Geological Structures and Roof Profiles in a Myra Canyon Tunnel Mapped from High Resolution Digital Rock Surface Models

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by

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ABSTRACT: Nearly 100 year old tunnels once used by the Kettle Valley Railway are now popular destinations for hikers and bikers in the Myra-Bellevue Provincial Park in British Columbia. These tunnels have never undergone detailed geotechnical mapping and remain largely unsupported and subject to freeze-thaw cycles and gradual deterioration resulting in some loose rock and small rock falls. Stereo photographs are being taken to establish high resolution digital rock surface models of the tunnel interiors and tunnel portal areas. These models permit accurate mapping of important geological structures and form an archive that can be used to identify changes in the tunnel conditions over time. The capability to monitor changes in the tunnel surface could become critical in detecting and managing possible rock fall hazards.

1. Kettle Valley Railroad Tunnels

The main branch of the Kettle Valley Railway was constructed in southern British Columbia and involved more than 10 unlined rock tunnels between Hope and McCulloch (Figure 1). The Myra Canyon tunnels, completed in August of 1913, linked the communities of Penticton and Midway. This section of the railway line opened on October 2, 1914 when the last piece of track was laid [1]. The Othello Tunnels were the final portion of the main line of the Kettle Valley Railway to be completed and on September 15, 1915 the first train travelled the entire main line [2]. The tunnels along the railway have similar dimensions and are typically 6 m wide and about 7 m high with an arched roof.

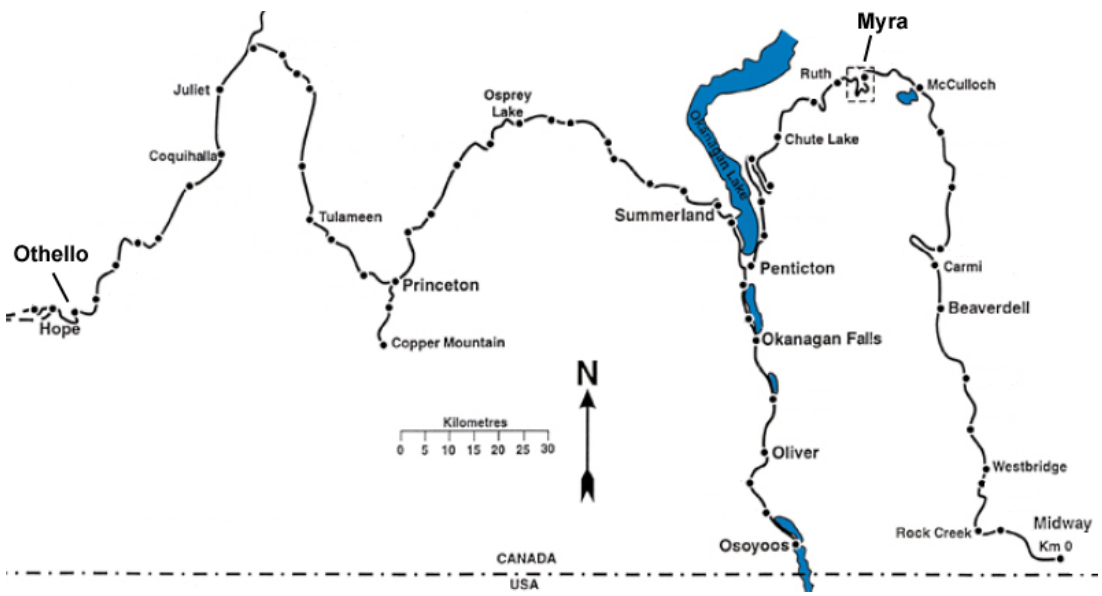

Figure 1 Location of Othello and Myra Canyon tunnels along the now abandoned Kettle Valley Railway in southern BC (after [3])

Five old railway tunnels are now located in the Coquihalla Canyon Provincial Park (Othello or Quintette Tunnels) and two more tunnels exist in the Myra-Bellevue Provincial Park (Myra Canyon Tunnels). All these tunnels are popular tourist attractions.

The last train to travel through the Myra Canyon was a steam locomotive used for the filming of the “National Dream” in June, 1973. After 1978, much of the railway grade was decommissioned and the track was removed. The province of British Columbia purchased the rail corridor from Canadian Pacific Railway in 1990. The Myra Canyon Trestle Restoration Society, established in

1992, began restoration and maintenance of the trail and trestles thus creating a cornerstone of the provincial Rails to Trails network, an important link along the Trans Canada Trail [4]. After a massive forest fire in 2003, many of the trestles were rebuilt.

The tunnels in both parks have experienced small rock falls and other deterioration over the years. Because these tunnels are used by the public, they have undergone geotechnical stability assessments and have had some rock stabilization measures implemented. At Myra Canyon, timber cribbing has been replaced near some portals. Loose rock was scaled from the tunnel roof and resin grouted 1.8 and 2.4 m long rock bolts were installed in the Myra Canyon tunnels likely sometime between 1995 and 1998. In the Othello tunnels, a concrete liner was poured to essentially connect two of the tunnels. Usually in the spring, after most of the freeze-thaw cycles end, the tunnels are visually inspected in preparation for another season of tourist traffic. A visual record is made of the locations where new rock has fallen to the tunnel floor and a general assessment of the tunnel stability is conducted.

To the author's knowledge, there has been no detailed geotechnical mapping performed in any of the tunnels. A georeferenced, dimensionally accurate, photographic archive of the tunnel surface and geological structures would facilitate future assessments of the tunnel conditions and would permit more accurate documentation of where rock has fallen from the tunnel roof or wall than the current technique of noting the position of the fallen rock on the tunnel floor. Furthermore, a detailed digital model of the rock surface in the tunnels would permit more rational design of rock support strategies should they be required in the future.

This paper presents some preliminary work done to generate digital rock surface models for one tunnel at Myra Canyon. The tunnel was located between trestles 11 and 12 at the highest elevation of the entire Kettle Valley Railroad. The methodology and equipment used to create the digital models of a section of the tunnel and the south portal area are discussed and the roof profiles and geological structures determined directly from the rock surface models are presented.

2. Field Equipment and Layout of Camera Stations

2.1. Photography Equipment

For the fieldwork, a Canon EOS-5D and a Canon EOS-5D Mark II camera were used. A fixed focus 24 mm EF series lens was used on each camera. The lens provides a relatively wide view angle of 74º on the horizontal and 53º on the vertical. The selection of an appropriate lens is a compromise between having a wide field of view (given by a shorter focal length) and using a lens with negligible distortion (shorter focal length lenses have greater distortion). Based on field experience in the 6 m wide tunnel, a 20 mm lens may be a better choice, as its wider field of view would reduce the number of photographs required from each camera station. Nevertheless, images were taken with the 24 mm lens that was available.

The camera was mounted on a spherical panorama head that in turn was attached to a tripod. This enabled the camera lens to rotate about its nodal point ensuring that images would be captured from exactly the same location in 3D space. This panorama head facilitated distortion-free merging of multiple images.

Tunnel lighting was supplied by two 5.4 m long LED light ropes and a 12 volt battery. The light ropes were centred in the middle of the tunnel on the floor and aligned parallel to the tunnel walls. The use of light ropes allows for dispersed lighting that helps to eliminate shadows since the rock surface is lighted from multiple positions along the tunnel axis. The LED bulbs produced a colour temperature of 5500K, which created 'natural' light conditions on the rock surface. The quantity of light was sufficient to work safely within the tunnel and to see the rock surface when aligning the camera. Nevertheless, in a tunnel that was 7 to 9 m high, the light was still dim and thus the shutter speed if shooting at f5.6 was a relatively long 20 to 30 seconds. By opening the aperture wider to f4.0, the shutter speed was reduced while providing brighter images. The images were taken at ISO 100 setting ensuring non-grainy images.

The photographs used to create the digital rock surface models of the interior section of the tunnel were taken at night to eliminate the influence of light coming in from both portals, which could generate uneven lighting conditions on the rock surface. The photographs taken of the south portal were taken around mid-day to minimize the effect of shadows on the rock surface.

2.2. Survey Control

A base station for surveying purposes was established outside the tunnel using a hand-held GPS to establish the approximate UTM coordinates with a WGS 84 datum and a Brunton compass to establish a bearing. The locations of rockbolts present in the tunnel and bolts holding timbers near the portal were surveyed with a Leica total station. Additional survey control was established by placing small white retro-reflective dots on the rock surface near the portal and within the tunnel. The reflective dots were made with 3M retro-reflective film. While the absolute coordinates of the base location are accurate to within a few metres, the relative locations are expected to be accurate within ±4 mm and the orientations are expected to be accurate within ±1°.

2.3. Camera Stations

A series of camera stations were placed in pairs along both walls of the tunnel (Figure 2). Three to four photographs were taken at each station in a vertical fan to capture overlapping photographs of the opposite wall and the roof. The camera tripod was set up as close as possible to one tunnel wall to provide as wide a field of view of the opposite wall as possible. The spacing between camera stations in each pair was 1.7 to 1.9 m while each pair was separated by about 5 to 6 m (spacing between centres of two adjacent pairs). This arrangement of camera stations provided ample overlap of photographs and overlap of the resulting digital rock surface models generated from each pair of camera stations.

3. Digital Rock Surface Models and Geological Structures

3.1. Models of the Tunnel Interior

Photographs taken from the pairs of camera stations shown in Figure 2 were used to create six digital rock surface models using Adam Technology software [5]. An individual rock surface model obtained from one camera station pair typically contained coordinates for 200,000 points and 400,000 triangles in a triangular irregular network. Three models covered one wall of the tunnel and the roof and another three models covered the opposite tunnel wall and roof. All six models were loaded into the software to create a larger combined model. The combined model covered a 20 m section near the middle of the 114 m long tunnel. The combined model was used to create tunnel wall profiles such as those shown in Figure 2, and tunnel cross-sections as seen in Figure 3. In addition, the combined model was used to digitally map the location and orientation of geological discontinuities. A typical tunnel cross-section is highly detailed and consists of 1800 to 2200 individual points.

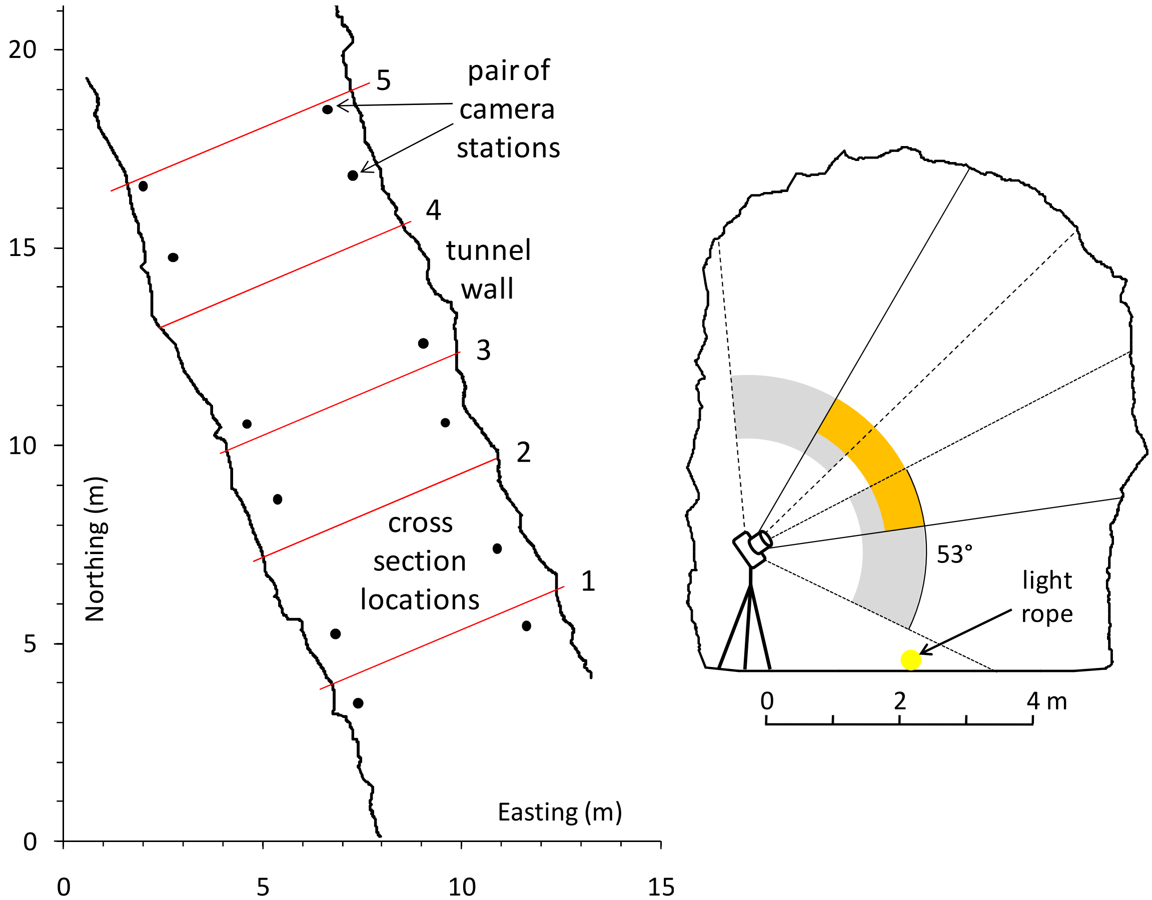

Figure 2 (a) Plan view of a section of the tunnel showing the location of 6 pairs of camera stations and 5 cross-sections and (b) typical tunnel cross-section showing overlapping photographs and location of light rope

Figure 4 shows the locations of geological structures mapping in the tunnel roof. Traces of discontinuities are shown in red while the circular discs represent the location and orientation of best fit planes to the discontinuity surfaces. The rock mass contains three steeply dipping joint sets and one flat set of discontinuities. The most dominant discontinuities are oriented sub-parallel to the tunnel walls and strike parallel to the valley wall containing the tunnel. These discontinuities can have trace lengths of 15 to 20 m and are possibly the youngest geological features in the rock mass. They are interpreted as joints created during erosion of the steep Myra Canyon which resulted in stress-relief and tensile strain perpendicular to the valley walls.

The flat lying discontinuities appear to be some of the oldest discontinuities and these have a wavy discontinuous nature. In some locations, the flat lying discontinuities are coincident with foliation structures in the metamorphic Okanagan Gneiss.

A shallow dipping, undulating, shear zone with a strike that is roughly perpendicular to the tunnel axis is present over the whole tunnel model. This geological structure occurs near the tunnel floor at the southern part of the model and gradually moves up both tunnel walls towards the northern part of the model.

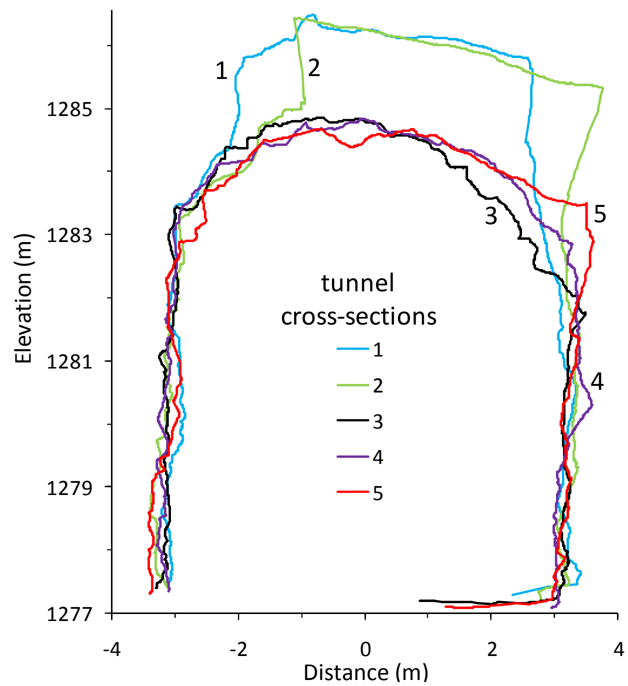

Figure 3 Tunnel cross-sections (profiles 1 and 2 are located where a large rock fall occurred)

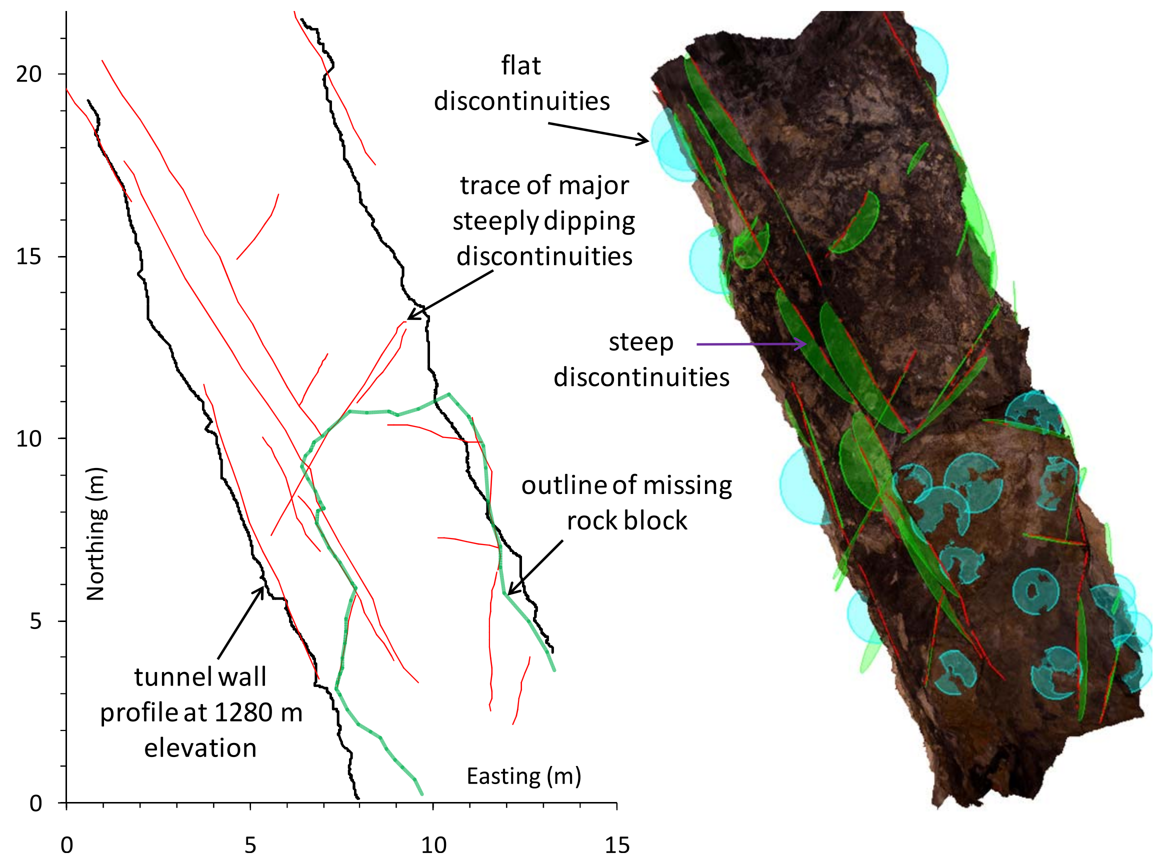

Figure 4 Plan views of the tunnel showing traces of major discontinuities, outline of the missing rock block and location of mapped discontinuities on the digital rock surface model

A combination of steeply dipping discontinuities and a wavy flat lying discontinuity define the boundaries of a large block of rock that is now missing from the tunnel roof. The block outline is shown in Figure 4 and two cross-sections through the void left by the missing rock are seen in Figure 3. The block has a thickness of up to 1.7 m and a plan area of at least 50 m^2. It appears that the void created by the falling block probably occurred in the past few decades because the rock now exposed has a cleaner appearance than rock surfaces elsewhere in the tunnel, which have been exposed to soot from steam engines or exhaust from diesel locomotives over the full life of the tunnel.

The present tunnel roof contains grouted rock bolts believed to have been installed between 1993 and 1995 when the Myra Canyon Trestle Restoration Society first began restoration and maintenance of the trail. These bolts are concentrated in the area adjacent to the void created by the missing rock block. The rock bolts were placed to prevent further rock instabilities around the perimeter of the existing void.

3.2. Models of the South Tunnel Portal

The south portal of the tunnel is located approximately 42 m away from the section of the tunnel used to create the tunnel model shown in Figure 4. Photographs were taken of the portal area from five different camera stations. These photographs were used to construct three rock surface models that were merged into one larger portal model. The portal rock surface model was used to map the locations and orientations of discontinuities. The mapping revealed discontinuity sets with similar orientations to those observed deeper in the rock mass near the middle of the tunnel.

The rock mass at the south portal contained two distinctive steeply dipping joint sets with a planar large scale topology and a flat but more wavy set of discontinuities (Figure 5). One of the steeply dipping joint sets strikes parallel to the local valley wall; a similar joint set is present within the tunnel. A sub-vertical fracture zone striking sub-parallel to the tunnel axis is located above the tunnel roof at the portal. This fracture zone is composed of the steeply dipping joints that strike parallel to the valley wall. As a consequence of the presence of this fracture zone, the south portal of the tunnel is currently supported with a full arch of timber cribbing. To preserve the historical nature of the tunnel, the timber cribbing uses a design that is consistent with timber support used in tunnels at the time of their creation.

Near the portal, the flat lying discontinuities sometimes form distinctive weaknesses in the rock mass that have been further exploited by surface erosion. These relic flat lying foliation planes are present at both the portal and the middle of the tunnel.

3.3. Comparison of Geological Structures within the Tunnel and at the South Portal

Figure 5 shows stereonet plots of the digitally mapped geological structures for a 20 m section of the middle of the tunnel and the south portal. Clearly, there are discontinuity sets that are common to both locations. Figure 6 is a stereonet obtained by combining the data shown in Figure 5. Interestingly, the steep joints that strike parallel to the valley wall dip to the NE inside the tunnel while they dip to the SW at the portal location. It is not known if there is a transition between these two orientations upon moving from the tunnel centre to the south portal because the section lying between these two has yet to be mapped. If these joints were created in response to tensile strain associated with valley erosion then local differences in valley wall orientations may correspond to changes in joint orientations. This is a topic for future research.

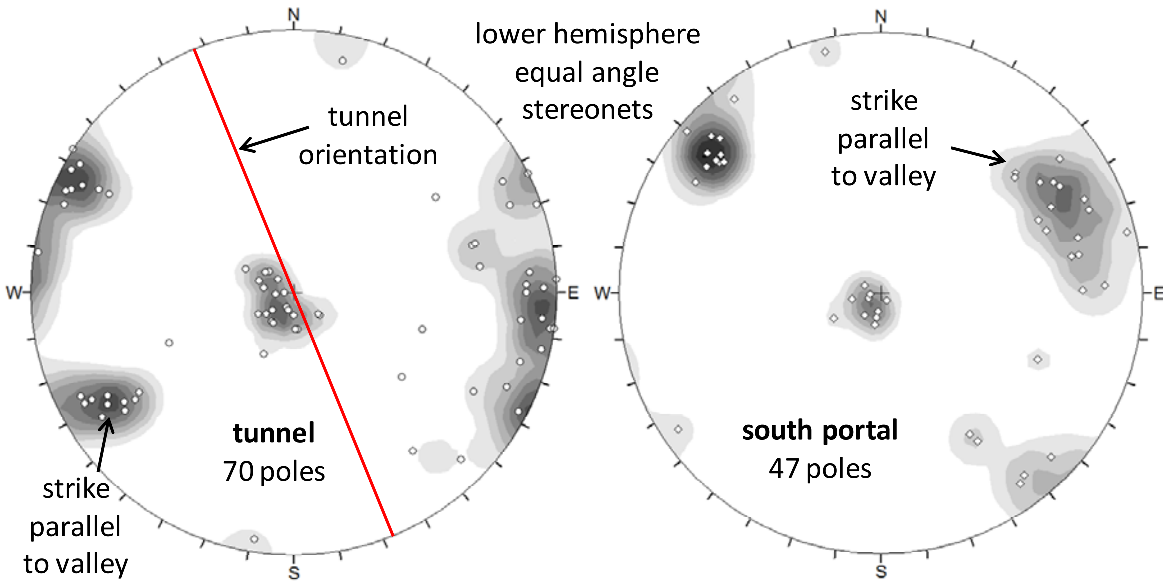

Figure 5 Stereonets of discontinuities mapped in the middle of the tunnel and at the south tunnel portal

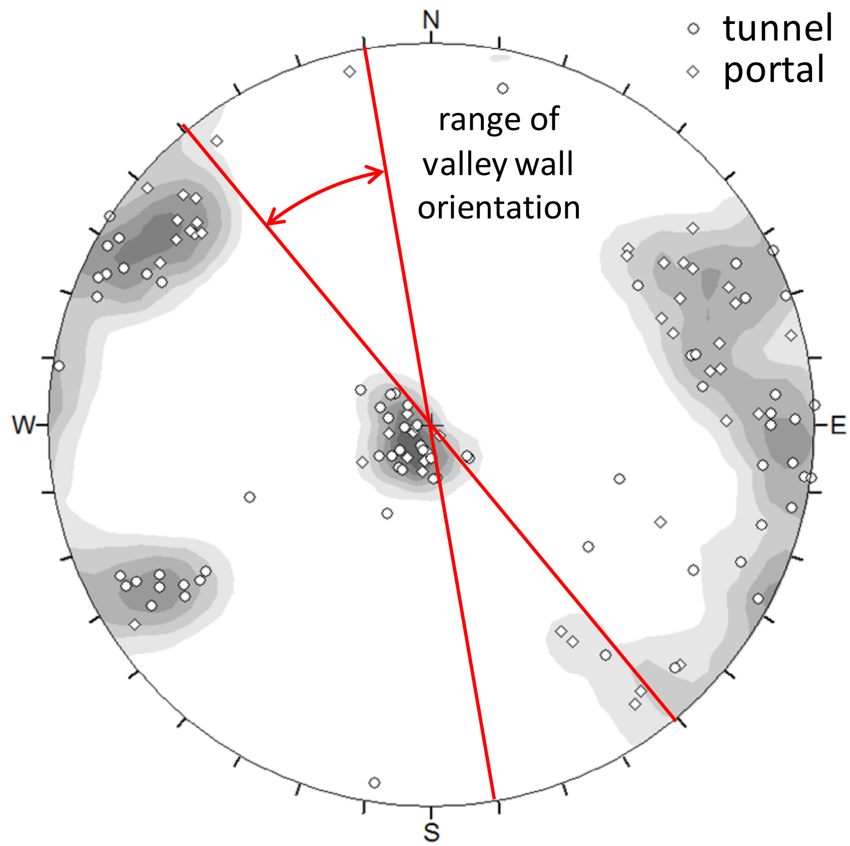

Figure 5 Lower hemisphere equal angle stereonet of all discontinuities mapped in the middle of the tunnel and at the south tunnel portal

4. Discussion

The field investigation demonstrated that highly detailed digital rock surface models of the interior of a tunnel or the portal area could be easily generated using minimal survey control, a standard digital SLR camera, and a light rope (for interior photographs). The fieldwork is quick and requires no specialized equipment. The photographs constitute archival quality data that can be used at any time in the future to construct digital rock surface models for various purposes such as generation of as-built tunnel profiles and cross-sections and mapping of geological structures. When photographs of the same area are repeated over time, the digital rock surface models created from the photographs can be used to identify and quantify changes in the rock surface, such as those resulting from rock falls.

Owners and operators of tunnels already conduct annual or sporadic visual tunnel inspections using geotechnical professionals and in the process of conducting these inspections, photographs are often taken. With little additional effort or cost, a better designed suite of photographs can be taken with a goal of at least providing the opportunity in the future, should the need arise, for creating dimensionally accurate, and highly detailed, digital rock surface models. The concept is no different than the demonstrated utility of standard aerial photography that has been widely used for decades, although with modern technologies, obtaining and processing the photographs is far easier.

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