Assessing Intact Rock Properties for the Salang Highway Tunnel Upgrade Route Selection Study

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ABSTRACT: The current 2700m long Salang Tunnel at the time of completion was the highest road tunnel at 3400 m providing all-weather connectivity from northern Afghanistan to the southern regions and the capital Kabul. The Salang Corridor is a crucial link within the Central Asian Regional Economic Cooperation Program's transportation network. The intact rock test results presented within this contribution are associated with work to identify and optimizing the central tunnel alignment to reduce the maximum elevation and optimize the road alignment. Eight boreholes were drilled between 150m and 220m depth to investigate the ground conditions and rock properties for three previously identified tunnel alignments, due to very poor ground conditions a 9th borehole was terminated at 42m depth. The results demonstrate that with appropriate sample selection and testing methods and procedures reliable and consistent data can be acquired to characterize and assess rock properties and associated tunnel hazards.

Keywords: Rock testing, Brittle failure, Granite, Alpine Tunnelling.

1 INTRODUCTION

As part of the Central Asian Regional Economic Cooperation (CAREC) Program the Salang Corridor was identified as a critical link between both Europe (Corridor 6) and East Asia (Corridor 5) with the Middle East and South Asia. One of the CAREC Program's key strategic planes is to improve and facilitate trade across the regions through improved transport quality and reliability. Additionally, these transportation network upgrades also improve local economic development, access to healthcare, education and improve food supplies across the region meeting several of the United Nations Sustainable Development Goals.

The Salang tunnel has significantly deteriorated over its nearly 60 year operational life including more than 30 years of conflict culminating with the 1997-1998 war in which the portals, lighting and ventilation systems were destroyed preventing vehicular traffic through the tunnel. Following the end of the conflict in 2001, joint efforts were undertaken to make necessary repairs and the tunnel was reopened in 2002. Feasibility studies completed in 2012 by USAID (USAID, 2012) identified 3 potential alignments to upgrade the primary Salang Corridor, this work was undertaken during the feasibility and alignment selection studies aimed at moving the initial findings towards a viable project for construction. Figure 1 shows the investigated alignments and geological map for the project region.

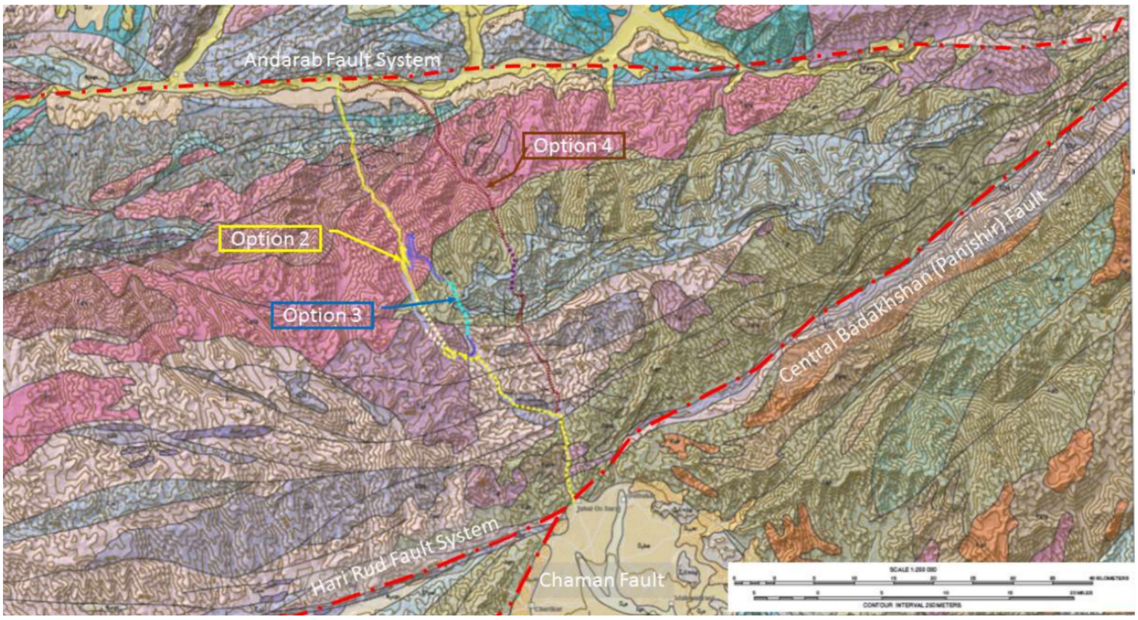


Figure 1. Alignment Options and regional geological map (modified after Lindsay et al. 2005). The current highway alignment primarily follows Option 2 shown in Yellow.

1.1 Project Overview

The Salang Corridor along Afghanistan Highway 76 (AH 76) extends from Jabal-Seraj at an elevation of 1600m in the south to Khinjan at 1075m in the north.is a key constraint within Corridors 5&6 This section extends over 93 km with the Salang tunnel at approximately km 43 and an elevation at 3400m. At elevations between 2000m and 2600m several sections of the road are affected by yearly avalanches and above this level the frequency tends to decrease to do spatial conditions but the intensity increases significantly. One of the key factors for lowering the alignment is to avoid the harshest weather conditions and associated maintenance to keep the road open and safe during the winter months.

As shown in Figure 1 the alignment crosses several geological domains within the Western Hindu Kush block and includes the contact to the Kabul block in the south. The region is associated with the accretion of island arc terrains and intrusive granites and is highly folded both at the local and regional scale. From south to north the alignment starts in early Paleo-protozoic gneiss and schists before crossing a series of metamorphosed sedimentary rocks consisting originally of sandstones, siltstones, limestone, and dolomites. The Hindu Kush ridge from west to east is composed of the Salang Granite, Paleo-Protozoic Gneiss and Schists, Carboniferous phyllites associated with tectonic mélange, and Permian limestones/marbles. It is within these sequences that the identified tunnels are located. Towards the north the alignment continues through Triassic granites and granodiorites, Protozoic gneiss before encountering thin wedges of metamorphosed Permian and Carboniferous sedimentary rocks and Triassic volcanics in the boundary region to the Andarab fault system. Figure 2 shows the central section of the project with the proposed tunnel alignments and the borehole locations. The borehole locations were based on the original tunnel locations proposed in the USAID feasibility study and were targeted at the general lithologies associated with the alignments considering the remote nature of the sites and the need to utilize helicopter transport for all the drilling equipment.

2 PRIMARY GEOTECHNICAL INVESTIGATIONS

The field investigation program utilized both satellite and field based mapping, core drilling, as well as electrical resistivity surveys and test pits at portal locations. The combination of investigation methods targeted key early questions for identifying the most feasible portal locations and tunnel alignments considering the natural hazards, the topographic constraints associated with the valley geometries related the portal elevation versus tunnel length and associated costs. This contribution briefly discusses the field mapping and drilling and focuses on the strength testing of the acquired rock core.

2.1 Geological Mapping and Characterization

Due to the remote conditions and security situation multiple methods were utilized to characterize delineate the geological conditions, lithological boundaries, and rock mass characteristics. Initially publicly available satellite imagery was utilized to refine published data. This information was supplemented with a 1m resolution digital elevation model and selected high resolution images based in ARCGIS® and ARCGIS Pro® to both spatially collate field mapping results as well as allow mapping to inaccessible locations within the alignment corridors. These data allowed key areas to be identified to guide the field based mapping as well extend the field observations beyond the locations observed. Multiple mapping campaigns were made to each alignment allowing full coverage of the alignment specific geological conditions, extensive photo documentation was obtained to “revisit” locations visited by various field teams and in selected locations photogrammetry was utilized to both evaluate local topography as well as discontinuity and structure mapping within the safety of the office. Figure 2 shows the database of the field photo documentation location plotted in google earth to indicate the coverage associated with the field work.

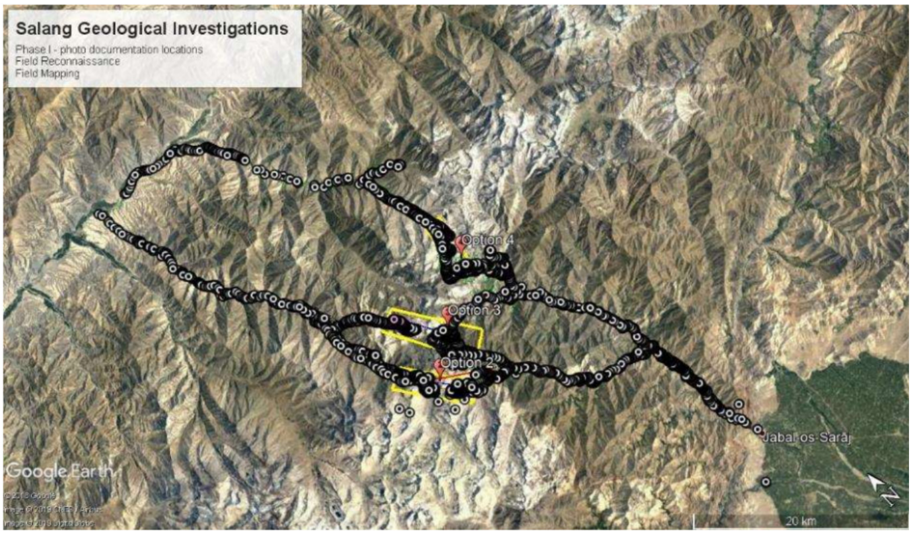


Figure 2. Map showing the location and distribution of photo documentation associated with the geological and geotechnical field work (plotted in Google Earth®.

2.2 Drilling Program

A total of 9 boreholes were drilled during the alignment selection studies as shown in Figure 3. Three were located along Option 2 and ranged from 180m to 220m in depth. Option 3 required a series of two tunnels due to a ridge parallel valley and two boreholes were drilled for each tunnel section, 2 of the boreholes reached their 200m target depths while 148m out of 180m was reached for 1 borehole and the northern most borehole, located in marbles, was abandoned after 42m due to major water loss in a suspected fault and karst zone as well as winter weather conditions which prevented a sufficient supply of water. Two additional boreholes were planned for the Option 4 tunnel with 150m and 180m target depths.

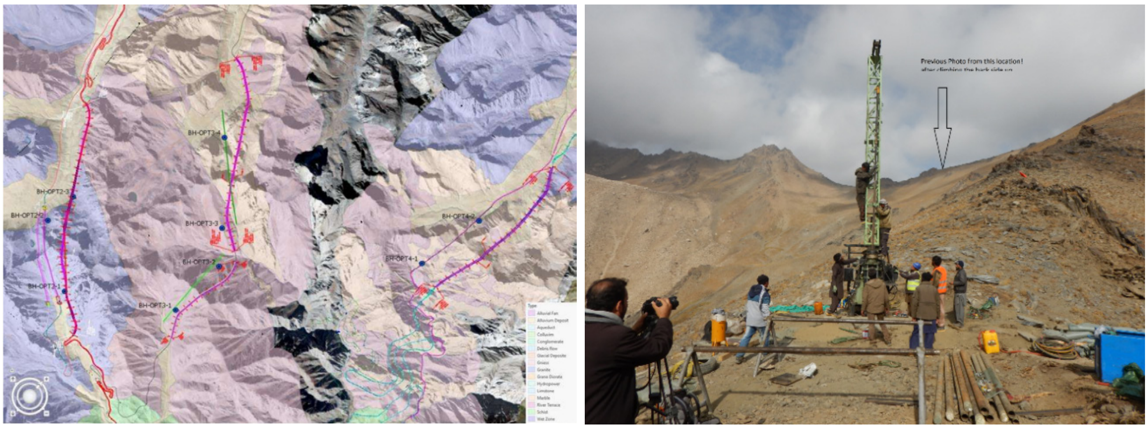


Figure 3. Overview of the proposed alignments and drilling locations (left) and the drilling rig set up at Option 3 BH 3-1 (right) associated with phyllites and schists.

The drilling utilized triple tube core barrels with a reusable split metal liner. Following field documentation, the cores were placed in a split PVC pipe and sealed for transportation to the laboratory. A total of 1537m of high-quality core was recovered, including multiple meters in crushed granite which following recovery required grouting the zone and redrilling to maintain a stable borehole.

3 LABORATORY TESTING PROGRAM

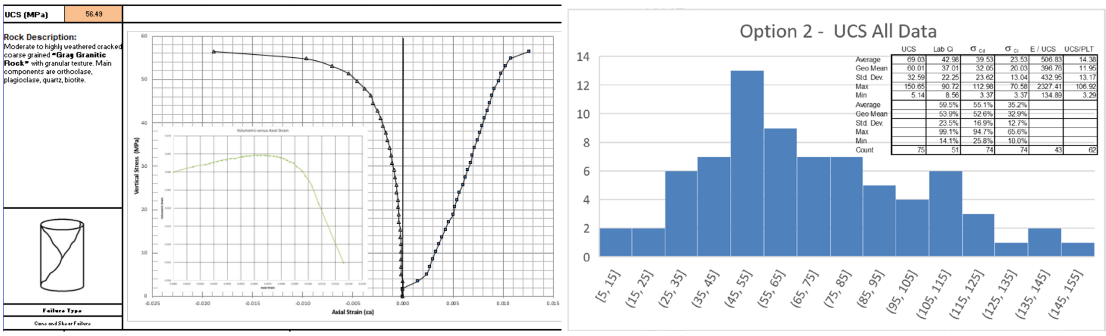
Following transport back to the geotechnical laboratory the core was re-photographed and logged in detail. After the initial core logging and documentation, sampling was undertaken in a systematic fashion to improve the quality of the testing program. It was planned to have a series of tests for either each 10m or 20m of core depending on the lithological and textural variability the lithologies sampled and specimens were preferably chosen within tight depth intervals when feasible. A test series typically consisted of:

- 1 to 2 UCS tests
- 1 Brazilian tensile strength tests
- 2 Point load tests
- Triaxial test series – single stage with typically 5 to 6 confining pressures
- Ultrasonic Velocity Tests (on UCS and Triaxial test specimens)

To demonstrate the results the data from the granite samples obtained from the Option 2 boreholes will be shown in the following sections. The discussion will focus on the UCS and Triaxial test results and their assessment.

3.1 Unconfined Compressive Strength

For the 3 Option 2 Boreholes a total of 75 UCS tests were performed. During each test the laboratory team marked the stress and strain if and when audible cracking could be heard (σ_{cilab}). Posttest processing estimated the crack initiation level by evaluating both the axial and circumferential strain paths as well as evaluating the volumetric strain for reversal (Crack Coalescence σ_d). Figure 3 shows an example UCS test result and a summary of all the UCS data for the granites.



Rock Description:
Moderate to highly weathered cracked coarse grained **"Gray Granitic Rock"** with granular texture. Main components are orthoclase, plagioclase, quartz, biotite.

	UCS	Lab Ci	σ_{cd}	σ_{ci}	E / UCS	UCS/PLT
Average	69.03	42.98	39.53	23.53	506.83	14.38
Geo Mean	60.01	37.01	32.05	20.03	396.76	11.95
Std. Dev.	32.59	22.25	23.62	13.04	432.95	13.17
Max	150.65	90.72	112.98	70.58	2327.41	106.92
Min	5.14	8.56	3.37	3.37	134.89	3.29
Average		59.5%	55.1%	35.2%		
Geo Mean		53.9%	52.6%	32.9%		
Std. Dev.		23.5%	16.9%	12.7%		
Max		99.1%	94.7%	65.6%		
Min		14.1%	25.8%	10.0%		
Count	75	51	74	74	43	62

Figure 4. Example UCS test data and the histogram summarizing the results of the granite samples.

3.2 Triaxial Test Results

To complement the UCS test results and especially evaluate the strength characteristics under low confinement 44 triaxial test series were performed with a total of 240 specimens. The tests were initially performed with confining pressures ranging from 0.25 MPa to 3 MPa in five steps. During initial phase of the testing program it was determined that the range did not extend to high enough confining pressures to transition the strength envelope into the frictional range and subsequent specimens were identified for the initial test series while later test series designated additional specimens for higher confinements typically designated at either 8MPa or 12MPa. Figure 5 summarizes the individual triaxial strength values for the granite samples and provides the average for each confinement level.

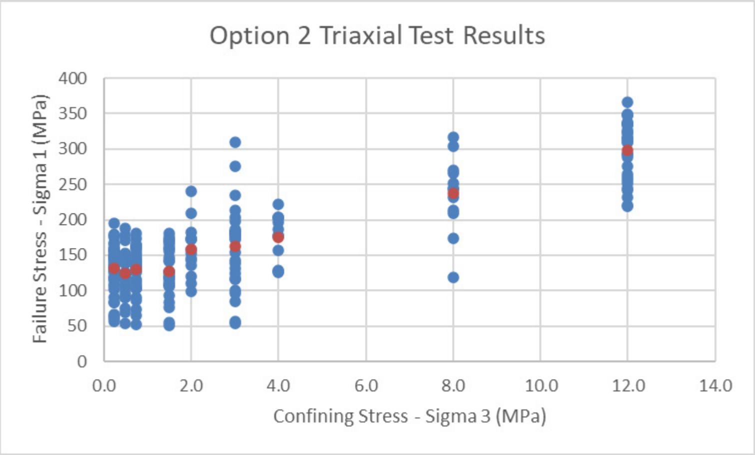


Figure 5. Summary of the triaxial failure strengths for the granite specimens.

These higher confinement tests were determined to provide a sufficient range of strengths to develop consistent strength results utilizing either a Mohr-Coulomb or Hoek & Brown Failure envelope (Hoek et al, 2002). For determining the Hoek & Brown parameters the triaxial test data was combined with the UCS test results and most importantly the factored Brazilian Tensile Strength. It was determined that including the tensile strength resulted in highly consistent results for each test series as well as the characteristic average and means for the data sets. Table 1 summarizes the assessed failure criteria for the complete data set on the individual test series for all of the Granite specimens.

Table 1. Summary of granite strengths considering all three test data sets.

	Mohr-Coulomb		Hoek-Brown Parameters		
Granite Test Results	C [MPa]	ϕ [°]	UCS_{rm} [MPa]	Hoek-Brown Parameter m_i [-]	Tensile Strength [MPa]
Average	13.85	50	77.95	21.1	3.66
Geomean	12.47	50	69.93	20.8	3.32
Std.Dev	5.63	1.6	32.15	3.5	1.47
Min	2.16	46	11.61	13.7	7.37
Max	25.06	53	139.45	28.9	0.79
Count	44	44	44	44	44

4 SUMMARY

The initial studies and investigations for selecting the preferred tunnel alignment involved a multi-disciplinary team to evaluate critical factors related to both the constructability and functionality of the recommended alignment and especially the tunnel position. Similar geological and geotechnical assessments were performed for each alignment with the data presented herein to demonstrate that even within challenging environments and limited access high quality intact rock parameters can be developed to guide tunnel risk assessments during feasibility design. The challenges faced by the investigation team could not be highlighted within this contribution.

For the Granite lithologies over 600 individual tests were performed to characterize the strength and deformability of the intact rock as well as rock joints. The high number of tests performed were to maximize the information obtained from the individual boreholes due to the effort and expenditure required to obtain the core and specimens for the laboratory assessment. The results presented are consistent with typical parameters associated with granitic rocks and provided a reliable data source for assessing the ground and system behavior and associated risks.

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