Application of High Resolution Remote Sensing Technology in Plateau Railway Geological Survey: *A Case Study of Atal Tunnel*

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Abstract. With the development of railways and tunnels' construction, more and more plateau tunnels are constructed. However, the construction of plateau tunnel is faced with many safety hazards, such as geological disasters, hydrological disasters, heavy snow and so on. Therefore, it is particularly important to monitor the safety of the plateau tunnels. The remote sensing technology was accurately and efficiently applied to monitor the external environment of the tunnel, especially in areas of mountainous topography, high altitude, and inaccessibility. This paper used GIS spatial analysis technology to monitor the geological features such as geological structure and surface cover types of Atal tunnel which passes through the Pir Panjal Range. Many significant factors such as geotechnical and mechanical characteristics, fault-like features, and geological disasters have been identified. The results show that application of high resolution remote sensing technology could provide scientific reference for geological survey in areas similar to where the Atal tunnel is located, especially in areas of mountainous topography, high altitude, and inaccessibility.

Keywords: plateau tunnels; high resolution; external environment; geological survey

1 Introduction

The Atal Tunnel in India linking Manali and Leh, is the world's longest high-altitude highway tunnel (9.02 km). It passes through the Pir Panjal Range below the Rohtang Pass, where the elevation is more than 3500m. Before the tunnel's construction, heavy snowfall over the Rohtang Pass could cut-off Lahaul for months at a time [1-2]. To characterize the tunnel's comprehensive engineering, geological, and hydrogeological conditions, and to monitor its external environment, multiple survey methods were applied, including integrated geological surveys and remote sensing (RS) approaches that are both accurate and efficient. Most tunnels are constructed in areas with challenging natural conditions, such as complex terrains (including mountains and large canyons). Conducting conventional ground investigations, particularly in remote areas

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with complex terrain, is extremely challenging. However, remote sensing (RS) techniques, which enable remote analysis of the Earth's surface, can be effective in areas with limited accessibility [3-4]. Satellite images obtained by sensors with high spatial and spectral resolutions have played important roles in geological surveys, fault mapping, environmental monitoring. Previous studies have revealed the effectiveness of RS, satellite imagery, and geographical information system (GIS) in controlling natural hazards, as well as for natural space management during engineering and construction projects [5-6]. Therefore, in this study, the application of high resolution remote sensing can provide geological structure and external environment investigation. The high altitude tunnels are mostly located in the mountainous area, where the patrol lines are difficult to arrive. Based on satellite remote sensing technology and its application in the external environment monitoring of plateau tunnels can provide reference for the geological survey in high altitude area.

2 Materials and Methods

2.1 Data Sources

According to the technical specification, in this study, we used the images from Satellite Pour l'Observation de la Terre (SPOT) satellite, which has four bands and records 6-m multispectral data (Tab. 1). SPOT satellite has high application value and popularization rate in regional ecological environment, geology and mineral resources, agriculture and forestry, environmental protection, disaster monitoring, surveying and mapping, urban planning and national defense and other fields [7-8].

The data pre-processing of SPOT satellite images is mainly data fusion, which can combine the advantages of high spatial resolution of panchromatic data and rich spectral features of multi-spectral data. In this paper, Gram-Schmidt fusion algorithm in ENVI software is used for data fusion.

Table 1. Parameters of SPOT images

band	Wavelength coverage (μm)	Spatial resolution (m)
panchromatic	0.455-0.745	1.5
blue	0.455-0.525	6.0
green	0.530-0.590	6.0
red	0.625-0.695	6.0
near-infrared	0.760-0.890	6.0

2.2 Methods

The analysis conducted this study was based on archived data georeferenced under the China Geodetic Coordinate System 2000 (CGCS2000). Its data meet the requirements of basic topographic and thematic maps. Information fusion technology was used in this study. Through the integrated usage of multiple-source information, data fusion can help achieve more objectives and reveal intrinsic knowledge regarding certain objects or targets. RS spatial analysis plays an important role in ore-forming predictions using multi-informational synthetic analysis. Through GIS, the spatial characteristics of information associated with fundamental states can be acquired, and this information can be manipulated (Fig. 1). One of the key steps in RS image fusion is band integration; this process can utilize fusion technology to achieve the best fusion image; thus, this method was considered to be appropriate for the present study area.

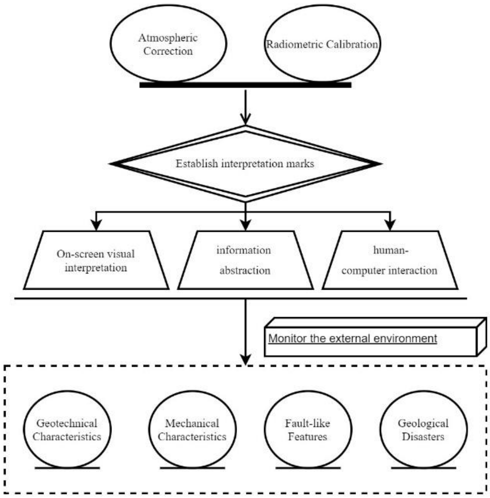

Fig. 1. Technology roadmap

3 Results and Discussion

3.1 Regional Geoligical Framework

The study area features variable water conditions; it is drained by the Beas River, and its tributaries originate from several unnamed glaciers. The Beas River originates from the Beas Kund and is joined by streams originating from several hanging valleys. After cutting through a deep gorge with knife-sharp cliffs near Kothi, the Beas River then meanders between Kothi and the Rohtang Pass. The tunnel's north portal is located on the south bank of the Chandra River Valley, running to the northwest, whereas the south portal lies in the Solang River Valley, which is one of the tributaries of the Beas River. The sediments in this area comprise fine muds that are interrupted by coarse sands and conglomerates. An ancient moraine in the area forms a crescent-shaped longitudinal ridge, which is considerably preserved in the bed of the Beas River, to the west of Kulang. A large fold dominates the structural geology of the Pir Panjal Range, comprising the southwestern slope of the Great Himalayan Range. This forms the root zone for the Jutogh thrust sheet of the Kulu–Mandi–

Narkanda area, such that these rocks occupy the southern limb of a regional anticlinal fold that varies from 25º to 35º in the area Rock exposures in the area's ridges are gneisses and granite gneisses, with migmatites and thin bands of schists in the eastern portion of the Rohtang gneissic complex. (Fig. 2).

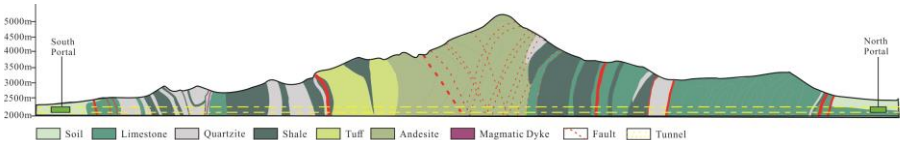

Fig. 2. Profile map of the Atal Tunnel

3.2 Land Cover

The data show that the Atal tunnel has a total length of 9.02km (of which the tunnel part is 8.8km long). It is a two-hole two-way four-lane tunnel with a single hole width of 10m. The tunnel section is horseshoe-shaped. The landform types of the study area are mainly mountain, terrace, river and flood plain. The landform of the north exit of the tunnel is more complicated than that of the south side. In the north exit area, there are rivers, floodplains, large undulating mountains and high mountains and small undulating mountains. The mountain through which the tunnel passes is mainly a large undulating mountain, with erosion surface landform near the north exit of the tunnel, which may be shaped by ancient glaciation. The topography and geomorphology of the south exit area are relatively simple, mainly developed large undulating mountains. In addition, the first grade roads adjacent to the north and south exits of the tunnel are constructed along the river direction (Fig. 3).

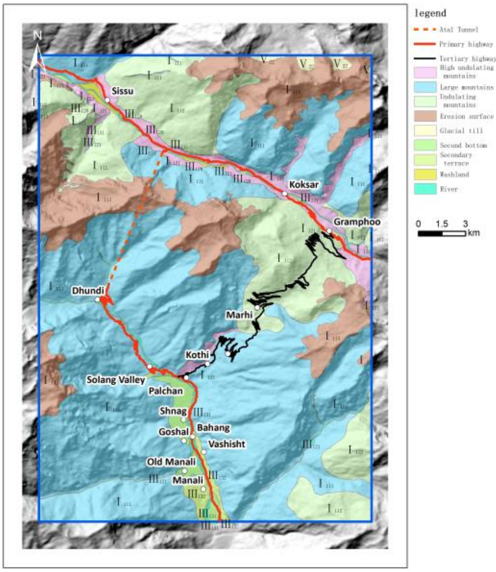

Fig. 3. Topographic and geomorphic interpretation map

3.3 Hydrogeology Conditions

Through the investigation of the lithology and distribution range of surface rivers, we can conduct the geologic structures and the affect of engineering operations and traffic. According to the porosity and permeability of different rocks, water permeability and water richness are analyzed and judgedthe surface water and groundwater storage types in the working area are divided. There are two rivers (Chandra River and Solang River) adjacent to the north-south tunnel exit of the surface water in the study area and the flood plain developed around them are geomorphic types. The groundwater can be mainly divided into magmatic rock, sedimentary rock and metamorphic rock fissure water (Fig 4). Based on the collected data and remote sensing interpretation results, metamorphic rock and sedimentary rock fracture water are mainly developed in the tunnel passage area, which is consistent with the interpretation results of basic geological strata lithology. The results show that the south exit of the tunnel is also located in the fault fracture zone, high water pressure and low buried depth would take place.

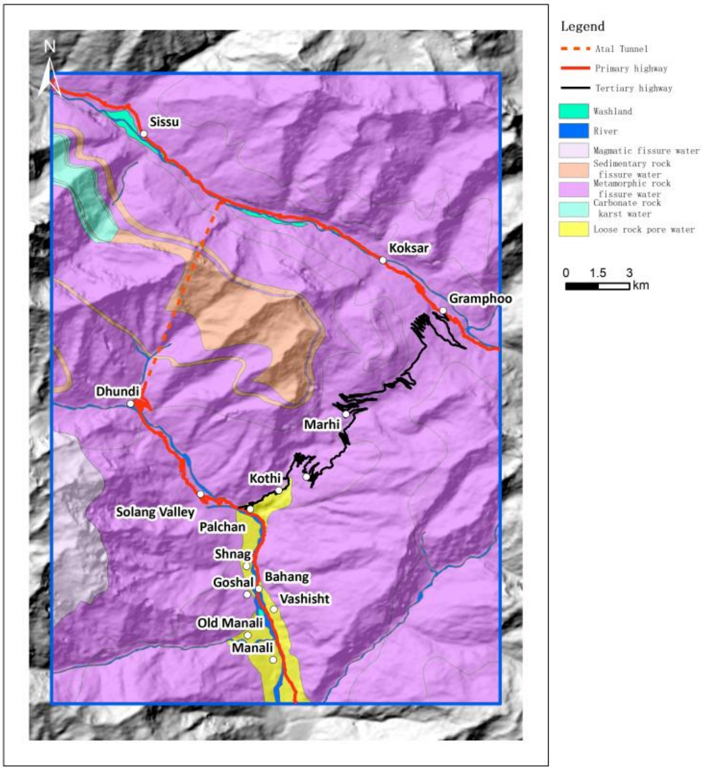

Fig. 4. Hydrogeological interpretation map

3.4 Analysis of Engineering Geology

Analysis of engineering geology is particularly important for heterogeneous rock conditions of the tunnel excavation. A joint aquifer ensures continuous water inflow to the tunnel in areas with hard rock types; less seepage water is encountered in areas featuring shale. To increase the safety of re-profiling works in challenging ground conditions, the Atal tunnel is designed and built as a drained tunnel that is completely straight, with the north portal being located at a high altitude in a region with a high rock hardness and small ridges (i.e., a stable region). The first blast took place at the south portal, which was through Quartzitic Schist, highly jointed and crossed by numerous shear-zones, parallel or sub-parallel to the axis. The rock surrounding the south portal is soft, with high levels of water ingress in fault zones; these conditions resulted in mud inrush disasters during excavation. From the assessed rock mass behavior, and control water inflow, the tunnel was progressed in accordance with the actual geotechnical conditions. Using remote sensing in mapping and recognition studies of rocks on the satellites images, combined with the petrophysical parameters collected as detailed above, the identified rocks were classified into seven levels (Fig 5).

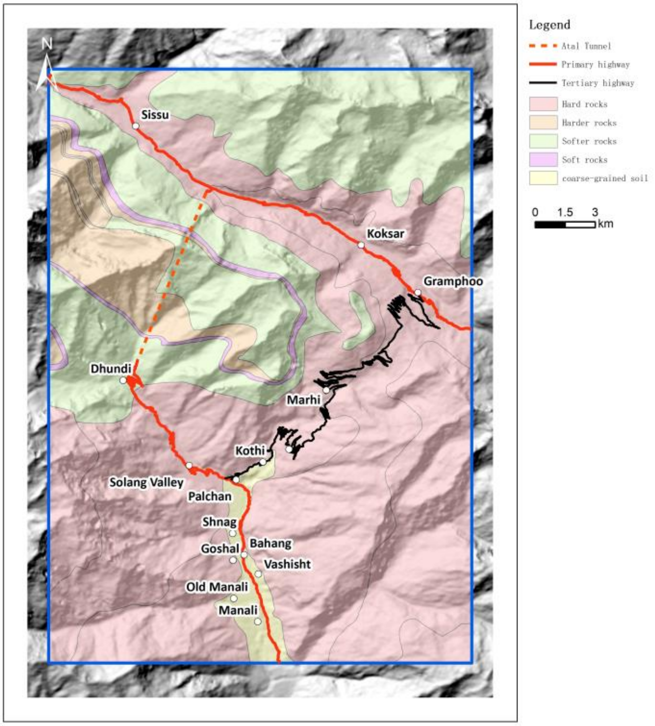

Fig. 5. Hardness classification map

4 Conclusion

In this study, land cover information and fault fractures were extracted from satellite images in a clear, concise, and targeted manner. Existing geological maps in the study area exhibit several similarities with this extracted information, implying that it is possible to use the 3S technology to aid in site selection as well as guaranteeing the safety of tunnels, especially in areas of mountainous topography, high altitude, and inaccessibility.

Tunnel construction is affected by various factors, and it is unlikely that any stand-alone method based on a single causal factor would be able to ensure tunnel safety. In lack of geological surveys and drilling, several important geological problems cannot be identified in advance. RS-based multi-informational synthetic analysis can estimate both engineering geology and geological disaster recognition. With the development of railways and tunnels' construction, increasing numbers of tunnels will be constructed in the similar area where the Atal Tunnel is located, especially the Inner Himalayas feature complex geological conditions. The remote sensing technology was accurately and efficiently applied to monitor the external environment of the tunnel, could provide scientific reference for geological survey in areas similar to where the Atal tunnel is located, especially in areas of mountainous topography, high altitude, and inaccessibility.

Acknowledgments

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