Modern Transport Tunnels under Indian Himalayas

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1. Introduction

India, a country and almost continent, with fast and steady economic growth in recent decade, is speeding up in effort to develop its traffic infrastructure to match with increased needs. In multimillion cities as Delhi, Mumbai, Calcutta and others it means mass transport systems separated from jammed roads, as underground metros and above ground light rails. On long distance national transit routes it means new motorways with controlled access and new or reconstructed rail tracks. In northern, mountainous parts of the country any new transport project can not be realized without sections going underground, into tunnels.

Recent Indian tunnelling was focused almost completely to Himalayan hydro power schemes; and an experience with construction and operation of modern transport tunnels is limited. There is existing demand for international experience and know-how with aim to realize new transport tunnelling projects safely and effectively. Experienced international tunnelling consultants and contractors are required, and there are already examples of existing successful ongoing projects with their participation.

In North-Western Himalayan state of Jammu and Kashmir, new railway line from Jammu to Srinagar is under construction with numerous tunnel sections. The longest tunnel of approx. 11 km under the Pir Panjal range is close to completion of excavation; detail design and construction supervision has been awarded to a JV with the Geoconsult Austria as a lead partner.

National Highway 1A (NH1A), from Jammu to Srinagar is to be upgraded to a 4-lane highway, using mostly existing alignment and several shortcuts with tunnel portions, where the longest tunnel under the Patnitop mountain range is now designed as a 9 km, single tube, 2-lane, bidirectional tunnel with a parallel escape tunnel to be later widened to the second traffic tube. Feasibility study of different variants, detail and tender design were provided by the D2 Consult Prague (a Czech branch of D2 Consult group of Austrian tunnel consultants), which was employed as a specialized subconsultant for tunnels for the Delhi based Louis Berger Group Inc.

In the North Himalayan state of Himachal Pradesh, there are several road tunnel projects in preparation, with completed detail and tender design. Four tunnels are in the city of Shimla, former summer capital of the British India and two tunnels are in western part of the state. Design works...
including geotechnical investigation were performed by the Geoconsult Austria, proof design review is currently prepared by the author.

2. Patnitop Tunnel on NH1A

The Patnitop tunnel is a part of the project having the aim of increasing the capacity of the National Highway NH-1A, running across India from the south to the north. In northern part of highway, in the Himalayan foothills, this originally ancient trade route passes through very difficult terrain configuration. The horizontal alignment of the way has remained virtually unchanged since 1914, when it was converted to a single lane road.

Since 2004, National Highway Administration of India (NHAI) is preparing four-laning of the National Highway 1A (NH1A) in section Jammu to Srinagar (Fig. 1). Performed activities consisted of evaluation of geotechnical investigation and carrying out variant designs for possible tunnels under the Patnitop mountain range, comparisons of the variants using the Multiple-Criterion Analysis and recommendations for the most suitable solution. The tender documents, based on the selected final variant, are presenting a 9 km long, double-lane bidirectional tunnel and a parallel escape gallery. The 9 km long tunnel under the Patnitop ridge will reduce the length of the route by 30 km and will allow the route to avoid original 1000m high ascending and descending of the road.

Geotechnical Investigation

Performed site investigation consisted of a limited amount of exploratory drilling and laboratory testing of samples. Drilling was performed in the tunnel portal areas. Deeper drilling was realised from the top of the ridge, however, the drilling did not reach the tunnel level. The geological survey was conducted in 2005. The entire survey was supplemented by detailed geological mapping and a geotechnical assessment, which was carried out with participation of the experts of TechnicalUniversity in Graz, Austria. Methodology of geomechanical design followed the Guideline for the Geomechanical Design by Austrian Society for Geomechanics (OEGG). The tender documents were developed in 2006 – 2007, for the selected final variant.

Fig. 2 Typical geology at the northern portal (outcrops of sedimentary sandstone layers)

Fig. 3 Excavation modelling using the software UDEC

Geology

The geological composition along the tunnel route consists of sedimentary rock types, so-called Murree Formation. The Murree formation consists of Lower to Middle Miocene rocks, primarily dark red, purple and grey sandstone, marlstone, claystone, brittle shales and various conglomerates. Medium blocky sandstone displays various texture, with the grain size ranging from fine to very coarse. The strength of the material varies between medium and high. Joints between blocks are frequently filled with clay. The sandstone layers are locally weakly weathered to weathered. The
bedded claystone and clayey shales are finely grained, with a low compressive strength. Limy marmoration or venation is frequently observable. Stress relaxation results in decomposition and loss of moisture. Alternation of weak rock (claystone and clay) zones with hard rock (sandstone) layers is typical in this formation. The ratio of claystone to sandstone, which are found in layers with various thicknesses, and the possible presence of ground water during the excavation are the main factors affecting the stability of the tunnel face and unsupported opening. This ratio will be the basis for the decision making for application of particular NATM classes, namely for the tunnel face sequencing and the advance length.

The fundamental influence of the thickness of the clay layers was also proven by numerical modeling (see Fig. 3). Another factor which significantly influences expected stability and deformational behaviour of the excavation is the primary stress of the rock mass. At the maximum overburden 1000m high, the vertical component is expected to correspond to the overburden height. Considering the active tectonic history of the area, the terrain morphology and available information about faults in the tunnel area, there is an assumption that the horizontal stress perpendicular to the centreline of the tunnel will be rather low. The design for the excavation technique, a tunnel face sequencing and excavation support is based on the anticipated types of the unsupported excavation behaviour, including extreme ones, i.e, very unfavourable behaviour requiring the division and support of the tunnel face and measures to be implemented ahead of the face. With respect to the limited information obtained by site investigation, and considering a very limited experience with excavation of the similar profiles in the given area, the estimation of the distribution of the geotechnical types and the expected excavation procedures (NATM classes) is subjected to a great uncertainty.

Tunnel cross section
The tunnel cross section design was affected, above all, by spatial requirements for the clear cross section of the tunnel, the width of the roadway and the minimum dimensions of the ventilation ducts for the planned transverse ventilation. The width of the roadway in the Patnitop tunnel was also one of the main issues which were discussed for a long time. The final design for the cross section was determined on the basis of the following NHAI requirements: the road width of the roadway 9,35 m, two 1m-wide raised walkways on both sides, and a parallel escape gallery with cross passages. The cross-sectional area was increased to about 147 m² (see Fig. 4).

The gallery excavation will start with a short advance ahead of the main tunnel. It will serve as a pilot drift and it should indicate the rock mass behaviour and anticipated problems; further it will have drainage and transportation functions.

The cross section has three basic variants, depending on the respective NATM class (A, B and C). For the variant “A”, the tunnel an open profile without invert. The variants “B” and “C” have the excavation bottoms stabilized by an invert (see Fig. 5). The minimum thickness of the lining in the crown is 400 mm. The tunnel waterproofing will be of the umbrella type with side drains and a central collector. A space under the both walkways will be used for the cables and water main. The escape gallery may be constructed with a shotcrete lining only due to possibility of a subsequent construction of the second tunnel tube, or as decide during construction. Ventilation buildings are located at each portal.

Tunnel Alignment
Due to topographic conditions minimum horizontal radius is 300 m, longitudinal profile is of a roof shape with average 0,5% inclination.
Tunnel Equipment and Safety Standards

The tunnel equipment has been designed in compliance with the current international standards and it follows the requirements of the European Directive 2004/54/ES. A typical arrangement is shown in Figure 8. The basic measure in terms of safety of persons in the case of an emergency (an accident) is the possibility of escaping through cross passages to the parallel escape gallery, which can be even used as an access route for rescue units; it will be pressure ventilated from the portals in the case of a fire in the tunnel. The operation management centres are located at both portals. The main centre is at the southern portal, while the management centre at the northern portal is a standby. Reservoirs supplying the fire main are provided also at both portals. A transverse ventilation system with ventilation ducts above the roadway and ventilation plant buildings at the portals is designed for the road tunnel. Additional fans, which are located within the tunnel cross-section, are intended to allow easier control of the airflow in the tunnel. The performance requirements for the operation, safety and maintenance management system are conceptually defined in the tender documents; requirements for specific systems, equipment and facilities will be specified during the construction.

Fig. 4 Typical cross section of the completed tunnel – class “C” (1 – primary lining, 2 – waterproofing layers, 3 – secondary lining, 4 – cable duct, 5 – fire main, 6 – central tunnel drain, 7 – clearance profile)

Fig. 5 Primary lining cross section - class “C”: (1, 2 – rock bolts 8m, 12m long, 3 – primary lining, 4 – yieldable elements, 5 – spilling, 6 – face anchors, 7 – temporary anchors in a partial top heading, 8 – top heading invert)

Fig. 6 Arrangement of Safety Equipment
3. Himachal Pradesh Road Tunnels

Shimla, summer Capital of British India, was founded on the steep ridge in elevation of approx. 2000 m in the mid of 19th century. A difficult traffic connection has been improved by the construction of a narrow gauge railway in 1903, having over 100 mostly short tunnels, hundreds of hair pins and climbing over 1400m from Kalka in lowland.

City, designed for minimum of non pedestrian traffic expanded during over more than half century of independent India to both steep sides of the ridge, with pedestrian Mall Street on the top. Fast expanding automobile traffic is now congesting existing roads and it is a severe obstacle to a city life and to further development.

The local state traffic authority HPRIDC is preparing a construction of 4 road tunnels in Shimla and 2 additional on important state roads of national importance. Project, co-financed by the World Bank, is in the DPR stage with ongoing proof design review and tender preparation.

Shimla Tunnels

Tunnels in Shimla are of short to medium length (150 m to 1150 m), urban tunnels and shall be used by bi-directional vehicular and pedestrian traffic. Standard cross section is governed by clear profile 7.5 x 5 m and sidewalks of 1.5 x 2.20 m (Fig. 7). Safety arrangements are in general following recommendation of 2004/54/ES directive. Both longer tunnels have escape possibility through side tunnels in the middle of their lengths. Tunnel operation shall be controlled from one centre and should be coordinated with the traffic control of the main road system in Shimla. There is foreseen a longitudinal mechanical ventilation with jet fans.

Local geology belongs to Lesser Himalaya zone represented by proterozoic origin metamorphic formations of Juthog and Shimla Groups composed of lithological units of quartzite, slate, paragneiss, and phyllite with fault zones in a phyllite. The area belongs to the seismic Zones IV and V of the Seismic Zoning Map of India.

The geomechanical design was performed in compliance with the Guideline of OEGG and principles of the New Austrian Tunnelling Method (NATM). Excavation shall be made by drill and blast or by roadheaders.

Fig. 7 Typical Cross Section of Shimla Tunnel T01

Fig. 8 Typical Cross Section of Kanchimore Tunnel T05
**Tunnel T05 Kanchimore**

The longest tunnel on the scheme is 1,700 m long Kanchimore tunnel with max. 300 m overburden. The tunnel is located in countryside, and creates a shortcut on NH 21 between Chandigar and Bilaspur continuing farther to Mandi and Manali. The longitudinal roof profile has approx. 1% grade and standard cross section has clear profile 7.5 x 5 m with sidewalks of 0.75 x 2.20 m (Fig. 8). Due to tunnel length, estimated traffic volumes and high portion of trucks with high level of emissions, a semi transversal ventilation system was adopted. There are designed parallel escape tunnels and cross connections at each 450 m as a basic safety arrangement. Ventilation buildings shall be at each portal and control centre at the southern one.

The tunnel is situated in a wider tectonic zone, the area belongs to the Siwalik Formation of fresh water sediments consisting of sandstones, calcareous sandstones and marly shale uplifted during Himalaya rising. Behaviour during excavation shall be influenced by water presence and may be varying in different weather seasons (rain and dry season).

4. Discussion and Conclusions

The both road transport schemes include road tunnels located in Himalayan environment, in higher attitudes and geological conditions influenced by forming of the Himalaya. Similarities are in the designed cross sections with double linings (shotcrete outer and cast in situ inner), umbrella type of waterproofing with a membrane between linings. Conventional tunnelling is foreseen for all tunnels, even for the longest, 9 km one. Main reason is uncertainty of foreseen geotechnical conditions considering high (up to 1 km) overburden, hydrogeological conditions and primary stress state in the ground influenced by tectonical history. Existing limited local experience with construction of similar tunnels, remote locations with communication and transport difficulties are additional factors influencing adopted solutions. Future clients should be aware of the fact that tunnel construction is activity depending on observation and consequent reaction. Independent geomonitoring and designers involvement during all tunnel construction activities, as well as organization of the construction and daily decision making process are important premises of successful and effective realization of tunnels. It is believed, that involvement of internationally experienced tunnel experts and consultants is beneficial and reduces risks which are always present in tunnelling. This was also confirmed on construction of the new rail link to Srinagar in section Katra to Qazigund with many shorter tunnels and one long the Pir Panjal rail tunnel.

Safety standards for both schemes are corresponding to current European requirements on safety in the road tunnels. It is to be decided by the future tunnel owners and operators, if immediate full application of these standards is desirable. Because the general traffic safety conditions and traffic control on Indian roads varies considerably from European ones, a gradual application of designed operation and safety arrangements may be an effective approach. A real operational experience gained during the first years of tunnel operation should be analyzed and optimum solutions found for each tunnel in its specific conditions. A risk analysis may also help to find reasonable solutions corresponding to overall traffic control and safety level on state/national roads.

Steady fast growing Indian economy needs corresponding transport infrastructure. Improvement of the road transport needs also many road tunnels, in particular in hilly northern parts of India. The competence in project preparation and realization will decide if future tunnels shall be constructed and operated effectively and safely.

References:

