Engineering Geological Complications of the Nepal Himalaya

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Abstract

The earth's crust has been folded and uplifted due to the tectonic movement resulting in the elevated surface which is known as Nepal Himalaya. Geologically Nepal is divided into Terai, Churia, lesser Himalaya, Higher Himalaya and Tibetan Tethys zone from south to north. Due to the difficult and heterogeneous geology and topography of Nepal Himalaya; it is always challenging to establish any kind of engineering project. Geology always impacts on any kind of engineering construction within the earth. It is high time skilled manpower from geological and engineering fields collaborated for the sustainability of the engineering project. Risk and cost can be effectively reduced along with increasing the life span of the project if the proper engineering geological study is done before the establishment of any kind of engineering project. The tremendous loss of economy and destruction of the infrastructure has occurred in the past in different places of the world due to the negligence of engineering geological features of the site. Hence, proper engineering geological investigation is crucial for establishing any kind of engineering project within time, with minimum effort and cost for a longer period of time. This paper is the compilation of numerous literature review along with different professional and academic visits for addressing engineering geological complications of Nepal Himalaya.

Keywords: tectonic, topography, engineering, geological, sustainability, investigation

Introduction

The shortening of the earth's crust due to the northward movement of peninsular India helped to establish 2400km long mountain range known as the Himalaya which can be transversely divided into Punjab Himalaya, Kumaon Himalaya, Nepal Himalaya, Sikkim-Bhutan Himalaya and NEFA Himalaya (Gansser 1974 and 1964). Nepal Himalaya lies in the mid portion of the Himalayan mountain arc and covers 800 km of the distance bounded by Mahakali River in the west and Tista River in the east. (Upreti 1999 and Dhakal 2014). Physiographically Nepal is divided into 8 parts namely Terai, Churia Hills, Dun valleys, Mahabharat range, Midland, Fore Himalaya, Higher Himalaya and Trans Himalayan valleys which tentatively follows east-west trend but geologically Nepal is divided into five parts namely Terai, Churia, lesser Himalaya, Higher Himalaya, and Tibetan-Tethys zone which also follows east-west trend. Each geological unit is divided by the well-defined geological tectonic structures as shown in Figure 1. (Hagen 1969, Upreti 1999 and Dhakal 2014).

Every engineering project is constructed within ground which is impacted by the ground conditions; the engineering task must withstand the engineering behavior of the ground. Due to the negligence of geological conditions in engineering project like Austin Dam in Texas in 1900 and St. Francis Dam in California in 1928, they failed. (price 2009). The bridge failure of Kamala and Jabdighat in Nepal is also another example of poor engineering geological investigation. (The Himalayan 2021). Engineering failures can delay projects, and cause injuries, loss of lives and money. To be on a safe side from such casualties it is necessary to comprehend the impact of the geology of the site on the overall project (Price 2009).

This article aims to highlight the general engineering geological characteristics of the Nepal Himalaya based on literature review, academic and professional

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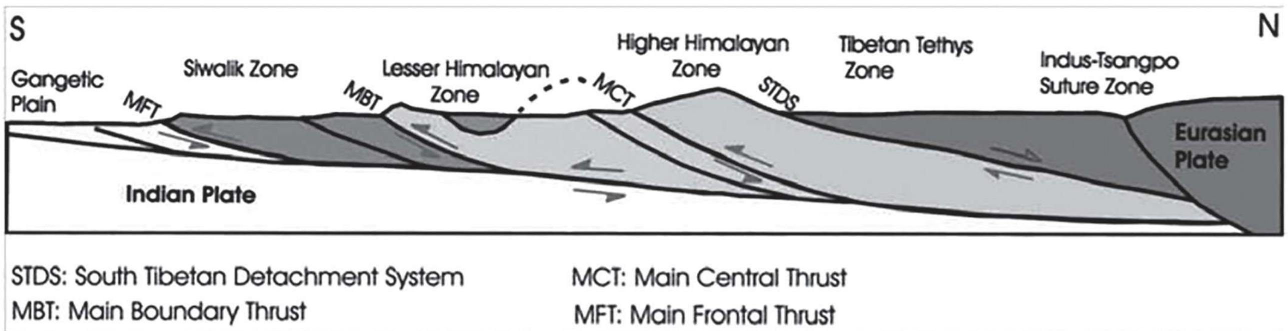

Figure 1: Geologocal section of the Himalaya *(Source Dhakal, 2024)*

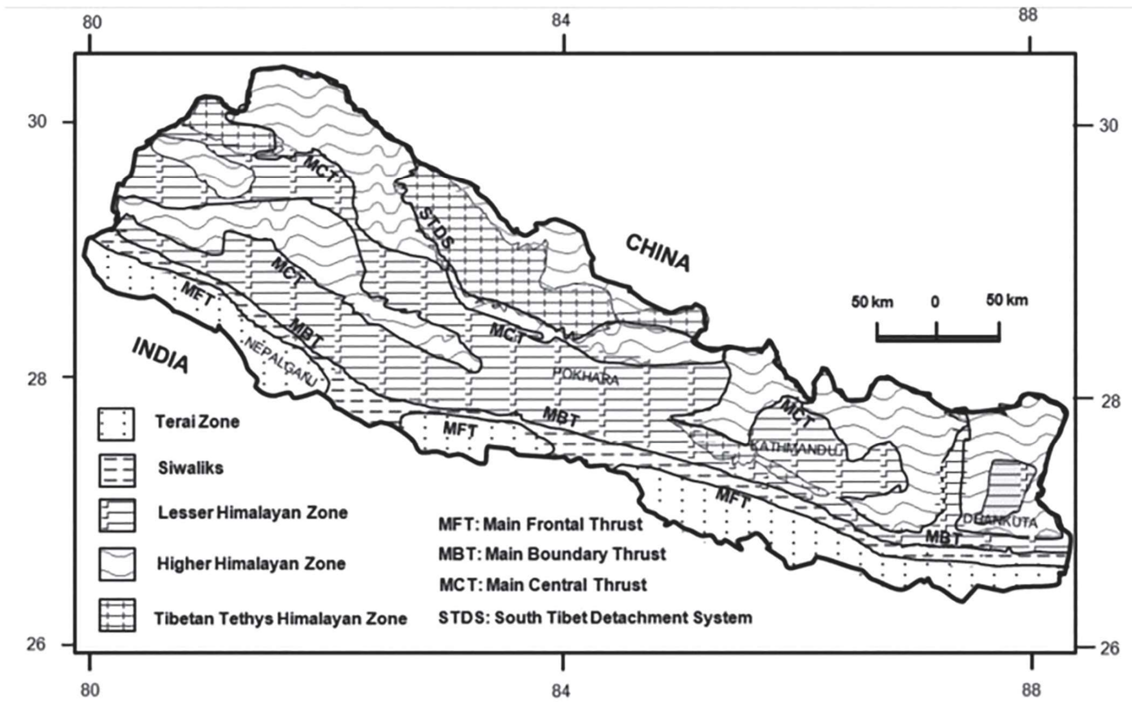

Figure 2: Generalized geological map of the Nepal Himalaya

visit of the different areas of Nepal. The compilation and correlation of engineering information with geological perception can be fruitful for the future and ongoing engineering projects by reducing possible adversity.

Geological Division and related engineering properties

Terai

Terai is a flat land just south to the Siwalik (demarcated by Himalayan frontal thrust) which extends around 25 to 50km in width from north to south. Its elevation ranges around 100 to 200 m. It can be divided into three zones; Upper Terai or Bhabar zone (composed of boulder, cobble, pebble and coarse sand), Middle Terai or Marshy land (composed of pebbly and sandy sediments) and Lower Terai or Gangetic Alluvium (composed of fine sediments like clay, silt and sand) from north to south. Bhabar zone is groundwater recharge zone due to presence of coarse sediments and marshy land is good reservoir of groundwater. (Dhakal 2014 and Dhital 2015). Terai is composed of around 1500m thick fluvial deposits on the bedrock which is a good source of groundwater. The average water level from the ground surface is 4.55m and 5.92m for shallow and deep aquifers respectively. (Shrestha et al. 2018) Flood and debris flow are very common in Terai. Due to the large amount of sediments carried by the rivers; rivers frequently shift the channel which gives unexpected challenges for the infrastructure (Dhakal 2014).

Siwaliks/Churia/Sub Himalaya

The sudden rise in the elevation to the north of Terai demarcates the boundary of Siwaliks. Its altitude ranges from 200m to 2000m and 1km to 20km in width from north to south. The southern face of the Siwaliks is steeper. In most of the places Siwaliks is separated into two ranges by flat plains called ''mari'' or Vitri Madesh in common. (Dhital 2015) In general Siwalik can be divided into three parts namely lower, middle, and upper. Lower Siwaliks is composed of shale, mudstone and fine-grained sandstone where shale and mudstone are dominant. Middle Siwaliks is composed of medium to coarse grained sandstone and a relatively smaller proportion of shale and mudstone. The Upper Siwaliks is composed of conglomerate. (Dhakal 2014).

Long term rainfall seems to be more dangerous for Siwaliks. Upper Siwalik faces problems like debris fall due to the loosening of cementing materials. Landslide in middle Siwalik is due to the presence of smoothly erodible mudstone between large beds of sandstone. Lower Siwalik is prone to erosion and erosion induced landslides due to the dominance of weak rock like mudstone and shale (Bhandari and Dhakal 2018,2019,2020).

Lesser Himalaya

This zone is confined by the main boundary thrust in south and main central thrust in north. Lithologically it is dominated by metasedimentary rock. Rocks like Quartzite, phyllite, slate, dolomite, limestones are common in this zone. Numerous faulting and folding are very common geological structures in this region. This region can be divided into low grade metamorphosed zone called Lesser Himalayan meta sediments and high-grade metamorphosed zones called Lesser Himalayan crystallines. (Gansser 1974 and Dhakal 2014)

Lesser Himalaya is prone to landslides due to the presence of highly folded and faulted rock types. Due to the presence of weak rock like phyllite, slate and schist in this kind of fractured zone rainfall can easily induce landslides. Jogimara landslide and landslides along the Muglin-Naryanghat road section are best examples of geohazards in Lesser Himalaya. (Dhakal 2014) The area with larger proportion of calcium carbonate gives rise to karst topography like in Pokhara. Karst features like caves and sinkholes (formed due to the dissolution of carbobates) can lead to the damage of infrastructure and settlements. (Fort et al. 2018).

Higher Himalaya Zone

The Higher Himalaya Zone is bounded by the Main Central Thrust in the south and the South Tibetan Detachment Fault System in the north. The zone comprises medium- to high-grade schists, marbles, quartzites, augen, banded and calc-gneiss, migmatites, and granites (leucogranites). Banded gneiss possesses dark bands of dominant biotites and light strips of granitic and tourmaline-rich pegmatitic materials. Augen gneiss comprises large feldspar lath. Leucogranites are rich in feldspars (Dhital, 2015). The zone includes elevated peaks having slopes greater than 5000m in altitude with vertical and steep rock slopes. The precipitation rate is high in the southern face. Landslides, rock-related failures, Landslide Dammed Outburst Floods (LDOF), and Glacier Lake Outburst Floods (GLOF) are common issues in this zone. One of the major problems in the engineering construction of the zone is the MCT zone (Dahal, 2010).

The folding and anisotropic nature of gneiss results in lower strength and poor engineering properties as compared to marbles and quartzites (Gupta, 2009). MCT zone is the thick ductile shear zone where maximum deformation is at the boundary of the Higher Himalayan Zone and Lesser Himalayan Zone. MCT zone is a weak and seismically active zone which can cause serious problems in surface and subsurface engineering constructions. In the zone of high precipitation, landslides are frequent. Fractured, faulted, and sheared zones common due to faulting, shearing, and hydrothermal alteration. This zone provides an excellent environment for the weathering process to intensify and thus weathering can reach to considerable depth.

Tibetan Himalayan Zone (THZ)

THZ lies between the South Tibetan Detachment Fault System (STDFS), a north-dipping normal faults system, and the Indus-Tsangpo Suture Zone (ITSZ). This zone has limited aerial extent in Nepal with the best section in Western Nepal in the Annapurna-Dhaulagiri and Dolpa regions. Most of the high peaks of the Nepal Himalayas are made up of the rocks of this zone. The zone comprises Mesozoic and Paleozoic rocks throughout its length and width (Gansser, 1964). The Paleozoic unit comprises phyllites, siltstones, limestone, and quartzite. The Mesozoic unit comprises limestone, shale, and sandstone. The average thickness of the Paleozoic and Mesozoic units is 3000m and 2000m respectively. The lower rock of THZ has undergone regional metamorphism. This zone lies in the rain shadow region and the rare rainfall causes flash floods. Besides, the zone is vulnerable to GLOF, debris flow, and river bank failure by the bank erosion of alluvial and glacial moraine deposits.

Sedimentary strata such as sandstone, siltstone, and shale are susceptible to mechanical weathering by snow which results in unconsolidated sediments and the strong wind blows easily erodes the unconsolidated sediment (Dhakal, 2014). Folds and thrusts have weakened the strength of rock. Limestones are resistant to erosion as very little rainfall avoids chemical weathering in this zone.

Discussion

The rugged and fragile topography of Nepal has been a challenging task for infrastructure developments. Moreover, the influence of the monsoon adds more complications. Rock mass quality, weathering and fracturing, rock stresses, water condition, and orientation of discontinuities in rocks are the significant parameters for both surface and subsurface engineering constructions. Inappropriate geological investigations have caused the failures of numbers of design so far. Especially on the road, controlling the slope failures is more challenging. Haphazard construction of roads have caused frequent slope failures and blockage of roads during the monsoon. Moreover, different engineering issues have been faced by people living in the road corridors.

1. Geological Complexities

The northward movement of the Indian Plate has caused the folding and faulting of rocks in Nepal resulting in the uneven and fragile topography. High peaks and elevated land are the result of crustal thickening by the folding of rocks. Folding is the result of compressive stress whereas in the core of fold, both extension and compression stress play the role. Thus, the core of the fold is a weak zone. Landslides and slope failures are frequent in the cores of folds in several places of Nepal. For instance, Ramche Landslide in Nuwakot-Dhunche road lies in the core of Gorkha-Kuncha Anticlinorium. Similarly, faults and thrust planes are weak zones and also they form a shear zone of considerable width. In these zones, weathering of rocks can reach a greater depth and decrease the rock mass quality. Also, the deep seated landslides or the large block failures in the rocky terrain may have formed the weak zones along the sliding plane. Such weak zones in response to water can cause failure of the rock blocks or slope masses as the increase in pore water pressure increases the driving forces for slope failure. Likewise, the long monsoon can increase the groundwater table and ingress of water or water leakage through these permeable zones can bring considerable challenge during the underground constructions. Hence, detailed geological mapping and investigations are crucial in faulted and folded zones before the planning as well as constructions of engineering structures.

Moreover, the difference in the lithology has also been a cause for engineering issues. In the region of competent and weak rocks, weak rocks are easily weathered and eroded causing the failure of structures. For instance, in the area having alternating layers of sandstone and mudstone, a weak mudstone layer is washed away in response to water resulting in the overhung sandstone bed or the sliding of sandstone beds. Likewise, in the region of calcareous rock terrain, the dissolution in the rock can reduce the shear strength as well as overall quality of the rock mass. In the region of alluvial deposits like Terai regions and valleys like Kathmandu, over exploitation of groundwater can cause the subsidence of land. Also, the attitude of major discontinuities is the important parameters to be considered during the planning of engineering structures.

2 .Rainfall and related hazards in Nepal

Rainfall can be the reason for disasters like floods and landslides. Landslides are a serious problem in Nepal because most of the area of Nepal is either hill or mountain. Geological, morphological, physical and human causes are four main reasons for the landslide in Nepal. Geological causes can be due to weak, fractured and weathered rock types. Morphological causes can be due to steep slope, toe cutting of slope by erosion or tectonic upliftment. Heavy rainfall, earthquakes and ice melting can be the physical causes for landslides. Unscientific land use, road or tunnel construction, deforestation and mining can be the human causes for the landslide. In Nepal, 12mm/hr rainfall for 10 hours is enough to trigger landslides whereas average 2mm/hr is enough for triggering landslides if rainfall continues for 100 hours. In the same way, 144mm of rainfall within 24 hours is sufficient to activate landslides in Nepal. (Dahal et al.).

The kagbeni disaster of 2023 is the result of damming of Kag River by landslides in the upstream which on bursting causes devastating damages. Likewise, one of the reasons for the devastating disaster in 2021 by flooding in Melamchi flooding is the landslide damming upstream of Melamchi River. Likewise, frequent landslides in several places in Jomsom-Beni road during the monsoon period is the result of weak geology along the section. Moreover, most of the roads in the himalayan region are along the river corridor. Most of the rivers are steep and during the monsoon, high discharge with high velocity intensifies the river bank erosion.

3. Seismic Hazard in Nepal

The impact of an earthquake covers a wide area so it can be considered as the most disastrous hazard. The destruction is widely spread in case of large earthquakes. Even the earthquake that occurred beyond the territory of Nepal can have a severe impact. The major earthquakes over the last century are shown in table 1. Besides, the 2015 Gorkha earthquake is another example.

Table: Major Damaging earthquakes and their casualties (Chamlagain, 2009).

Place	Date	Magnitude	Casualty
Shillong Plateau	Jun 12, 1897	8.7	About 1542 people died.
Bihar-Nepal border	January 1, 1934	8.4	>10,653
Quetta, Pakistan	May 30, 1935	7.6	About 30,000
Assam, India	August 15, 1950	8.6	1500
Udayapur, Nepal	1988	6.5	1000 Approx.
Uttar Kashi, India	October 20, 1991	6.6	>2,000
Chamoli, India	March 29, 1999	6.8	>150
Hindukush, India	November 11, 1999	6.2	no death reported
Kashmir, Pakistan	October 8, 2005	7.6	74,698

Nepal lies in the central part of the seismically active Himalayan Orogenic Belt. Geologically, Nepal is divided by four mega fault structures as Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT) and South Tibetan Detachment System (STDS). They are the parts of basal decollement Main Himalayan Thrust (MHT). MBT and MFT are active thrust. These faults extend throughout the Himalayan Belt. The seismic zoning map shows the high peak ground acceleration values in Western Nepal in the Himalaya regions (Parajule et. al, 2021). Likewise, high seismic activities and active faults are concentrated near the zones of MCT. The northward convergence of the Indian Plate beneath Eurasian Plate has resulted in several active faults in the Himalayan Belt. These faults are mainly concentrated along the major thrust belts (Chamlagain, 2009). In the faulted areas, monitoring of faults is quite essential as fault itself is a weak zone and if there is movement of blocks, then structures in such zones can fail. One of the major associated hazards related to earthquakes is liquefaction that can cause loss of lives and damage to structures in the areas of sediments fill valleys. For instance, during the 2015 Gorkha Earthquake, liquefaction was observed in 12 different locations in the Kathmandu valley in the form of sand blows and lateral spreading (Gautam et. al, 2017). Liquefaction, landslides, foundation failures, fault rupture, ground shaking, and ground rupture are the other associated hazards that can be triggered by earthquake.

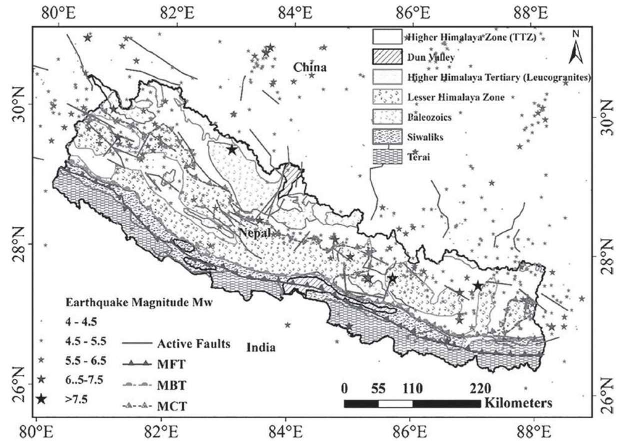

Figure 3: Geological Map of Nepal showing active faults and decluster catalogue (Dahal, 2006)

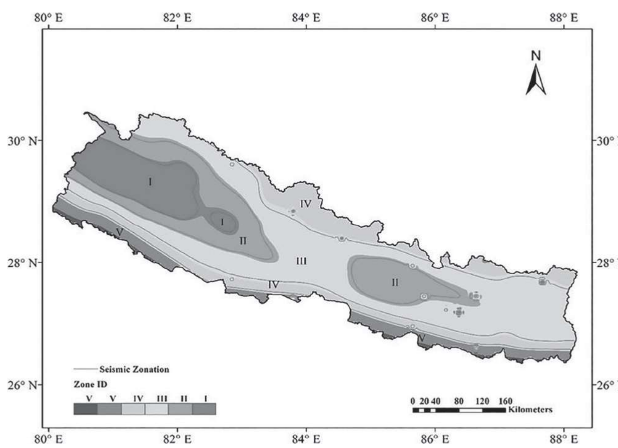

Figure 4 : Seismic Zoning map of Nepal (Parajuli et. al, 2021)

Conclusion

The geology of the given area gives the foundation for any infrastructural project. Knowing geology means having power to predict future of the project. From the numerous literatures review it can be concluded that Nepal is not deprived of geohazards due to its complex geology. We cannot change the geology of the area but we can utilize maximum potential of the earth reducing hazards if we know how rock mass will behave for the particular project. The rock mass on itself is not a problem the way we try to manipulate the rock mass is the problem. The major engineering geological complications according to the geological divisions are as follows:

Terai: Due to the presence of flat land and sudden elevation changes Terai is prone to flood and debris flow. The river in Terai carries large amount of sediments from the northern part and deposit towards the southern part which can causes river to shift the channel frequently posing threat to roads, bridges and settlements.

Siwaliks: Siwalik is prone to the geohazards like erosion induced landslide and debris flow due to the presence of weakly cemented and fragile rock type. Landslide in Siddhababa section of Siddhartha Highway is the best example of geological issue in Siwaliks.

Lesser Himalaya: Lesser Himalaya is highly critical area for problems like landslide due to the steep slope, higher elevation and higher precipitation rate. This area is highly folded and faulted due to the tectonic activity. Deep seated landslide in this region is posing serious issues on infrastructure and settlements. Landslide in Muglin-Narayanghat road section, Jogimara landslide are best example of geological issue in Lesser Himalaya. Valley like Pokhara is facing problem of caving and sinkhole formation due to the presence of karst topography.

Higher Himalaya: Even though rock types in Higher Himalaya are competent overall rock mass seems weaker due to the fracturing, folding and faulting resulting from tectonic movement. Glacial lake outburst flood (GLOF) can also occur in this region. Landslide is common in this region due to highly fractured and deeply weathered rocks.

Tibetan Tethys zone: Due to dominance of sedimentary rock this zone is susceptible to weathering and erosion is done by strong wind. Due to the long-term tectonic movement this zone is highly folded and faulted. Dry landslide, debris flow, flash flood and GLOF are common in this zone.

Recognition of suballuvial structures and their impacts on flood should be studied well and plan accordingly to mitigate flood. (Wierzbicki et al. 2018). Most of the landslide caused by construction activities can be controlled by the proper alignment of road and tunnel considering geology and geological structures. Researching in the field of seismology and engineering, investing on research, training and human resources development should be enhanced along with mapping of the earthquake hazard and linking these maps with the development plans and activities to reduce seismic hazards in engineering projects during and after the completion. (Chamlagain 2009).

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