning occasion a digital 6 Mpixels camera, a Nikon D70, was mounted on top of the laser scanner. With this arrangement the integration of laser scan image and digital photos will take place automatically when the function “Apply pictures” is used. On the two last occasions a high resolution 50 Mpixels line-camera, a SpheroCam HDR, was used. In this case the camera was mounted on the same tripods that had been used for the laser scanner after removal of the latter. The alignment of scan data and colour photo had to be done manually.

The spherical photos taken by the SpheroCam-camera are of very good quality. Unfortunately it takes about 10-30 minutes to capture a high resolution image whereas it takes only about 4-5 minutes to capture the digital photos with the Nikon camera. A fast digital camera mounted on the laser scanner, with no parallax errors and automatic fitting of the photo to the laser point cloud would be a perfect arrangement.

To obtain good results the tunnel has to be clean; walls and roof has to be flushed with water. The laser scanner does not need any light but the digital cameras need massive light arrangements to give acceptable image quality. Either a very good camera flash can be used or preferably a good continuous light source close to the camera tripod as was the case on the last two scanning occasions.

In order to connect the laser scan image and the colour photo to the coordinate system ÄSPÖ96 a geodetic survey was carefully executed. The obtained point accuracy of the scan cloud is less than 5 mm.

After having connected scan data, photo and coordinates all points in the scan cloud will carry XYZ and RGB information.

An overlay of the laser point cloud on the 3D model of the theoretical tunnel made it possible to compare the theoretical tunnel with the real one. A number of cross sections were generated with the help of the software Real Reality Tunnel (RRT) to compare the theoretical tunnel contour with the final one. Using the same software the volume of the excavated niche could be calculated by comparing the scans made before the excavation with those made after the excavation.

The purpose with the last scanning event was to visualize the reinforcements in the new niche NASQ0036A. In the FaroScene software for example the bolts could be marked out as small squares or points that were labelled and the coordinates established. These objects (marker, label and coordinates) could then be exported in open CAD-formats such as igs and dxf.

Geological test mapping was performed in the niche. Some fractures and rock boundaries were drawn in the 3D laser scan image combined with colour photo with the help of the software FaroScene. As for the reinforcements, the objects could be labelled and exported in open CAD-formats. By comparing the mapping that had been performed in the traditional way; by hand in the tunnel and then digitized in Microstation, with the test mapping in FaroScene it was quite obvious that there was a difference in the positioning of the objects. No doubt an improvement can be encountered by mapping based on the 3D laser scan image.

To make the FaroScene or equivalent software a useful tool in geological mapping it must be possible to:

- attach geological data on the features drawn in the laser scan image
- choose between a number of line styles
- export to Microstation to fulfill the SKB requirements.

The laser scanning test in the TASQ-tunnel has shown that based on the same laser scan data the following can be performed:

- comparisons between theoretical and real tunnel contours
- volume calculations
- documentation of reinforcements
- geological mapping, although so far rather primitive

Sammanfattning

Laserskanning i kombination med digital färgfotografering har år 2006 utförts i Q-tunneln (TASQ) på -450 m nivå i Äspölaboratoriets underjordsdel. Skanningen utfördes i tre etapper; den första innan den nya nischen NASQ0036A sprängdes ut i TASQ, den andra efter det att nischen var uttagen och den tredje efter det att nischen även var förstärkt. Vid det tredje tillfället skannades och fotograferades hela tunneln medan vid de två tidigare bara sektionen som berörde själva NASQ0036A-nischen.

Vid alla tre skanningstillfällena så användes en Faro 880HE40 3D laserskanner. Vid det första tillfället var en Nikon D70 6 Mpixel digitalkamera monterad direkt ovanpå laserskannern. Med denna uppsättning kunde laserpunktmoln och digitalfoto automatiskt sättas ihop med hjälp av en funktion som kallas ”Apply pictures”. Vid de två senare skanningstillfällena användes en högupplösande 50 Mpixel SpheroCam-kamera. Efter det att skanningen var utförd monterades kameran på samma stativ som lasern hade använt och som hade lämnats kvar på plats. Sammankopplingen av laserpunktmoln och foto fick dessutom göras manuellt.

Bilderna (sfäriska bilder), som togs med SpheroCam-kameran var av mycket hög kvalitet. Tiden för att ta bilderna med detta kameraalternativ var c:a 10-30 minuter per uppställning jämfört med den vanliga Nikon-kameran som tog 4-5 minuter för att ta de digitala bilderna. Med en snabb digitalkamera monterad ovanpå lasern, utan parallaxfel och med automatisk sammankoppling av punktmoln och foto så skulle man få ett utmärkt instrument.

För att uppnå ett gott resultat måste tunneln vara ren. Tak och väggar måste spolras med vatten. Själva laserskanningen kräver inget ljus men däremot behöver fotograferingen detta. Antingen måste en mycket bra konventionell fotoblixt användas eller som vid de två sista tillfällena en central ljuskälla bestående av strålkastare monterade som en ring under kamerastativet.

För att kunna ansluta skannadata och foto med gällande koordinatsystem behövs en noggrann geodetisk inmätning av ett antal referenspunkter göras. Noggrannheten som uppnåddes för punktmolnet var <5 mm.

Efter det att skannadata, foto och koordinatsystem har kopplats ihop kommer x, y, z plus RGB att finnas i varje punkt i punktmolnet.

Genom att drapera en 3D-modell över den teoretiska tunneln med punktmolnet kunde en jämförelse göras mellan verklig och teoretisk tunnel. Med hjälp av ett antal tvärsektioner som skapats med hjälp av programvaran Real Reality Tunnel (RRT) kunde den teoretiska tunnelkonturen jämföras med den verkliga. Med samma programvara kunde även volymen av den utsprängda nischen göras genom att jämföra skannadata, som erhöles före utsprängningen, med den som erhöles efter.

Syftet med den sist utförda skanningen var att dokumentera förstärkningarna i den nya nischen NASQ0036A. Med hjälp av programvaran FaroScene kunde t.ex. bultar markeras som små fyrkanter eller punkter. Dessa kunde sedan namnges/etiketteras samt koordinatsättas. Bultar, etiketter och koordinater kunde sedan exporteras i ett öppet CAD-filformat såsom igs och dxf.

En geologisk testkartering utfördes i den nya nischen. Några sprickor och bergartsgränser ritades med hjälp av programvaran FaroScene på den 3D ”bild” i färg, som skapats över området. Även i detta fall kunde objekten namnges/etiketteras och exporteras i öppna CAD-filformat. Genom att jämföra den kartering som gjorts enligt den konventionella metoden; handritad karta i tunneln som sedan digitaliserats i Microstation, med testkarteringen gjord i FaroScene kunde man se att lägena för de olika objekten inte helt sammanföll. Utan tvekan har en förbättring skett i karteringen utfördes med hjälp av den färgsatta 3D-”bilden”.

För att göra FaroScene eller liknande programvara till ett användbart redskap för geologisk kartering behövs en hel del utveckling:

- det måste bli möjligt att koppla geologisk data till de objekt som ritas i ”skannbilden”
- det måste bli möjligt att välja bland ett antal linjetyper
- det måste på ett enkelt sätt bli möjligt att exportera allt till Microstation för att SKB:s krav skall kunna uppfyllas.

Laserskanningstesten, som utfördes i TASQ har visat att det redan är möjligt att:

- göra jämförelser mellan teoretisk och verklig tunnelkontur
- göra volymeräkningar
- utföra dokumentering av förstärkningar
- utföra geologisk kartering, dock ännu på ett ganska primitivt stadium.

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1 Introduction

1.1 Background for the study

SKB and Posiva began some years ago a project called RoCS (Rock Characterization System, Magnor et al. 2006). The intention was to accomplish a new mapping system that could be used for rock characterization underground. Modern technology was believed to give a better accuracy and traceability in the mappings that are performed. The new characterization system was meant to be used also for documentation of reinforcements, drift installations, calculations of excavated volumes, tunnel geometries etc. Within the project photogrammetric and laser scanning techniques were tested. After some time it was concluded that laser scanning combined with digital colour photography was the best technique to use as a base for the new mapping system.

When the excavation of a niche for the “Alternative buffer material experiment” at Äspö HRL was decided, the opportunity was taken to test the laser scanning technique combined with digital photography in a larger scale than had been done within the RoCS project. The idea was to demonstrate:

- How to calculate the excavated rock volume
- Comparison of theoretical and real tunnel sections
- Comparison between a present standard Äspö geological mapping with test mapping on an image resulting from laser scanning combined with digital photo
- How well reinforcements would show up on the scan/digital photo image

The study was initiated by SKB and was performed by the authors Rolf Berlin, laser scanning operator at Advanced Technical Solutions AB (ATS) and Carljohan Hardenby geologist at Vattenfall Power Consultant AB assisted by Bengt Eliasson surveyor at Geoiden AB and Michael Müller, high resolution camera operator at Spheron GmbH.

1.2 Location

The laser scanning was performed in the TASQ tunnel at the –450 m level of the Äspö HRL where the new niche was to be excavated. The niche, later called NASQ0036A, was excavated between the sections 28 and 44 on the left (northwest) side of the TASQ tunnel when looking towards the tunnel face. It is a quite shallow niche, only about two metres deep (Figures 1 and 2).

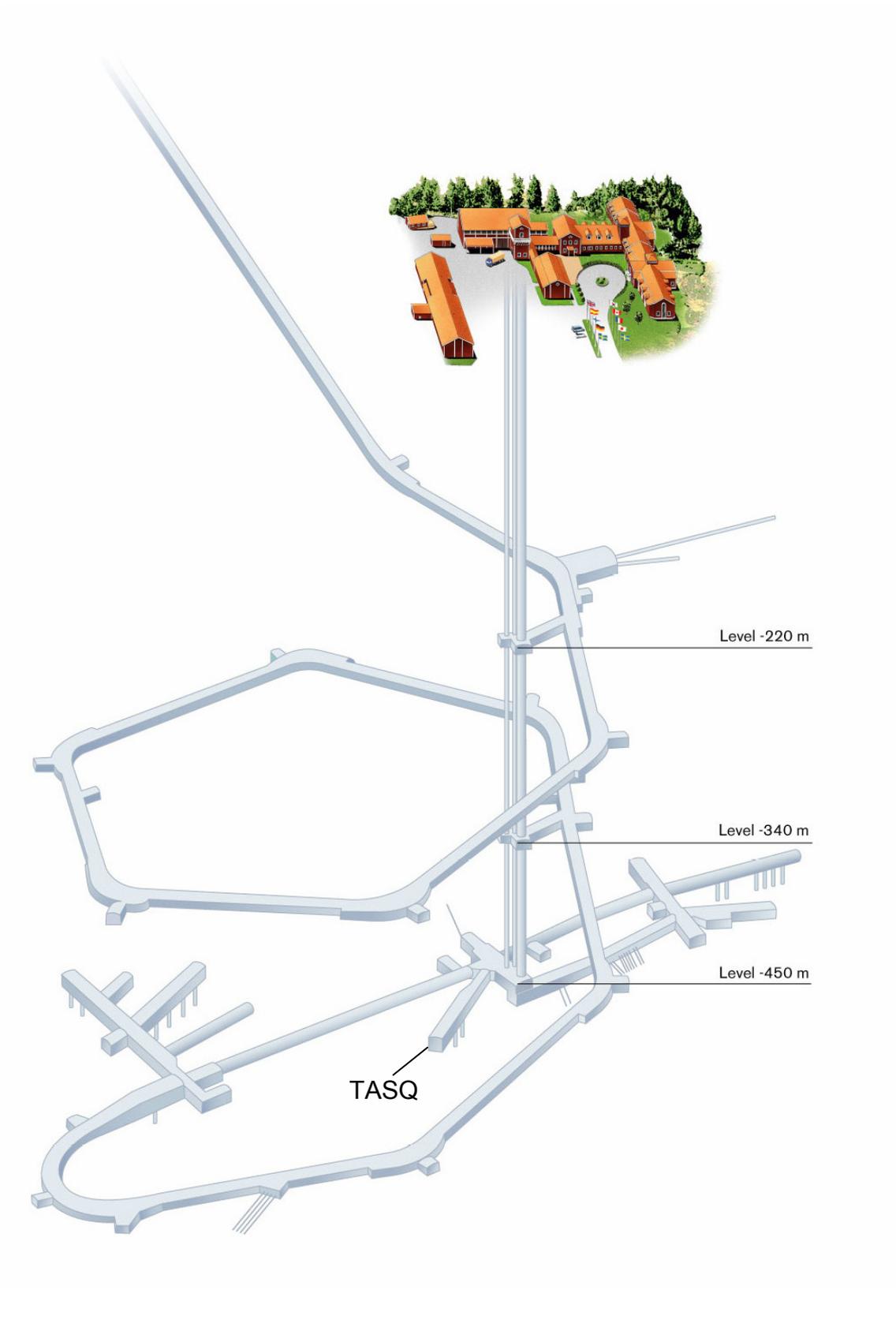


Figure 1. The tunnels and shafts of Äspö hard Rock Laboratory.

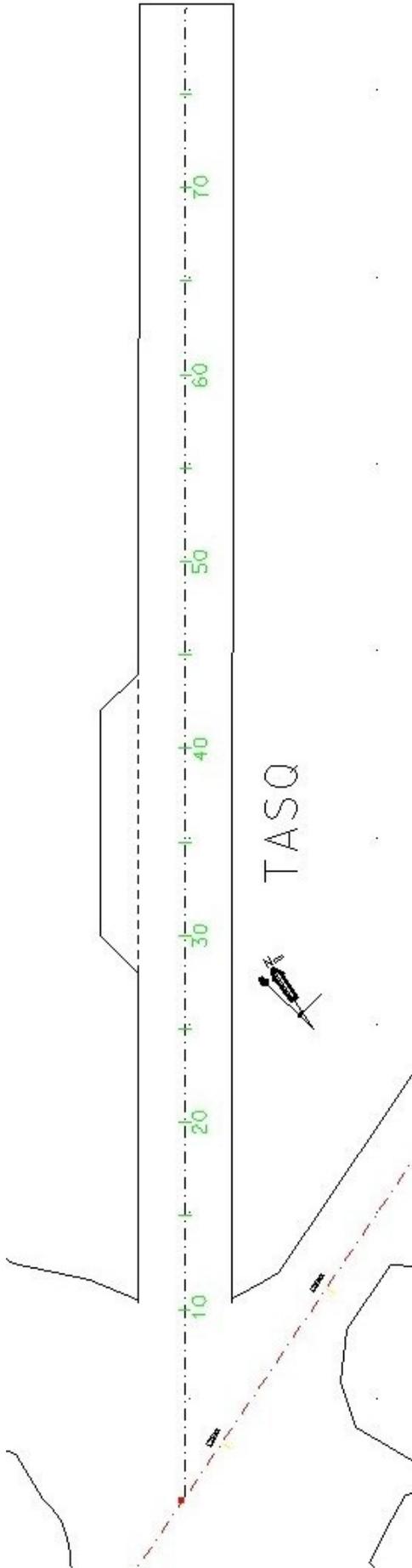


Figure 2. The TASQ-tunnel and the shallow niche NASQ0036A (section 28-44 m), top view, theoretical tunnel and niche contour.

1.3 Scanning occasions

The laser scanning combined with digital photography took place at three occasions in the year of 2006 (Figure 3):

- The first one was executed before the niche was excavated (phase 1). At this time only the niche section of the existing tunnel was scanned and photographed.
- At the second occasion the niche had been excavated but not reinforced (phase 2). At this time too, only the niche section was scanned and photographed.
- The third scanning and digital photography session took place when the niche had been reinforced. At this occasion also the rest of the TASQ tunnel was scanned and photographed (phase 3).

All scan data have been stored on DVD-discs in SKB's Sicada archive.

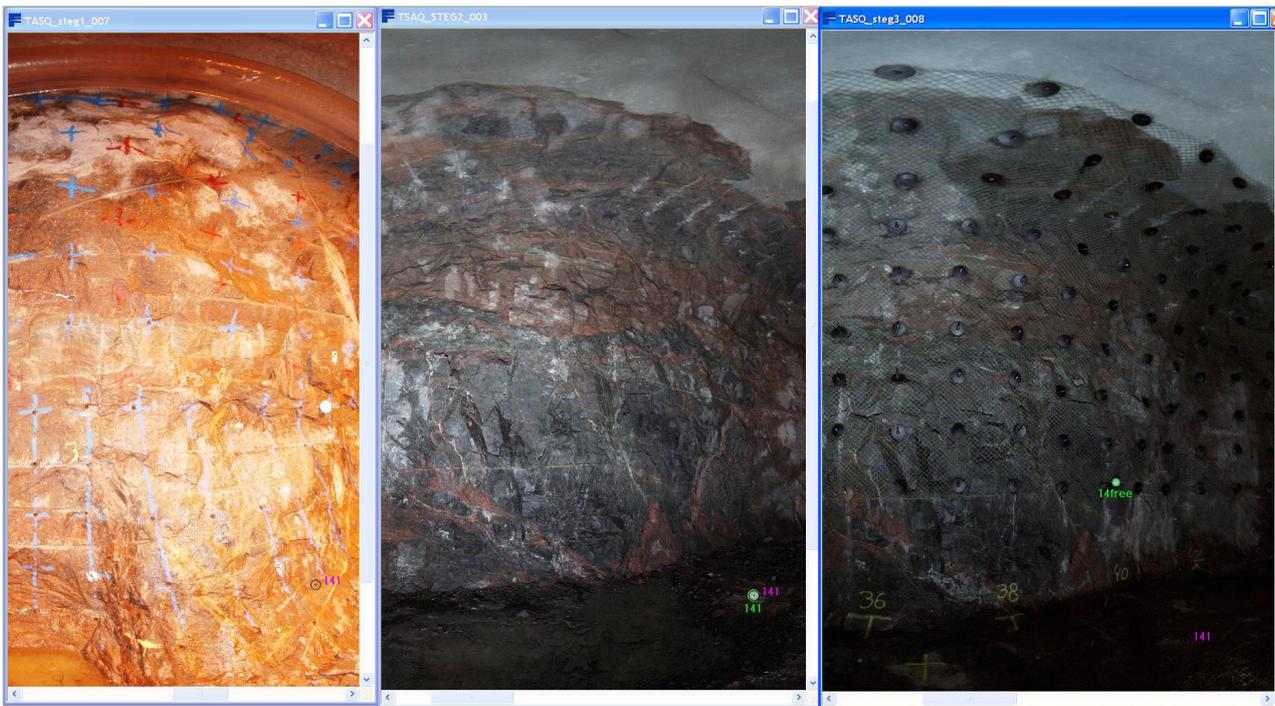


Figure 3. Laser scan-data from the same area of tunnel recorded at phase one, two and three.

2 3D laser scanning and colour photography

2.1 Laser scanning equipment

Faro 3D laser scanner 880HE40 placed on a surveying tripod was used during all three scanning occasions in the tunnel (Figure 4). During the first occasion a FARO colour option with an onboard mounted Nikon camera was used (Figure 5). During step two and three a separate line camera solution was used (Figure 6). The line camera was placed on the same tripod as the scanner after the 3D scan was performed.

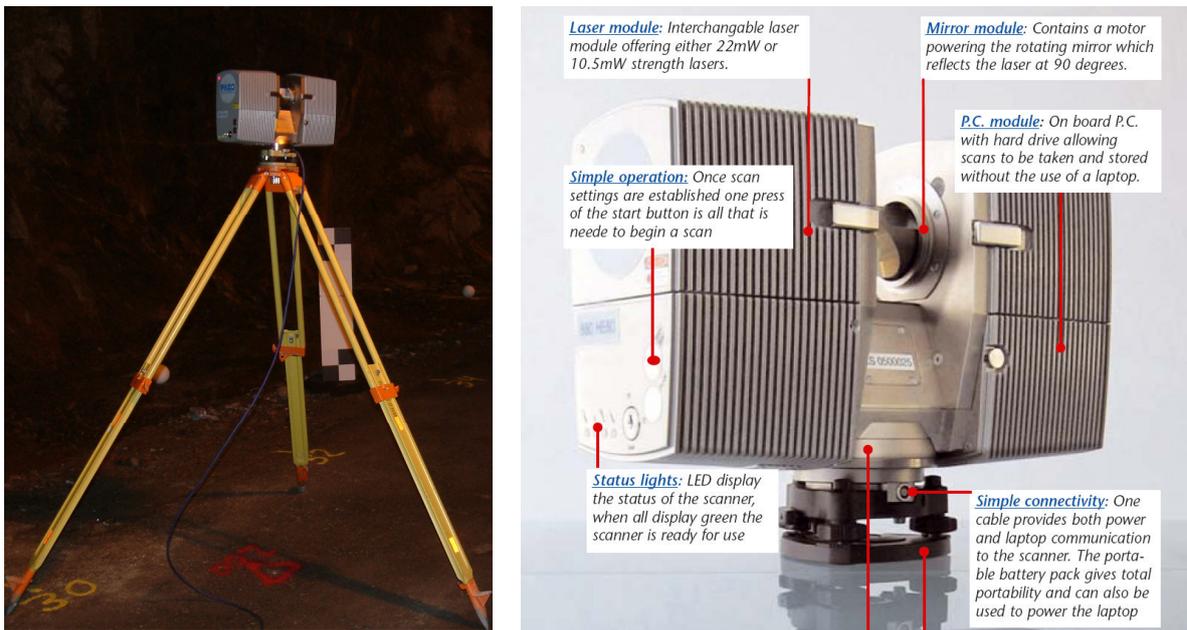


Figure 4. Faro LS880 HE40 mounted on a surveying tripod.

FARO LS880 HE40

Range	0,6m-40 m
Distance error	3mm @ 25m
Measurement speed	120 kHz
Laser power	10mW
Wavelength	785 nm
Laser Class	3R
Dimensions WxHxD	400x160x280 mm, 14,5 kg

2.2 Photography equipment

2.2.1 Normal digital 6 Mpixels camera

In step one the standard Faro 880 colour option with a Nikon D70 camera with a fish eye lens was used (Figure 5). When a colour scan is taken, the scanner first performs a normal scan. Then it automatically takes an extra turn determining a balanced exposure setting. Finally in a third run 10 digital pictures are taken during short stops.

With the function “Apply Pictures” the integration of scan data and images is later automatically done at the office. The Apply Pictures function will first load the scan and all its pictures, then remove distortions from the pictures and finally add the colour information to the scan points.

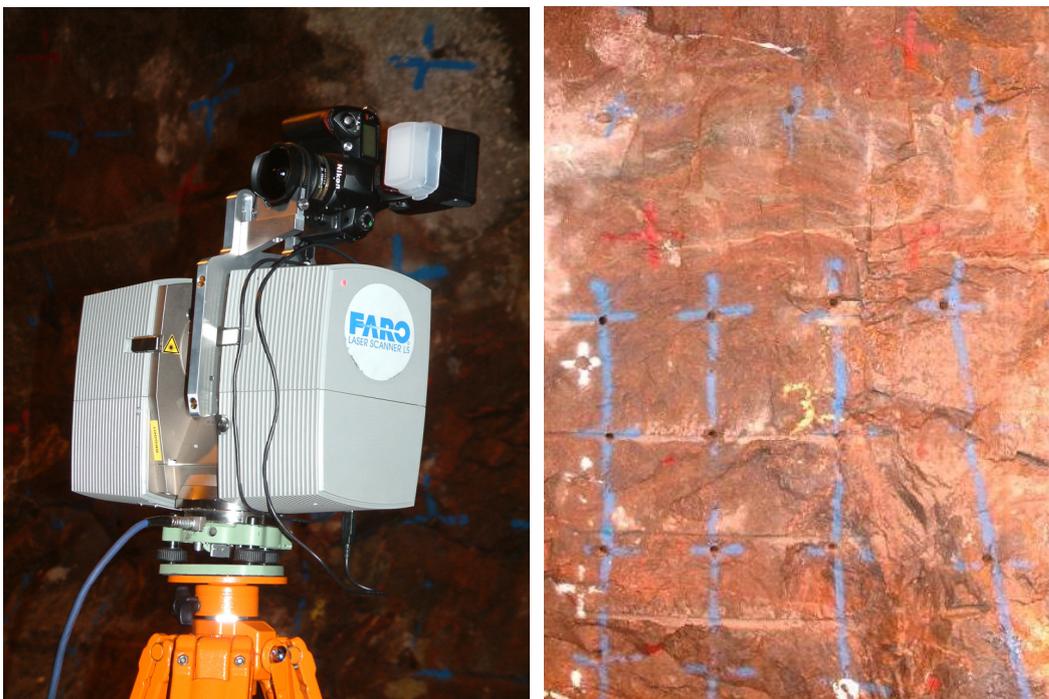


Figure 5. To the left, FARO LS880 with colour photo option NIKON D70 and flash. To the right, a colour scan image showing a part of the tunnel wall.

NIKON D70

Pixels	6,1 million,
Sensitivity	ISO equivalency 200 to 1600
Storage	Compact Flash
Dimensions	WxHxD 140x111x78mm, 595 g

2.2.2 High resolution digital line camera

In step two and three a line-camera, SpheroCam HDR from the company SpheronVR was used (Figure 6). With up to 26 f-stops of dynamic range in one image the SpheroCam HDR captures all levels of light intensity, in all directions in a single scanning pass. This means that the light intensity of the image can later be adjusted. The view is 180 degree vertically and the camera rotates 360 degree capturing a full spherical image.



Figure 6. To the left the high resolution line-camera, SpheroCam HDR To the right a colour scan showing a part of the TASQ tunnel wall.

SpheroCam HDR

Pixels	up to 50 million,
Data Path	96 bits per pixel (3x32 bits RGB)
Storage	Laptop
Dimensions	Diameter 140mm height 300mm 1,9 kg
Operation	scans vertical lines pixel by pixel while rotating about the vertical axis.

3 Laser scanning and digital photography procedure

3.1 Theory behind 3D laser scanning

A 3D laser scanner works by sending an infrared beam into the centre of a rotating mirror. This deflects the laser beam on a vertical rotation around the environment being scanned, the beam is then reflected back into the scanner and the distance to the object can be calculated (Figure 7).

By using encoders to measure the mirror rotation and the horizontal rotation of the laser scanner the X,Y,Z coordinates of each scan point can be calculated.

Resolution can be selected depending on what the data shall be used for. The resulting scan or “point cloud” is a matrix of e.g. 8000x4000 points or ca 30 million points.

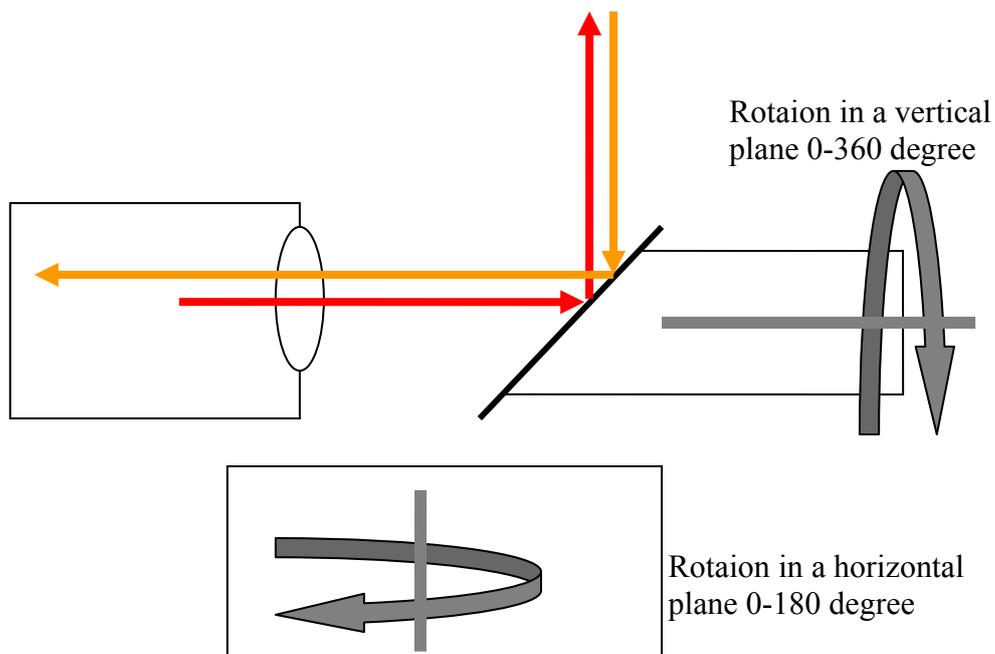


Figure 7. The principle of 3D laser scanning.

The used 3D Laser scanner LS880 from FARO use “phase shift technology” as opposed to “time of flight” distance recording.

This means that instead of a single pulse being reflected and the time of flight being measured, constant waves of varying length are projected.

Upon contact with an object they are reflected back to the scanner. The distance from the scanner to the object is measured by measuring the phase shifts in the waves of the infrared light.

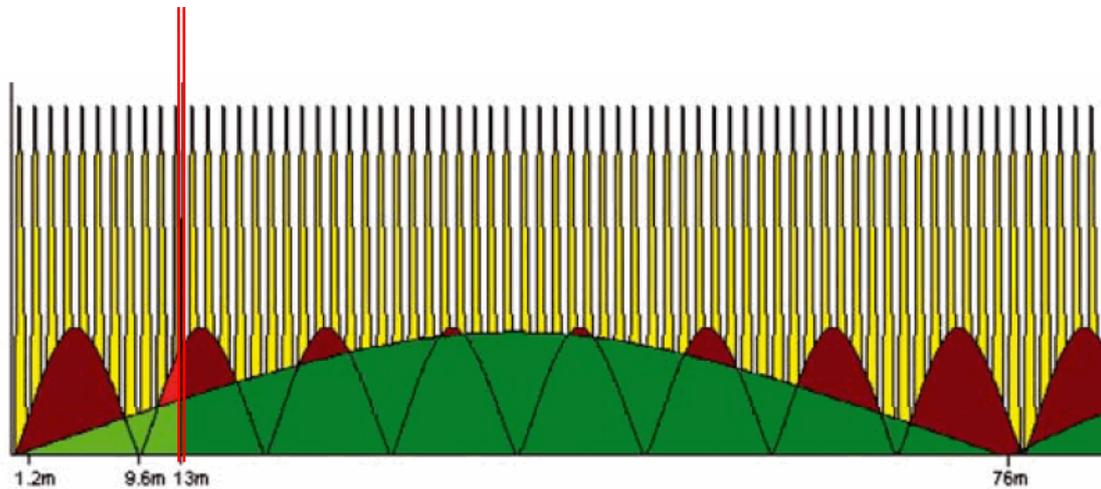


Figure 8. *The principle of Phase Shift Technology.*

The Laser scanner splits the laser beam into 3 components operating on 3 different modulation wave lengths 76 m, 9,6 m and 1,2 m as illustrated in Figure 8. The distance of the reflecting object from the scanner is determined by identifying the point in the corresponding combination of wave length cycle. For example; a reflection from 13 m will be detected within the 76 m range as shown by the light green area on the diagram. Then the next wavelength 9,6 m is evaluated and the reflection is detected in the second cycle of the light red area, (9,6-19,2 m). Finally the third wavelength is evaluated and found to be in the last part of the third cycle. The accuracy is achieved by measuring in the 3rd cycle. $13\text{ m} = 9,6\text{ m} + 2 \times 1,2\text{ m} + \text{a measured part of } 1,2\text{ m}.$

The main advantage of phase shift technology is speed of point capture, 120 000 points per second, compared to approximately 4000 points for time of pulse based scanning. The uses of 3 wave lengths give a higher degree of accuracy. With a digital range resolution of 17 bit, the resolution is 0,58 mm.

3.3 Execution of the field work

3.3.1 The geodetic survey

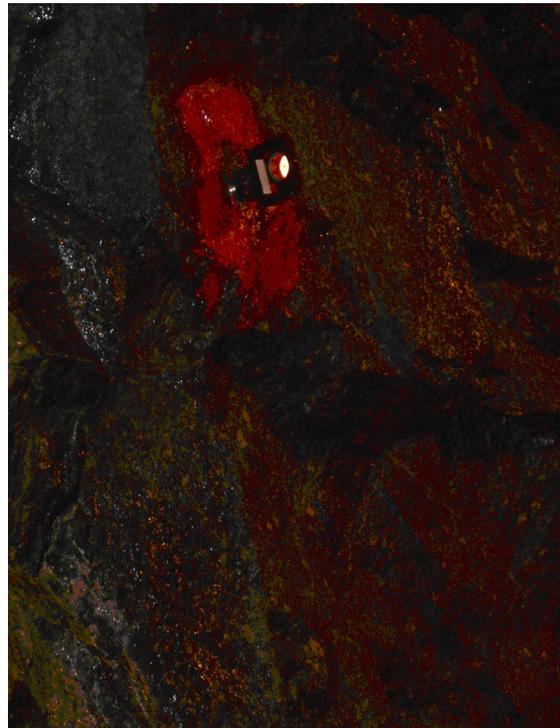
A carefully executed geodetic survey is the key to high precision in the laser scan data. A Leica TCA2003 total station and three polygon spades defining the known points 39F, 39G and 39Q in the TASQ-tunnel were used to define the ÄSPÖ96 coordinate system in the tunnel. All complementary reference points mounted mainly on the tunnel walls were surveyed accordingly (Figures 10 and 11). At least four reference points are needed for each scan with the laser scanner. Normally each scan covers a tunnel section not exceeding the double tunnel width. To cover the demand of reference points for the TASQ-tunnel a total of 40 points had to be positioned. The positioning of the complementary reference points was performed accordance with HMK (Handbok till mätkungörelsen, C-G Persson et al 1993)

The complementary scan references on the tunnel walls were accomplished by drilling an 8 mm hole into which a plastic plug was put. A metal nail with a M8 thread head was then hammered into the plug. On the M8 thread either a special designed prism or a white sphere was mounted. The prism was used while surveying and the spheres during scanning. Due to special design of the equipment the centre point of the sphere and the prism were identical. Each reference bolt with mounted prism was surveyed several times from different locations. The resulting net adjustment of all reference data showed stable values with a variation below 0,3 mm (Figure 12).



a)

Figure 10. a) Fix point with a prism mounted.



b)

Figure 10. b) Reference bolt with a prism mounted.



a)

Figure 11. a) Some white reference spheres mounted on reference bolts.



b)

Figure 11. b) Surveying of reference points with total station.

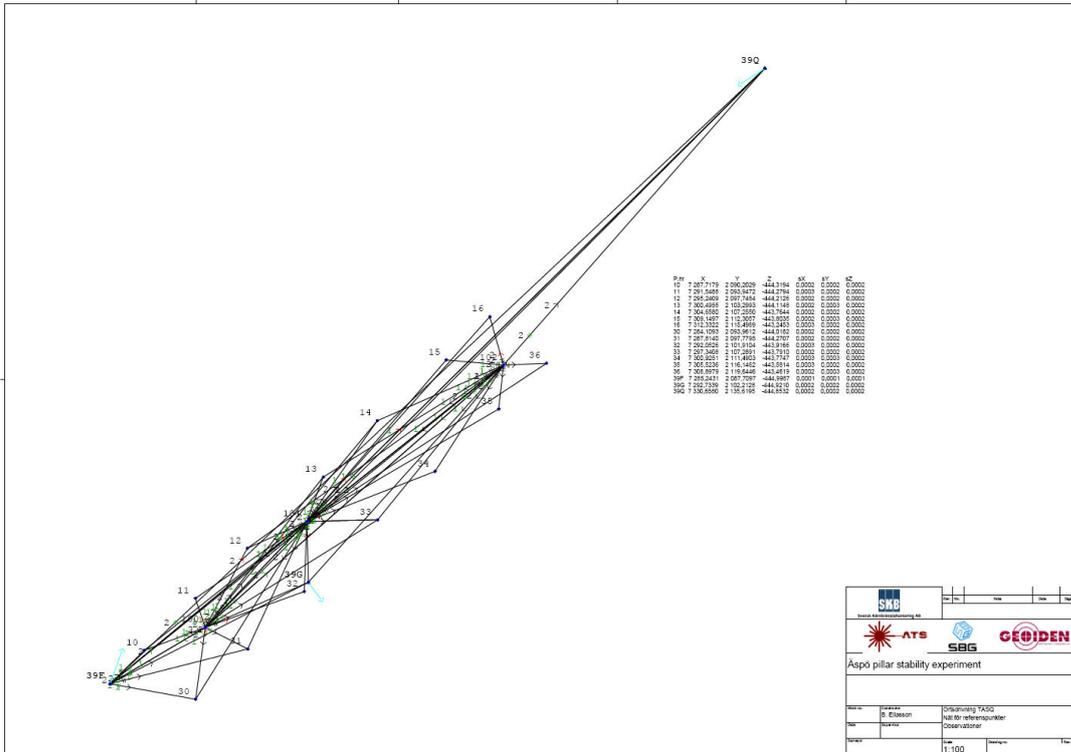


Figure 12. Drawing of the net analyses of surveyed references in the TASQ-tunnel.

When positioning (registrating) a scan cloud the surveyed references and corresponding objects in the scan cloud is matched mathematically with “best fit” resulting in tensions <5mm (Figure 13).

The “distance” value in the quality registration table below includes all errors of scanner, mounting spheres, detection of sphere centre, surveyed data etc. The value gives a good answer of the overall achieved scanning quality.

Scan Name:	TASQ_steg3_001			
Name:	ScanFit8			
Inclinometer:	<input type="checkbox"/> level scan according to inclinometer			
Position:	2136.7627 7328.9496 -443.3717			[m]
Orientation Axis:	-7.1667885e-005 0.00013720948 -0.99999			
Angle:	140.3435			[°]
Point distance:	2.772066	[mm]		OK
Point drift:	0.003139	[mm]		OK
Long. mismatch:	2.092999	[mm]		OK
Angular mismatch:	0.026954	[°]		OK
Orthogonal mismatch:	1.817863	[mm]		OK
Inclinometer mismatch:	0.056478	[°]		OK
Registered by:	Distance [mm]:	Long. [mm]:	Angular[°]:	Orth.[m]
/References/20	2.8	-0.7	0.040107	2.7
/References/21	4.2	-4	0.017189	1.4
/References/40	1.6	-1.1	0.017189	1.2
/References/41	1.5	-0.2	0.022918	1.5

Figure 13. Registration of scan references and surveyed data results.

3.3.2 The laser scanning

The FARO 880 scanner was set to resolution 8000 points per mirror rotation; this gives a total point cloud of 30 million points 360 degree around the scan position. The geometrical resolution is one scan point each square mm at a distance of 2,5m. In each scan point the received laser amplitude is recorded and converted to a greyscale level.

Scanning time is about 4 minutes for a complete 360 scan with this resolution.

3.3.3 The digital photography

Nikon D70 camera

At the first scanning event, when a normal 6 Mpixels system camera Nikon D70 was used, a flash together with the tunnel illumination gave sufficient light (Figure 5).

The Nikon D70 camera is mounted on top of the laser scanner. The whole system is automatic and the camera is controlled by the laser scanner. When the scanning of a section is completed the system automatically takes a second turn to determine a balanced exposure setting for the photography. After that, during a third turn, the camera takes 10 digital pictures during 5 minutes.

SpheroCam HDR high resolution camera

At the last two scanning events, when the high-resolution digital line camera SpheroCamHDR was in use, the light source consisted of a ring of floodlights placed under the camera tripod (Figure 6 and 14). The floodlights were connected by an ordinary electric cord to one of the electric outlets in the tunnel.

Unfortunately the socket to attach this camera on the laser scanner was not yet ready when the scanning of the TASQ-tunnel took place. Therefore the digital photography took place after the scanning had been performed, using the same tripods that had been used by the scanner. To minimise parallax and positioning errors the line camera lens has to be placed in the same height as the rotation mirror of the scanner. In order to achieve this, the line camera was mounted on an adapter with the same tribrach foot as the scanner.

It took about 10-30 minutes to capture the pictures on each position. The resulting spherical photos are of extremely high quality.

To support the manual overlay of the Spheron picture on top of the scan cloud 8-12 black and white targets were placed around the camera. (Figure 14)



Figure 14. The SpheroCam HDR high resolution camera mounted on a tripod with the ring of flood lights needed for illumination underneath. In the background the laser scanner on its second tripod.

4 Results and calculations from scan data

4.1 The combination of laser scan image and the digital photo

The goal of the scanning test at Äspö HRL was to use state of the art solutions with available technology and if possible compare that with technology that may be available on the common market within some years ahead. The latter is of great interest due to the long planning horizon for the nuclear waste repository. The quality of the camera resolution was vital, due to the wish to perform geological mapping and to be able to analyse geological features with the coloured scan.

As mentioned before all scan data have been stored on DVD-discs in SKB's Sicada archive. Some examples of coloured scans as well as a model of the TASQ-tunnel based on the scans are shown in the Appendices 1-8.

4.1.1 Experiences with the FARO camera option used in phase one:

- The system works completely automatic, the camera is controlled by the scanner.
- The need of light is high for the Nikon camera. The flash used was too weak. The same arrangement with flood light that later was used with the Spheron camera would have been better.
- The extra camera capturing time is about 5 minutes per scan.
- Due to different position of camera and scanner parallax errors of several cm on the tunnel wall was observed.
- The fish eye camera lens was not able to see fully 180 degrees, and thus some areas, either at the floor or the roof, was not coloured.

4.1.2 Experiences with the SPHERON camera used in phase two and three:

- The camera system works manually.
- The need of light is high to process a fast photo. Using the described arrangement of flood light it took about 10-30 minutes to turn 360 degree with the line-camera. Time for mounting is not included.
- Due to observed parallax errors in phase two, an improved camera adapter was used in phase three.
- Alignment of scan data and colour photo was made manually by best fit of selected points in the scan cloud and photo. Due to the high quality photo and the well identified black and white targets the resulting overlay was extremely good. Typically 2 pixels error when 10 targets were used.

4.1.3 Advantages and disadvantages

The resulting colour scan in phase three was extremely good (Figure 15). However the manual work to run the camera and to fit the colour to a scan cloud is presently not on a practical level.

The work flow in phase one is preferable, with the automatically controlled camera integrated with the scanner, automatically fitting the colour value to the scan data. Due to parallax errors and lens problems the quality needs to be improved.



Figure 15. Image of a colour scan from a Spheron camera, phase three.

4.2 Comparison between theoretical tunnel and real tunnel

After registration a scan cloud is positioned in ÄSPÖ96 co-ordinate system and possible to overlay and compare with existing 3D drawings of the TASQ tunnel mapping (Figure 16). This analyse was performed in the program FaroScene (scanner software) with an imported model from Microstation.

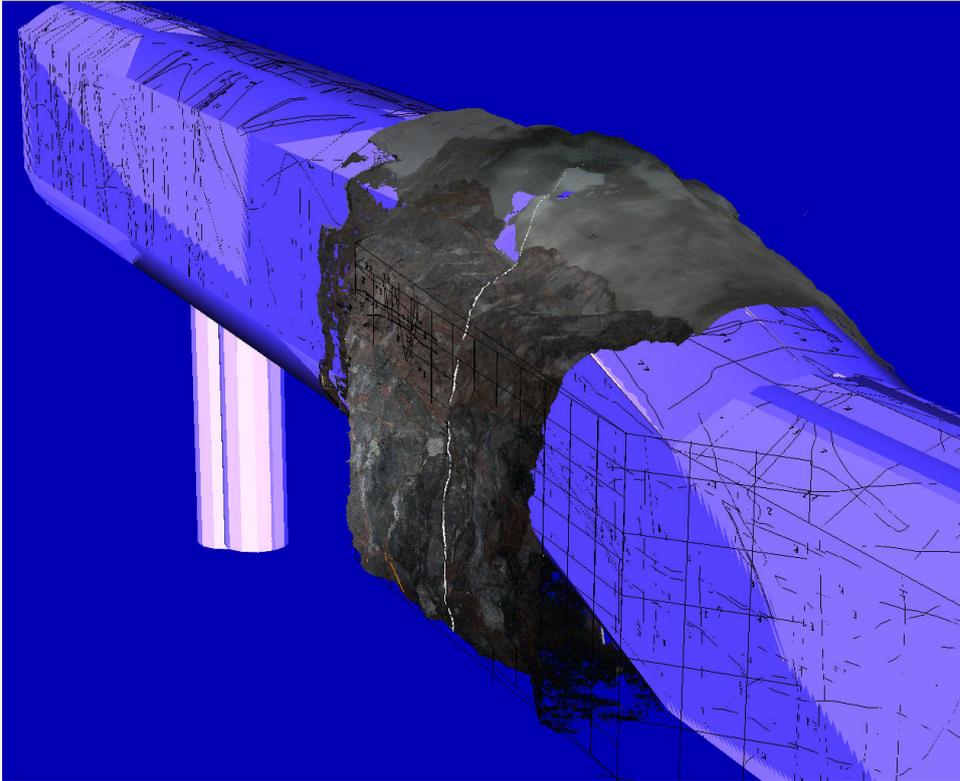


Figure 16. Theoretical tunnel contour overlaid with a scan cloud.

Based on the same scan data, theoretical tunnel centre line and profile traditional 2D tunnel production documentation can be generated. In this example the program RRT (Real Reality Tunnel) from Faro was used. Cross sections with any centre-to centre (cc) distance is automatically generated and presented as dwg drawings (Figure 17).

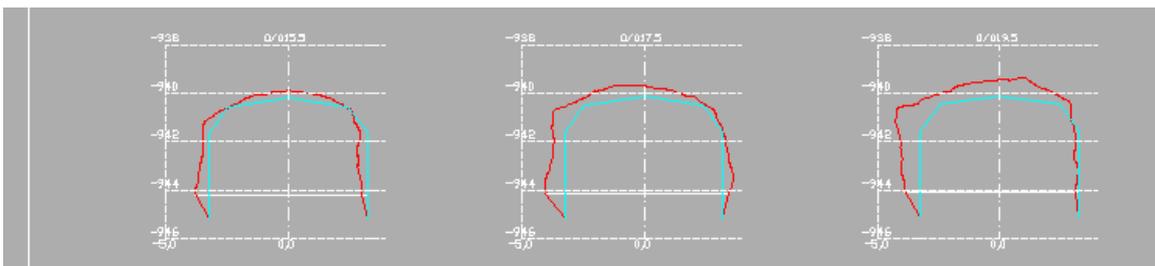


Figure 17. Cross sections from scan data (red) and theoretical tunnel profile (bluish).

4.3 Volume calculations

The niche NASQ0036A area was scanned before and after excavation. The combined scan data was used to generate cross sections from section 27 to 45.

Comparison between red and dark blue cross sections from scan data on the opposite side of the niche shows that the positioning of scan clouds in ÄSPÖ96 is within +/- a few mm (Figure 18). The dark blue cross section originates from scan data obtained before the niche was excavated (phase 1) and the red one from scan data obtained after the excavation (phase 2). See also Appendix 1.

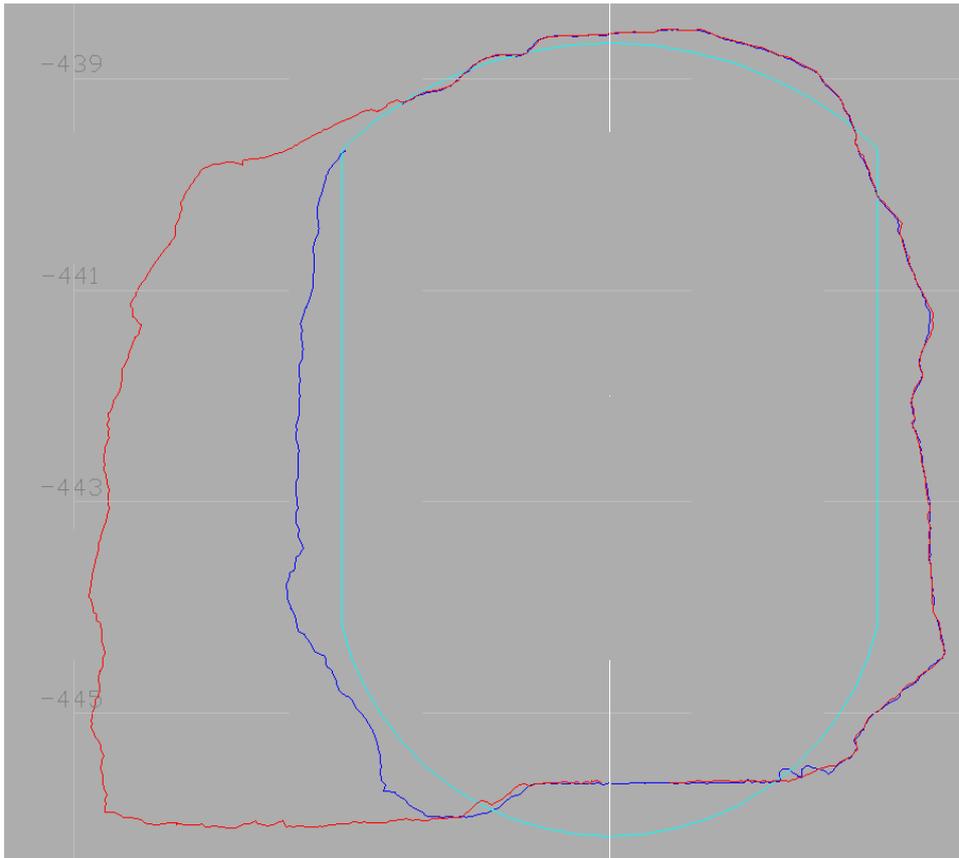


Figure 18. The theoretical tunnel contour (light blue) of the TASQ-tunnel and scan data from phase one (dark blue) and two (red) at niche NASQ0036A. The rather flat surface over the circular theoretical tunnel floor represents the roadbed that was constructed after the tunnel excavation.

By using the tunnel program RRT the tunnel volume of section 27-45 was calculated before and after excavation of the niche (Table 1).

Table 1. Volume calculations.

TASQ, Äspö

Section 27-45

Real volume phase one		589,34m ³
Real volume phase two		738,17m ³
Excavated rock volume		148,83m ³

4.4 Documentation and illustration of reinforcements

Scan data from phase three shows the reinforcement work in the niche NASQ0036A (Appendix 6).

Based on the scan data image in FaroScene it is possible to:

- Point at and select the bolt
- Generate a mean point value (x, y, z) from scan data
- Name the point in a logical way
- Export the position and name

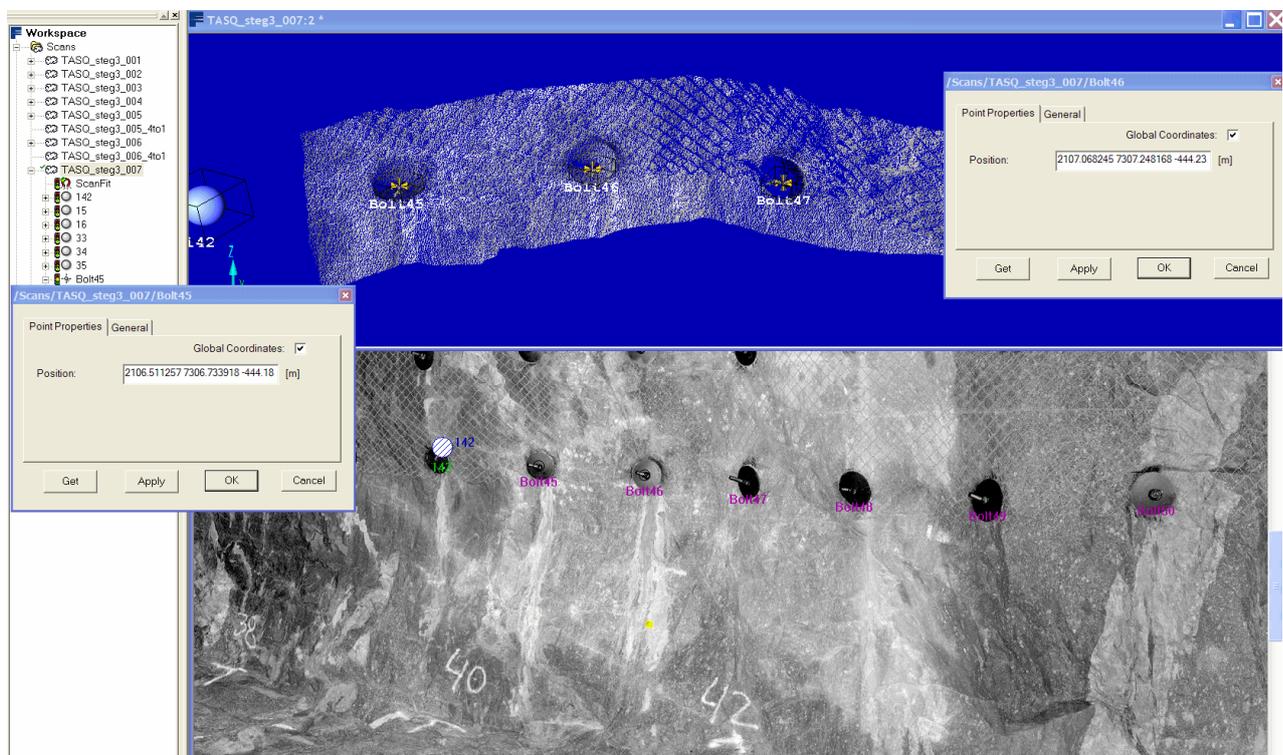


Figure 19. Position data of reinforcement bolts in FaroScene software.

From FaroScene single or groups of objects such as reference bolts can be exported in open CAD formats such as igs or dxf (Figure 19).

4.5 Tunnel mapping

Geological mapping is performed in many rock construction projects. The purpose is to document the geological properties of the rock (fracture intensity, fracture orientation, rock types etc) at the construction site. Since the Äspö HRL to the major part is an underground facility most emphasis have been put on underground mapping.

4.5.1 Ordinary tunnel mapping method

At Äspö HRL a rather conventional method is used for underground mapping. Walls, roof, front and occasionally also the floor of the excavated tunnels and niches are mapped. The field mapping is performed by hand on a sheet of paper on which the theoretical tunnel outline is projected to a plane with the walls and roof unfolded (Figure 20 and 21). Normally fractures, rock types, rock boundaries and zones of weakness are mapped. Data concerning these features are registered on special forms. After the field work is completed the field map is digitized and the data fed into a connected database. In the tunnel mapping system (TMS), used at Äspö HRL since many years, each feature on the digitized drawing carries its own data.

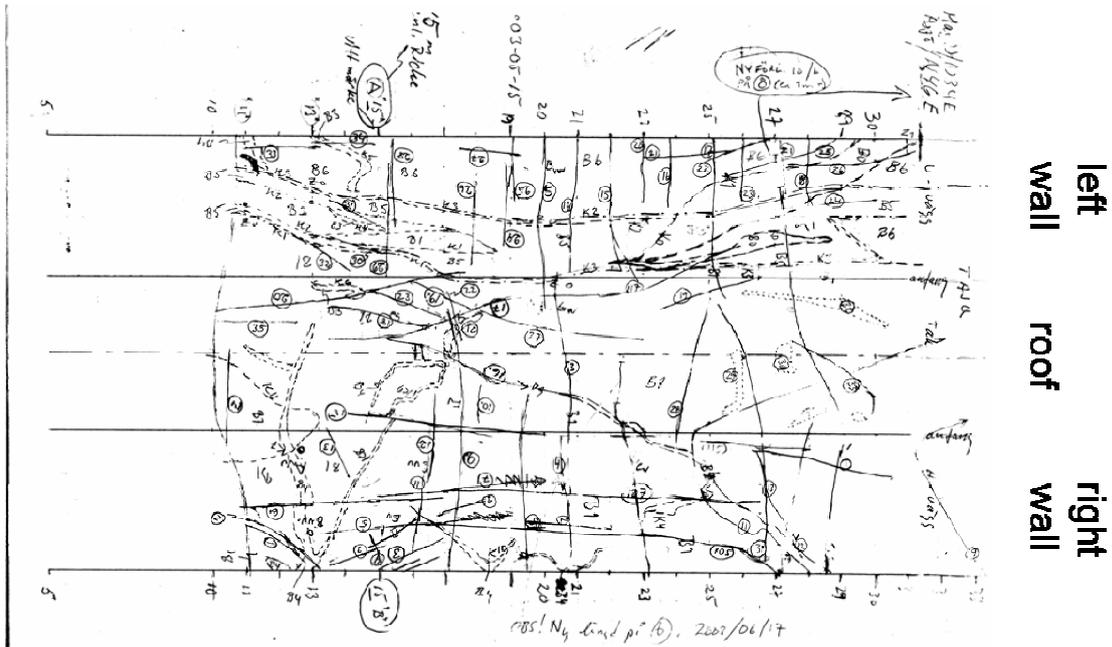
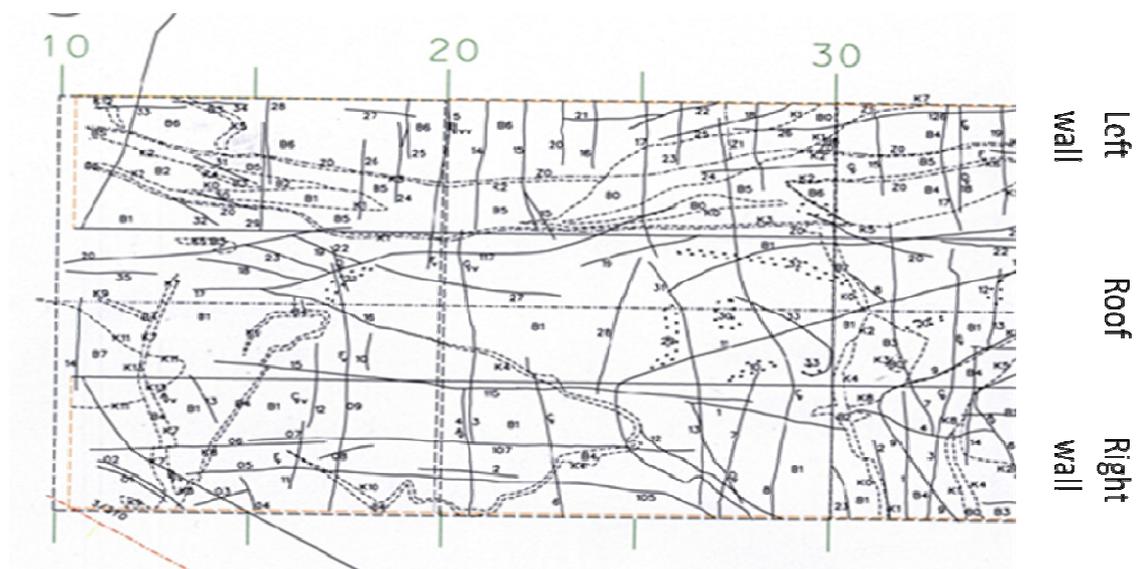


Figure 20. a) TASQ, field map, tunnel roof with tunnel walls unfolded (from B. Magnor et al. 2006).



b) TASQ, digitized map (TMS), tunnel roof with tunnel walls unfolded (before the excavation of NASQ0036A.)



Figure 21. Field mapping of deposition hole. The mapping is performed on plastic coated paper.

4.5.2 Mapping in 3D colour scan data

On the PC screen the selected area of the tunnel is visible and possible to zoom. The image is connected to the defined coordinate system (in this case Äspö96), enabling the user to read the xyz value of each pixel where the mouse is placed.

In the FaroScene program it is possible to create a string of points with the mouse or other digital pointing device directly on the PC screen. The string is then converted into a line which can be named/labelled in a logical way and exported in open CAD formats such as iges or dxf.

The test mapping was performed in a part of the NASQ0036A niche (in the TASQ-tunnel, Appendix 3 and 4) earlier mapped with traditional tools. A number of fractures and rock boundaries were identified on the niche wall and in the 3D colour scan where they were marked as lines (Figure 22).

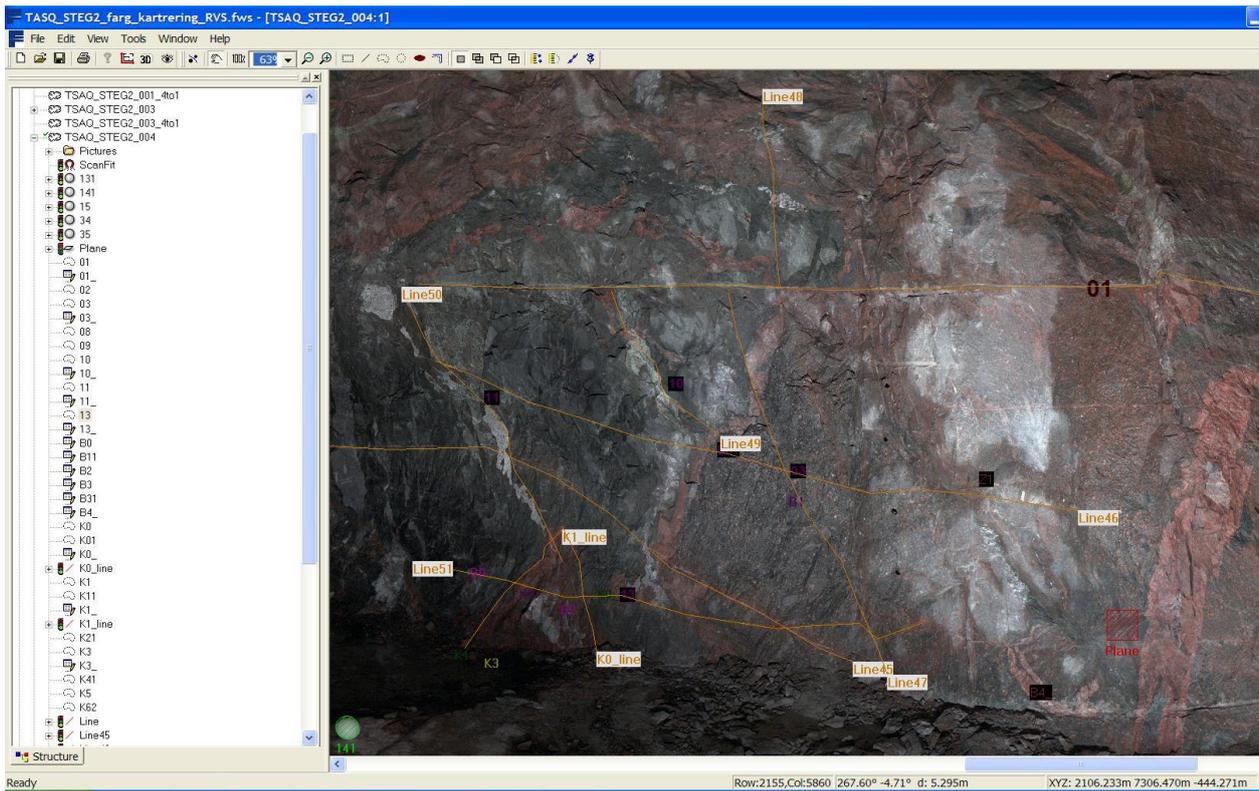


Figure 22. Geological mapping made on a 3D colour scan.

At present the lines drawn on the scan image are only of one type which means for example that there is no difference in the lines that represent a rock boundary and a fracture. Another problem is that geological data cannot yet be attached to the drawn features.

4.5.3 Comparison of ordinary and scanning based mapping

With a combination of 2D and 3D transformation the traditional manual mapping was possible to project on the theoretical 3D tunnel wall. (Figure 23).

The traditional mapping result was then exported in wrml file format from Microstation, and imported into FaroScene.

With all data in the same coordinate system ÄSPÖ96 it was possible to overlay them and compare the results. The difference in the position of the mapped features was occasionally as much as a couple of dm in the niche wall (Figure 24) or even more in the roof of the tunnel.

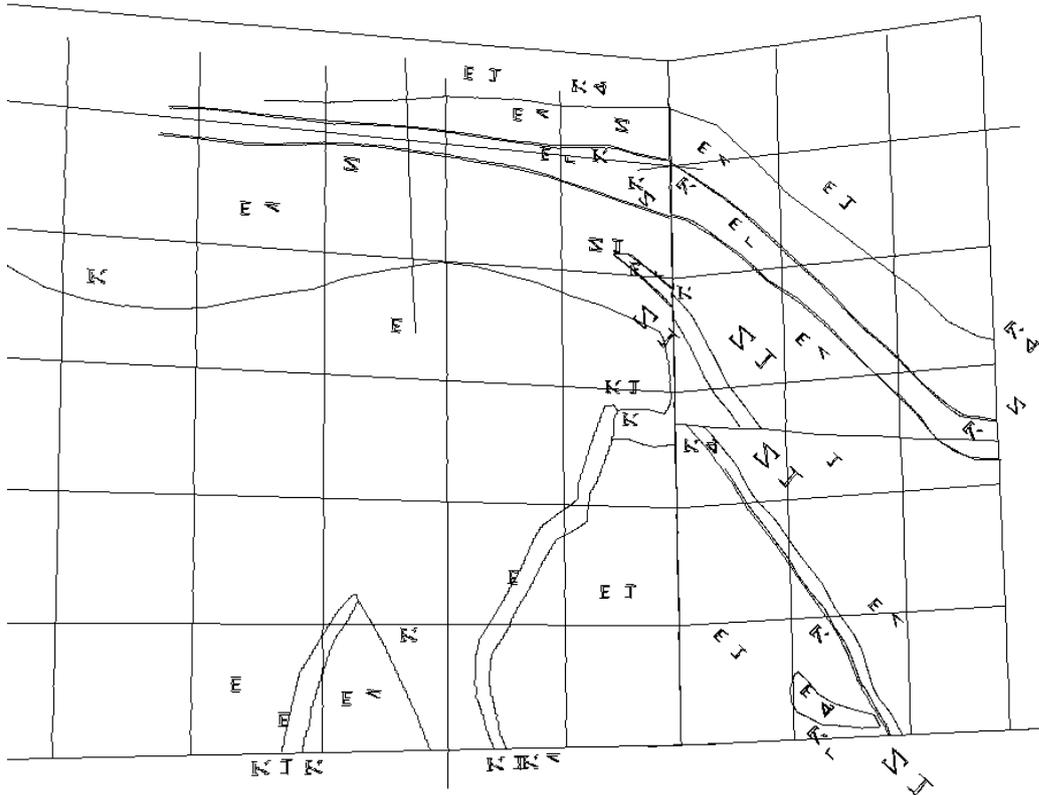


Figure 23. Traditional mapping projected on the theoretical tunnel wall. The mapping has been “refolded” from the plane field projection, NASQ0036A niche (TASQ-tunnel).

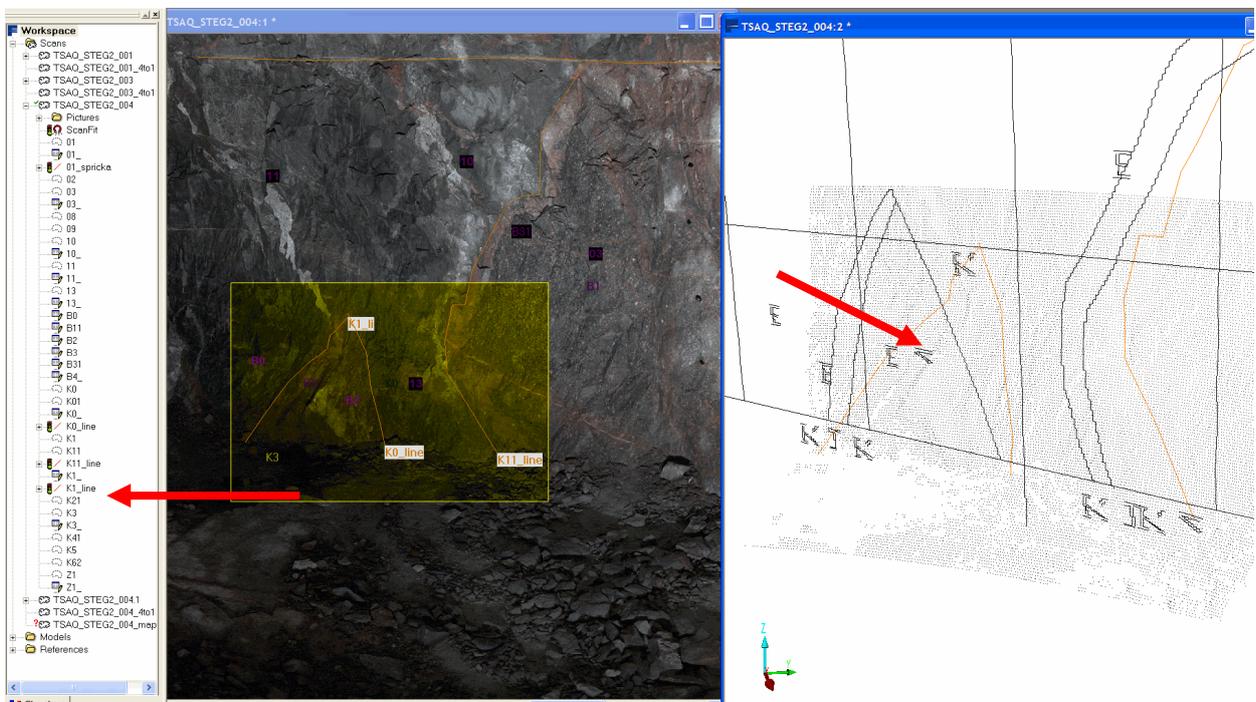


Figure 24. Comparison of traditional mapping (black lines) and 3D-scan based mapping (red lines)

4.6 Export of laser scan data

3D scan data especially colourised, use large file sizes.

The used resolution of 30 million points use about 500Mbyte RAM when open in full resolution and with the internal file format “fls” about 60Mbyte.

In FaroScene it is possible to export the full scan in several open CAD formats as:

dxf, wrml, ascii, iges, PTS, PTX, PTC. However the files will be extremely large and in many cases difficult to handle in a traditional CAD system.

It is preferable to select and define the fractures and other mapped features in the scanner software and then export only the geological information in preferred format to for example a CAD-system (Figure 25).

The generated 3D CAD lines of different fractures and rock boundaries (Figure 24) were exported in iges format. The name/label of the object is also possible to export. This file-format can be imported to any standard CAD system to create the same fracture or rock boundary lines. In this case the features were exported from FaroScene and imported successfully into Microstation to a 3D-model of a previous mapping of the TASQ-tunnel (Figure 26).

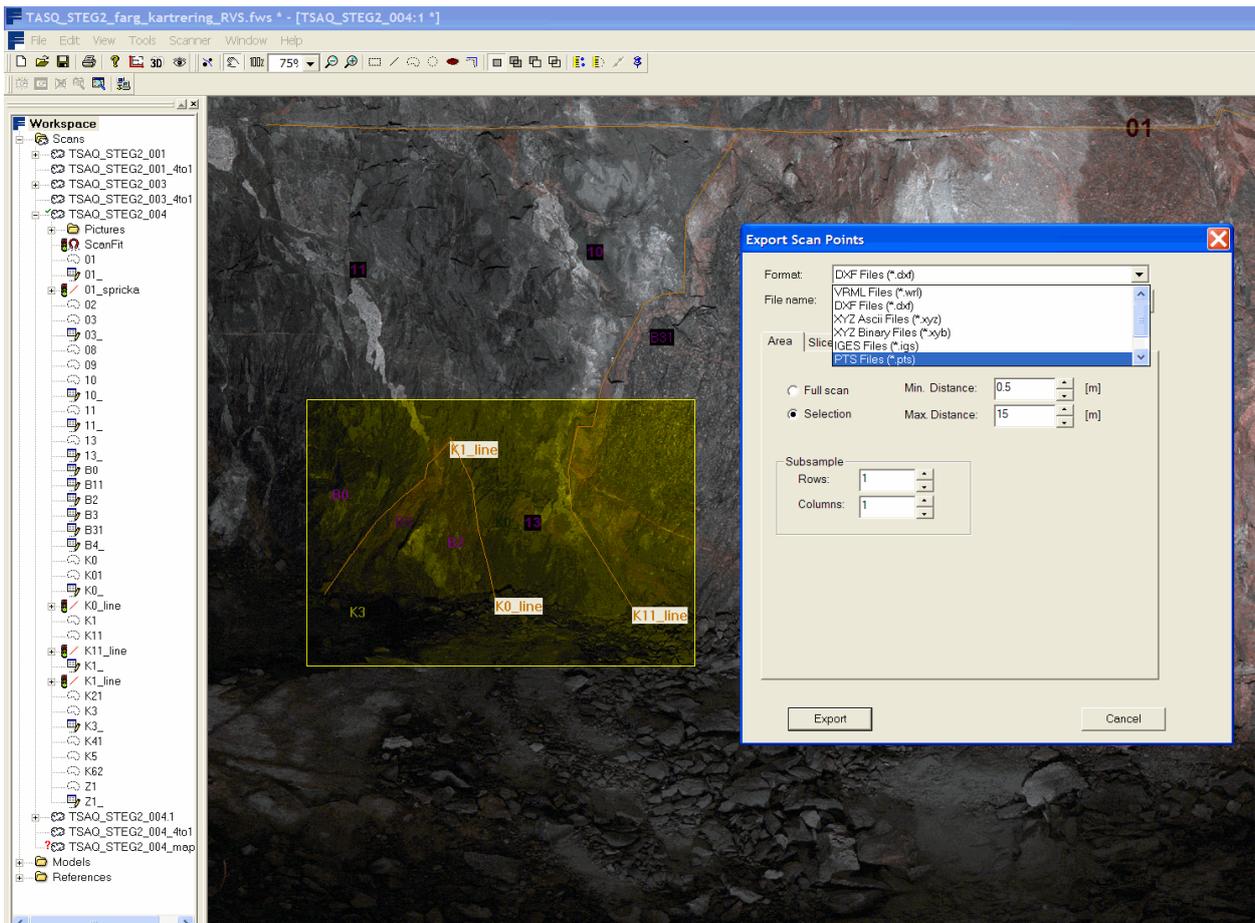


Figure 25. Export of scan data to different open formats.

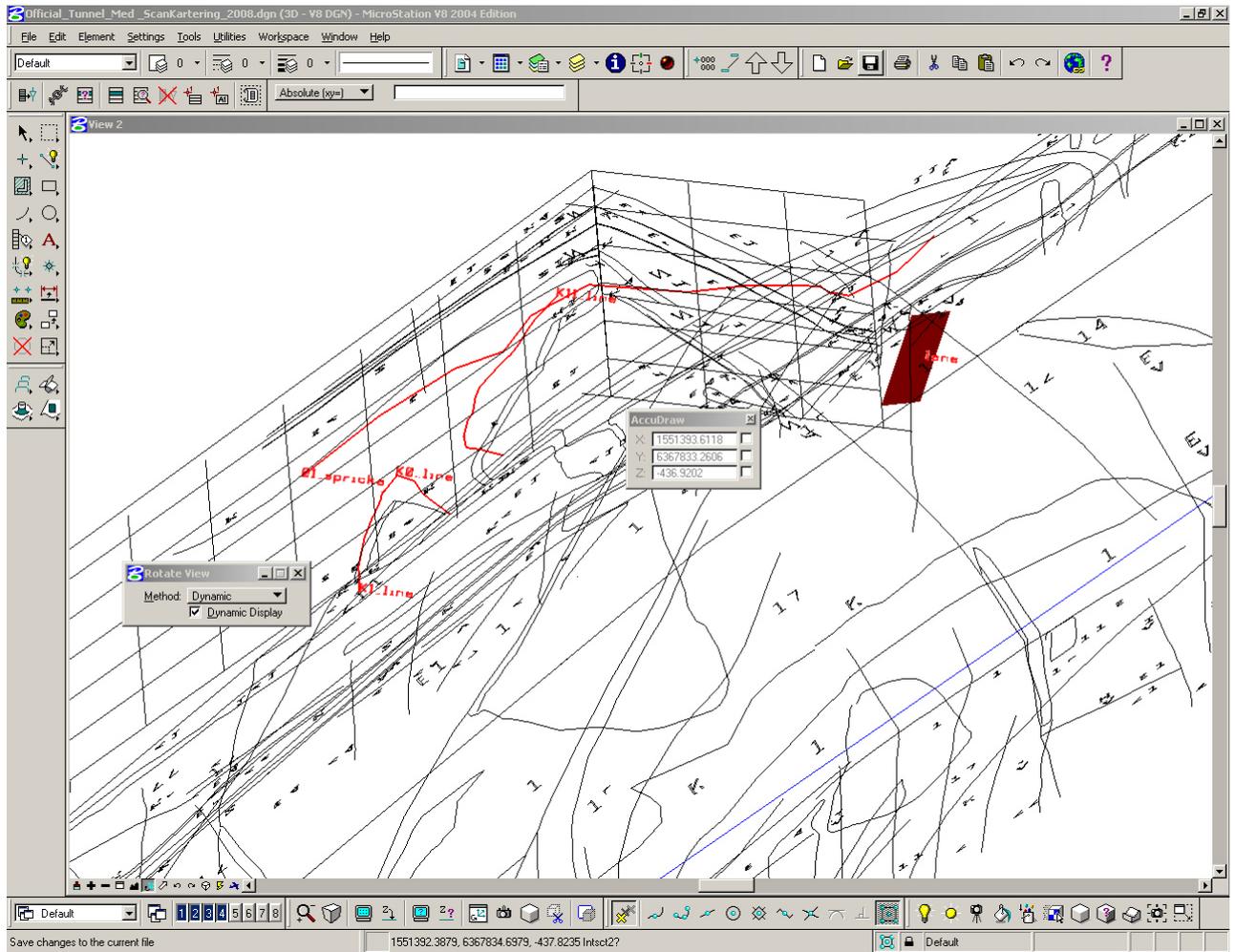


Figure 26. Export of selected mapped geological objects (red lines) from FaroScene into a 3D model of an existing mapping of the TASQ-tunnel.

5 Concluding remarks

Laser scanning with fixed mounted camera on the scanner and automatic overlay is the preferable way of collecting 3D colour scan data. The combination of laser scanning with digital colour photography gives very good 3D colour images.

To export large amount of scan data into Microstation and then perform mapping is not recommended.

Since it is possible to digitize objects in the used software (FaroScene) it should be possible to do geological mapping in the colour scan image. Placed in the tunnel with a computer equipped with a touch screen the geologist should be able to do the mapping in an easy way. Additional work and adjustments can of course still be performed in the office using the same scan data.

To be able to work efficiently with mapping in the future improvements will have to be made. For example:

- It will be necessary to have an automated process connecting in this case Faro Scene and a database with geological parameters. This is not possible today.
- More than one line style should also be needed when drawing the lines in the colour scan image to separate for example rock boundaries from fractures.

If these features can be obtained then the geological mapping may be performed in Faro Scene or some similar software. Afterwards the mapping including attached geological data could be exported to e.g. Microstation to be used in for example the SKB application RVS (Rock Visualisation System).

Based on the same scan data as the one to be used for mapping, volume calculations and cross sections can be generated. Comparisons between theoretical tunnel sections and real sections and the volumetric calculations will be useful in the tunnel production and documentation.

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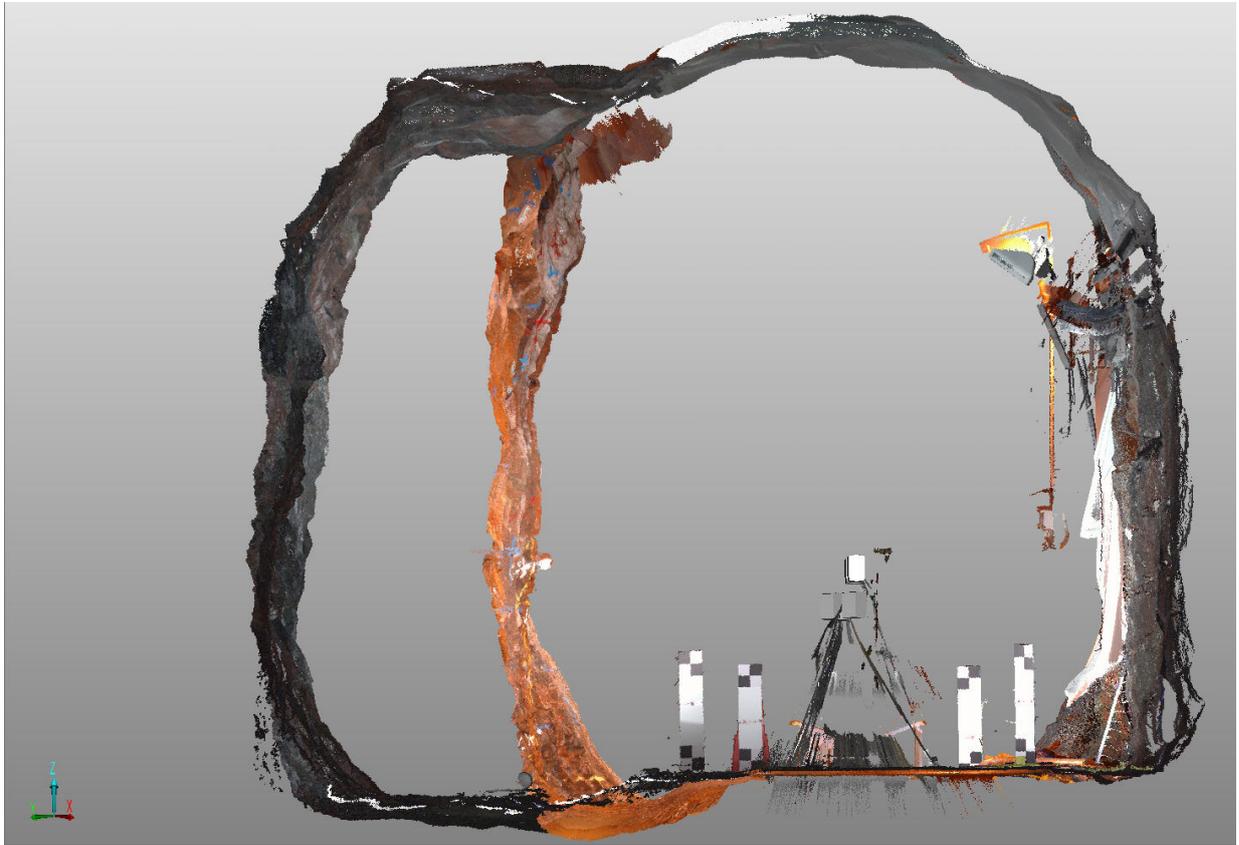
Johan Berglund at Vattenfall Power Consultant AB reviewed the report and offered a number of useful comments and suggestions for improvements.

Appendices

- Appendix 1** Colour scan of the niche section (approx. 4 m) before and after the excavation of the niche NASQ0036A (scan phase 1 and 2).
- Appendix 2** 3D view of a colour scan covering the niche section (scan phase 2, view point outside the niche).
- Appendix 3** Detail of colour scan of the niche wall (scan phase 2, view point inside the tunnel)
- Appendix 4** 3D view of several colour scans. The niche is located to the left in the foreground (scan phase 2, view point along the TASQ-tunnel).
- Appendix 5** 3D view of several colour scans. The niche, now reinforced, is located about 30 m to the left in the tunnel (scan phase 3, view point along the TASQ-tunnel).
- Appendix 6** 3D view of several colour scans. The niche, now reinforced, is to the left in the foreground (scan phase 3, view point along the TASQ-tunnel).
- Appendix 7** 3D view of several colour scans. The inner section of the TASQ-tunnel (scan phase 3, view point along the tunnel).
- Appendix 8** 3D model of TASQ-tunnel based on several scans from scan phase 3.

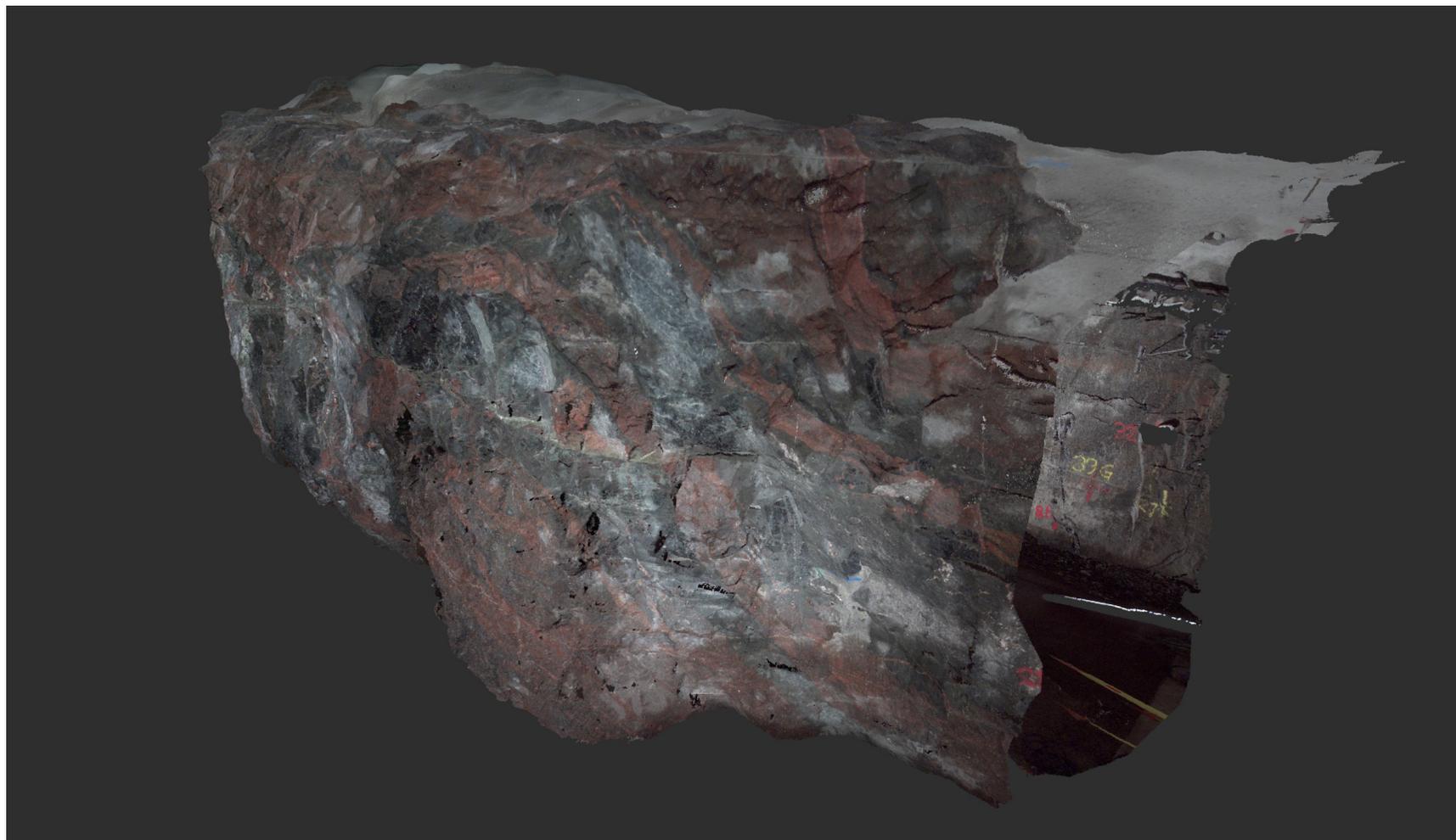
Appendix 1

Colour scan of the niche section (approx. 4 m) before and after the excavation of the niche NASQ0036A (scan phase 1 and 2).



Appendix 2

3D view of a colour scan covering the niche section (scan phase 2, view point outside the niche).



Appendix 3

Detail of colour scan of the niche wall (scan phase 2, view point inside the tunnel)



Appendix 4

3D view of several colour scans. The niche is located to the left in the foreground (scan phase 2, view point along the TASQ-tunnel).



Appendix 5

3D view of several colour scans. The niche, now reinforced, is located about 30 m to the left in the tunnel (scan phase 3, view point along the TASQ-tunnel).



Appendix 6

3D view of several colour scans. The niche, now reinforced, is to the left in the foreground (scan phase 3, view point along the TASQ-tunnel).



Appendix 7

3D view of several colour scans. The inner section of the TASQ-tunnel (scan phase 3, view point along the tunnel).



Appendix 8

3D model of TASQ-tunnel based on several scans from scan phase 3.

