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INFRASTRUCTURE PROJECTS AND GEOTECHNICAL CHALLENGES IN HIMALAYA, INDIA

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ABSTRACT

About 5 lacs square kilometer of Indian geographical area (16% to total area) have been covered by Himalaya Mountain, belongs to 10 states from Jammu & Kashmir to North Eastern states. For better connectivity and national security, government of India has started various infrastructure projects such road, railway, Airports/helipads etc. project in Himalayan region; which comprises of hill cutting, filling the valley areas, tunnels, minor & major bridges etc. Himalaya is youngest folded and tectonic active mountain; having various major and minor geological structures. Geological and hydrological factors are main causes which affects the costing and project completion time. Geological rock quality (RMR, GSI value), joint orientation, shear zone, topography, slope cutting, hydrological factors, overburden thickness, landslide, suitable rock strength, rock deflection, tunnel cavity formation, vegetation cover are main geotechnical challenges faced during the construction stage. These challenges called the geological surprises during the construction. Detailed Geological and Geotechnical feasibility study with local challenges needs to be implemented for mitigate geological failures. For finalize the method of tunnel construction should be depending on rock quality and construction feasibility, such as New Austrian Tunneling Method (NATM) is good for medium to poor quality rock (Siwalik and Middle Himalaya), Drill and blast method is good for (Middle to Greater Himalaya), now days Tunnel Boring Machine (TBM) are also available for tunneling in various types of rock. Each type of tunnel construction methods has its own limitations and have to recommend accordingly. During crossing of shear zone/ fault /thrust zone needs to be taken care about the geological surprises. Close monitoring of geological and geotechnical parameters with help of settlement markers, optical targets and other instrumentation can reduces the upcoming challenges.

Keywords: Geological Challenges, Shear Zone, Geotechnical Challenges, Landslide, Slope Failure.

I. INTRODUCTION

Northern boundary of India from East to West direction, Himalaya is natural geographical boundary of India, which protect from harsh cold polar winds as well as provide fresh water for Indo-Gangatic plane. Himalaya is youngest tectonically active mountain with varying geological, topographical, hydrological and meteorological condition.

There are varies hilly regions those are still untouched from road and railway such as Himachal Pradesh, Uttrakhand, Sikkim, North Eastern states. For better connectivity and national security, government of India has started various infrastructure projects such road, railway, Airports/helipads etc. in Himalayan region, comprises of hill cutting, filling the valley areas, tunnels, hill slope protection, minor & major bridges etc. Due to harsh topography, climate and approaches till project location, some engineering challenge have been taken by Government of India and it is not possible without geological and geotechnical solutions. Some Infrastructure projects are listed below:

1) Jammu- Srinagar & Srinagar- Leh Road project (Chennani- Nashri tunnel -9.2 km Completed (more than 1000 m overburden), Benihal- Qazigund road tunnel (Under Pir Penjal range)- 8.5 km (more than 1000 m overburden), and Zojila Tunnel- 14.31 KM and Z-Morh Tunnel- 6.5 km
2) Jammu- Udhampur- Katra- Srinagar-- Kargil-Leh Rail Project (World highest rail bridge on river Chenab- 359 m height from river surface, Bridge length: 1,315 m (4,314 ft), including the 650 m (2,130 ft) long viaduct on the northern side), T-80 tunnel Pir Penjal tunnel length is 10.96 km, under operational. Total 262 kms of approach roads to work site have constructed.
3) Rohtang to Leh road project (Atul tunnel- 9.02 km long at 3,000–3,100 m altitude of tunnel and longest tunnel above 10,000 feet in the world).

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4) Bilashpur Leh railway line (Total 458 km long and Taglang La railway station at elevation of 5,359 m i.e. 17,582 ft, and proposed the world highest railway station in this section).
5) Chardam Road and Railway project
6) Sevok- Gangtok Railway project.
7) Two Tunnels at Sela Pass in Arunachal Pradesh
8) Indian Railways Jiribam-Tupul-Imphal line (45 tunnel, longest tunnel is 10.28 km long with world tallest pier height of 141 metre at the valley of river Ijai near Noney).
9) Imphal- Moreh road and Moreh bypass road will facilitate trade with Myanmar.

For propose and construction of infrastructure projects in Himalaya; topographical, geological, remote sensing & aerial imagery interpretation studies used in primary stage and finalized the project components (road, tunnel & bridges alignment) as well as basic civil construction details. The geological features marking and know the geotechnical parameters along the project component helpful in design and planning of hill excavation and slope protection, bridge abutment depth. Hydro geological & meteorological studies should be done for mitigate the project from natural calamities such as landslide, flood, cloud burst etc. Rock burst study also preferred, as per requirement for construction of Tunnel.

In this paper will discuss the geological and geotechnical challenges encountered during the investigation and construction stage of Infrastructure projects in Indian Himalaya along with probable natural disaster and try to suggest the remedial measures accordingly.

1. Geological studies and parameters for Infrastructure Projects

Before starting the construction activities, field geological mapping as well as various bore holes and geotechnical investigation have been done to get the physical, geological, Geo-mechanical properties and subsurface strata. For verify the in-situ bearing capacity of bridge foundation; Plate load test/foot load test would be performed. As per requirement of project design, other geo-mechanical investigation and geophysical tests have been done along the tunnel alignment. The Laboratory test such as physical properties of materials, Unconfined Compressive Strength test (UCS), Point Load, Triaxial, permeability test etc. have done on drilling core samples as well as at field soil & rock samples performed for better understanding of subsurface in-situ profile. For in-situ rock stability and rock support system, Rock mass rating (RMR), Geological Strength Index (GSI), Slope mass rating (SMR) and Q- system to be calculated based on Joint pattern, Joint orientation, Joint volume, filling between joints, UCS value of rock, Rock Quality Designation (RQD), water seepage, intersection angle between joints/foliation/bedding and project alignment for slope stability.

The rock mass rating (RMR) is a geomechanical classification system for rock, developed by Z. T. Bieniawski between 1972 and 1973. Since then it has undergone multiple modifications based on the various project case studies and now RMR89 (Bieniawski, 1989) is commonly used.

The Geological Strength Index (GSI) system, proposed in 1994 by Evert Hoek, is used for the estimation of the rock mass strength and the rock mass deformation modulus. The GSI is a unique rock mass classification system related to the rock mass strength and deformation parameters based on the generalized Hoek-Brown and Mohr-Coulomb failure criteria.

The Q-system for rock mass classification is developed by Barton, Lien, and Lunde (Barton et al, 1975, 1976, 1988, 1993, 1994, 2000, 2002, 2006; Kainthola et al, 2012, 2014). It shows the rock mass quality round an underground opening, as well as for field mapping, on which are based design and support recommendations for underground excavations.

2. Project affecting factors

As projects are planned to passing through Siwalik Himalaya to Tethyan Himalaya, having different topography, variable hill slope, various rock conditions; creating various construction problem. Geological and hydrological factors are main causes which affects the costing and project completion time. Geological problems during the investigation and construction of projects are mainly affected by below factors:

(a) Geological & Geotechnical Factors
(b) Hydro-meteorological disaster

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(c) Man Made factors

Table 1: Project affecting factors

Geological and Geotechnical factors	Hydro-meteorological disaster	Man made factors
* Joint pattern * Project orientation pattern * Hill slope angle * Geo-mechanical Parameters * Seismological factors * Weathering * Liquifraction * Geological surprises- Landslide, water seepage, rock fall, rock burst, Tunnel failure, ground subsidence, liquefaction, frost	* Landslide * Cloud burst * Flood * Flash Flood * Lake Outburst flood * Avalanches * Heavy Snowfall	* Increase the landslide- Deforestation and slope excavation for construction * Water seepage * Vibration and noise

(a) Geological & Geotechnical Factors

As Himalaya is young mountain belt and tectonic active, various geological & geotechnical factors have been affect the construction of project. Landslide, rock fall, ground subsidence, liquefaction, frost weathering are major natural hindrance faces by the construction agencies. Apart from it; geological fault, shear zone, syncline, anticline, Seismotectonic factors playing the major role. The stability of rock/hill slopes is the manifestation of the type, frequency and direction of insitu rock discontinuities along the project component. Instability is a very common phenomenon in highly jointed rock mass. More sets of joint increased the chances of rock mass failure which brings uncertainty of slopes analysis (Kainthola A et al, 2012 & 2014). Geological mapping with discontinuity orientation and spacing with the parameters like persistence, block size and roughness to be mapped and interpretation closely because these are hill stability affecting factors during construction.

Landslides along the project alignment are normal phenomena. Several old landslide zones have observed along the project alignment. Landslide occurred due to various geological & hydrological processes, combination of one or more factors which include geological, geomorphological, meteorological factors such as rainfall & snow; and the reduction of shear parameter due to an increase the pore water pressure by saturation during precipitation and increased the landslide. The Rock fall occurs along the closely spaced and steeply dipping joints, while planar and wedge failures occur due to the intersection of adversely-oriented joint planes. Slides on the thick colluvium deposits have also observed. The Colluvium deposit has made up of boulders and sandy and clay soil, which increase the chances of liquefaction in the presence of water.

(b) Hydro-meteorological Disaster

Himalaya has highly variable climacteric condition. During monsoon season landslide, cloud burst, flood is common. For smooth running of traffic and less time travel, government authorities have proposed the tunnel. At the frost area, repeated cycles of freezing; change the structure of the soil and reducing the bearing capacity of soil which causes the chances of landslide, ground sinking and other related disasters.

Sometimes actual geological condition is much differed from prediction, based on geological & geotechnical investigations. The change in rock class, high water ingress, settlements is called geological surprises that affect the work progress. For the long length tunnel ventilation is also an important factor.

II. GEOLOGICAL AND SEISMOTECTONIC SETUP OF HIMALAYA

The Himalaya resulted from collision of the Indian plate with Asia and are well known as the highest, youngest and one of the best studied continental collision orogenic belts. Himalaya is comprises of many major and minor faults and seismically active zone. Himalaya is falling under seismic zone 4 according to Indian earth quack zoning mapping. Geological setup of Himalaya is shown in below figure 2. The Method of construction for underground structure such as tunnels, underground powerhouse, river diversion, shaft etc depends upon geological structure, rock quality, construction feasibility and project financial implementation. Main tunneling

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methods are Cut and Cover, Drill and Blast method, New Austrian Tunneling Methods (NATM) and now days Tunnel Boring Machine (TBM) are also available for tunneling in various types of rocks and used in some Himalayan projects. Each type of tunnel construction methods has its own limitations and recommend accordingly.

Geological challenge during the tunnel construction are encountered such as portal support, thrust zones, shear zones, clay band, in-situ stress/tunnel rock burst, cavity formation, tunnel sinking, unfavorable joint pattern, overburden thickness, high water ingress, high level of seismicity etc.

The TBM cutter head jam, deviation in tunnel alignment, crack in tunnel segments, ground subsidence and high water ingress are main geological challenges encountered during TBM tunneling.

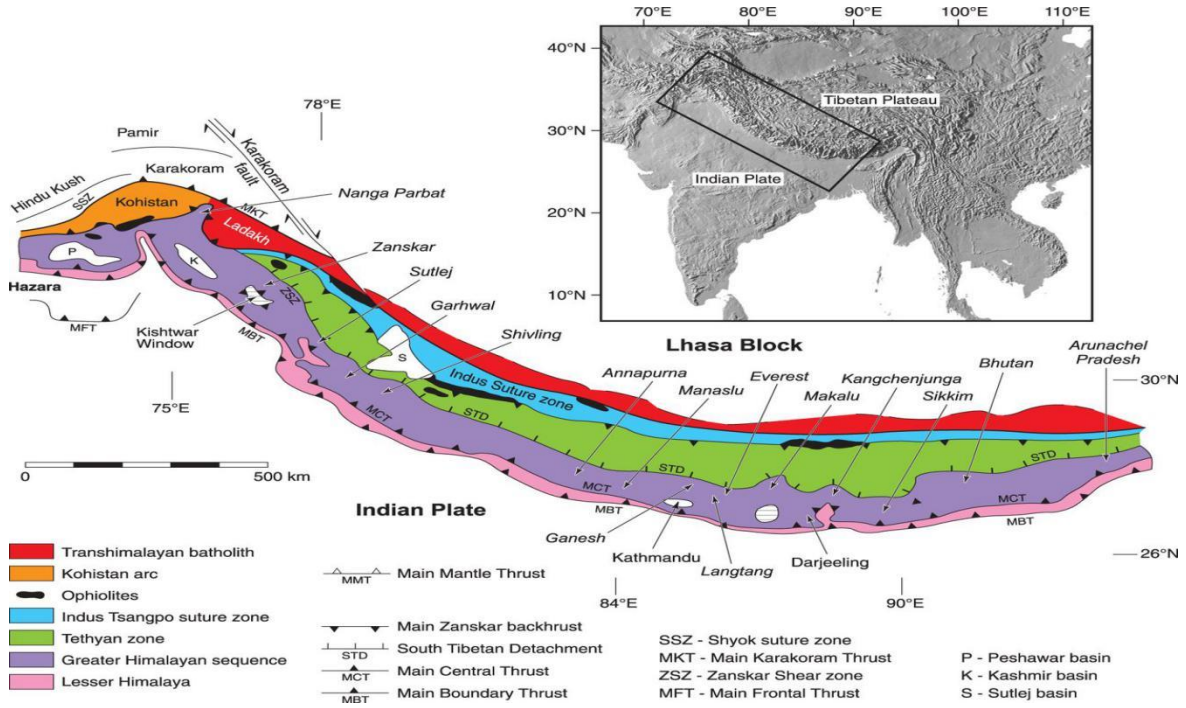

Fig 1: Geological setup of Himalaya (Michael P et al., 2019).

III. PRECATIONARY MEASURES

As various type of geological challenges involve during development of project in Himalaya, here trying to suggest precautionary measures according to type of challenges and mentioned in below table no 2:

Table 2: Geological challenges and mitigation measures

S No	Challenges	Mitigation measures in Himalaya
1	Geological challenges during tunneling (Cavity, encounter of shear zone, high water seepage)	Probe hole is best for predicting the geological condition.
		In case of high water seepage, dewatering & grouting to be proposed.
		Cavity should be filled with aggregate/impervious materials.
		In case TBM cutter is jammed,- pulling the TBM back a short distance and cleaning up the debris. This was followed by refilling the cavities with shotcrete or cement mortar from the feed in-cabin on the cutter head. If its impossible to push back TBM then Bypass tunnel, top heading tunnel should be adopted.
2	Slope cut Protection	Slope protection along hill & valley side are required.

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	towards hill and valley side	Retaining/breast/ gabion wall, shotcrete, rock bolt, Wire mesh, rock fall barrier, slope angle, vegetation etc to be done as per requirement.
3	Foundation of bridges (Foundation structure to be proposed as per bearing capacity of strata)	Actual bearing capacity to be confirmed by Plate Load test. If found variation in bearing capacity due to different rock encounter in foundation, should be take preventive measures to improve capacity
		Foundation slope direction, rock joint orientation and ground water impact to be considered.
4	Flood	Flash flood, Glacier lake out-burst flood (GLOF- Higher altitude), meteorological data need to be consider carefully.
		Road/Railway/Project component elevation always be higher than maximum flood level for 100 or 1000 year data as per project requirement.
5	Landslide and Ground Settlement	Landslide & ground settlement is normal phenomena in hills. Other required mitigation measures to be taken.
		Avoiding/safe practice during project alignment along old major slide, shear zone. Slope should be maintain during hill excavation and apply slope protection measures. Different type of protection works applied according to geological strata and joint orientation. Step wise slope excavation, rock net, anchoring, shotcrete, retaining/breast wall, cladding wall, box type road cover, rock fall barrier, micro pile, Bio-engineering methods are some important methods which used to protect the landslide zone.

IV. CONCLUSION

Working in Himalaya is full of geological and geotechnical challenges. Climatic and hydro-meteorological factors are playing as catalyst in construction complications. The applied of step wise mitigation measures will decrease the chances of landslide and geological challenges. Following points to be suggested for minimizing the challenges:

a) Detailed geological and geotechnical feasibility study with local challenges needs to be implemented for mitigate geological failures.
b) Method of tunnel construction should be depending on rock mass weathering condition and construction feasibility.
c) During crossing of shear zone/ fault /thrust zone needs to be taken care about the geological surprises.
d) Close monitoring of geological and geotechnical parameters with help of Geotechnical instruments such as settlement markers, optical targets and other instrumentation can reduces the upcoming challenges.

The mitigation measure may not be feasible financially but during operation stage maintenance, landslide on highway, tunnel or ground subsidence and impact on day-to-day life; will be more feasible. Above suggestions will be helpful in smooth running of infrastructure projects in Himalaya and other hilly region of world.

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