NATHPA JHAKRI HYDROELECTRIC PROJECT – A CHALLENGE TO BOTH – GEOTECHNIQUE AND GEOPOLITICS.

Abstract

Landslides in the Sutlej valley, particularly at Nathpa and further upper reaches of Sutlej River have been most frequent. These slides can be attributed to many geological factors. Having mega-projects in such regions of unstable valleys is a daunting and challenging task, as it requires much more technical and other skills to provide a viable and purposeful project. Nathpa hydroelectric project is one such project, which is currently underway. Bhaba power project (power house) has already been commissioned for more than a decade back which is situated nearly 10 Km. up from Nathpa Dam site. Apart from natural causes, human activities have also been causing great concerns for the longevity and purposefulness of such projects. While natural factors can be taken care off using more advanced geotechniques; the threat caused by human beings is a matter of political solution between the parties involved across the international boarders, particularly in view of heavy floods triggering landslides on 1st August 2000.

Introduction:

Himachal Pradesh is mostly a mountainous terrain of varied landscape. Landslides are common phenomena in this state; particularly in the geodynamically active region of Sutlej valley, along National Highway Number – 22 that are fragile due to tectonically active, folded, faulted and crumpled rock formations. Establishment of extensive road network, besides causing the economic emancipation of the region through tremendous development activities has led to increased human intervention with the

surrounding environment. As a result of such alterations, occurrences of landslides and other road maintenance related problems have become a perpetual problem in hilly areas. This region is subjected to earthquake tremors, which have also played greater role in the configuration and resulted in carving of the present topography of the region.

The area is located in Kinnaur district, nearly 35Km from Rampur and 175Km from Shimla. The area lies between $31^{0}33'$ N to $31^{0}35'$ N latitudes and $77^{0}45'$ E to 77^{0} E longitudes. The area can be approached by road network, which connects Nathpa Jhakri to Delhi via Rampur, Shimla, Kalka and Chandigarh. However, through railway one can only reach up to Shimla.

Nathpa Jhakri Hydroelectric Project presently under construction in Sutlej basin envisages the construction of 60.5 m. high concrete gravity dam across the river Sutlej. Figure 1 shows the plan of the Dam and underground silting basins. The proposed dam is about 900 m downstream of the confluence of the river with that of the tailrace tunnel of the existing Bhaba Hydroelectric Project. The valley at the dam site is narrow and has exposed rocks on the left bank (Plate 1). At dam site, the river flows in a narrow gorge about 40m wide at the riverbed level and about 100m wide at the top level.

Necessity for slope stabilization arose in the light of occurrence of massive rockslide in July 1993 on the Right Bank just up-stream of the dam axis (Plate 2). The debris blocked the proposed inlet of the Nathpa Jhakri divergent tunnel. This rockslide has probably been caused due to some undercutting in the Right Bank and excessive rock water pressure in the slope forming materials. The massive slide of 1993 has given a warning to all those involved in Nathpa Jhakri Project that slides may occur in this region as one set of joints present in the rock is dipping towards the valley at both the banks. Stabilisation condition is more crucial for left bank because of exposed rocks. As such, any deep excavation on the left abutment for the construction of the dam or intakes need therefore be taken only after insuring that the bank is stabilized. Exploratory drift on left bank has revealed three bands of biotite schist close to the left abutment, which are dipping towards the valley. Any under cutting of these

bands and also vulnerable joint planes may cause slide if proper stabilization measures are not taken in advance. Stabilisation measures need also to ensure the safety of the exiting Indo-Tibetan Road (NH-22) on the bank.

Apart from natural causes, human activities from across the boarder have also been responsible for triggering floods followed by landslides (Gupta, 2001). At 1.30AM on August 1, 2000 a 50 feet wall of high water tore into the mountain gorges of Kinnaur, Shimla and Mandi districts in Himachal Pradesh washing away everything that came in its path. More than 100 persons lost their lives, 120Km of strategic Old Hindustan-Tibet Highway (now National Highway 22) was washed away and 98 bridges of various sizes and shapes were completely destroyed. Official estimate of the loss was nearly 200 million rupees. The Nathpa Jhakri Hydroelectric Project was worst hit. Water entered the turbine section of the 1500MW multicrore project, setting it back by more than three years apart from heavy financial loss. Kinnaur district, famous for its apples and alpine landscape, remained cutoff from rest of the country for several weeks.

The present study is intended to investigate the causes of slide and their preventive and remedial measures in order to have a safe, long-lasting and productive Nathpa hydroelectric project. Whereas engineering geological techniques can help in correction and prevention of these slides, a strong political resolution between India and China is also of utmost importance to reduce the furry of flood and associated landslides. Since the upper reaches of Sutlej are in China, only a bilateral agreement mainly in form of 'advance warning system' can reduce the damage to life and property to an appreciable extent.

Geology and Stratigraphy

The granitic, gneissic and schistose rocks of Central Crystalline Zone in the southern part of Higher Himalayas, exposed at Jeori, Nathpa, Wangtu, Karcham, Sangla, Kalpa, Spilu and adjoining areas of Sutlej and Baspa valley have been investigated and classified into Wangtu Gneissic Complex, Karcham Group and Haimanta Group on the basis of lithology, rock association and tectonic setting. The Wangtu Gneissic Complex represents the oldest basement exposed in this part of the Himalaya and is of deep crustal origin. The klippen of Jutogh rock in the Lesser Himalayas, especially that of the Chor area, is comparable with the Karcham Group. The geology and stratigraphy have been studied by many workers incuding Sharma (1976), Sharma (1977), Sreedhar et al. (1984), Srikanta (1981), Bassi (1989) and several others. Table 1 gives the geology and stratigraphy of the area and figure 1 shows the geology and structure of the site.

Nature of landslide in the area

Most of the landslide activity in Kinnaur district of Himachal Pradesh is mainly

confined to postglacial and periglacial deposits and geologically weaker areas. The peculiarities of physiographic and climatic conditions have a major role on the type and intensity of landslides in Kinnaur district.

Physiographically the valley slopes in Kinnaur district are mainly of two types:

(i) Periglacial and glacial slopes: - Periglacial and glacial slopes are characterized by gentle slope at upper and middle part of the valley covered by periglacial and post glacial material. Different types of movements in these slopes are basically controlled by geological formations, overburdens and hill slope hydrology.

(ii) Neotectonic slopes: - Neotectonic slopes are developed below the periglacial and glacial slopes and are characterized by the deep gorges along the main channel courses. The continuous vertical uplift and changes in the base level of channels provide the necessary energy for the rapid down cutting by the river. This has produced the straight cliffs along the harder geological strata below the periglacial and glacial zone. Along the weaker formations in this zone, translational slides dominate whereas rockfall is common along the harder strata from upper slopes and toe erosion accelerates the mass movement in this zone.

Slides related to neotectonic slopes are most common type of mass movement near Nathpa Dam site. These movements could be of three types,

(i) Rock slide along predetermined surfaces

(ii) Long continued deformations of mountain slopes

(iii) Rock falls.

Rock slides on foliation planes or other such surfaces of separation (e.g. Bedding planes) may be very disastrous in mountain areas where there are great height differences, as the acceleration of movement may proceed at a high rate, similar to that of rockfalls.

The Nathpa slide

Two major landslide occurrences took place at Nathpa in recent times, one on each side of Sutlej Valley. The one located on the left bank towards the lower hill, west of Nachar Village, is more commonly known as Nathpa slide. This landslide occurred in 1989, affecting an area of about 90,000 to 1,00,000sq.m of land. It damaged about 700m of road length of NH-22 at its base and more than 300m of hill slope. The slided boulders were quite big in size and their removal from the road required blasting. The slope failure process had created alarming situation and slide is still active in nature. Average width of the slide was about 280m to 300m, while from toe to crown; it was about 300-325m in length.

The landslides can be divided into two parts. The lower starting from NH-22 up to a distance of about 100m towards uphill (Plate 2), where the slope angle varies from 50degree- 80 degree. The second part, extend further upward up to a distance of about 200-225 meters i.e. up to crown of the slide. The slope angle in lower portion of this part of slide varies from 20^0- 40^0. While towards crown portion, the slope becomes steeper (40-80 degrees) A number of tension cracks have been reported along the hill slope, further uphill side of the crown indicating thereby instability conditions of the material forming the slope. At the root area of the slide, bedrock is covered by thick blanket of past glacial and periglacial deposit. The slide is endangering the private property and land lying on the uphill side and contributing great amount of sediment to the Sutlej River.

On the right bank, a massive rock slide took place in the month of July, 1993, just upstream of the proposed dam axis, thereby blocking the river and raising it's water level which resulted in closure of existing upstream Bhaba power project situated 5kms upstream of proposed dam axis. The debris also blocked the proposed inlet of the Nathpa Jhakri diversion tunnel. The slide has upset the construction programme of the dam and also delayed the completion of the diversion tunnel. The occurrences of landslides, some 100m upstream the Nathpa dam site has been examined in the light of various causative factors of landslide as given by C. Vedar as (I) High relief and steep slopes (slope category), (II) Extensive development of weak rocks (Lithology, Petrography and Mechanical strength of rock), (III) Heavily fractured rocks because of folding and faulting (Sructure) and their weathering due to precipitation, (IV) Undercutting of the banks by deeply incised rivers and streams and, (V) Seismic activity.

Slope category map: A slope category map delineates and separates areas occupied by slopes of different angles. As slope angles change frequently, it is almost impossible to represent a slope at every point, thus the slope category maps depict average inclination values over an area.

A slope category map (Figure 3) of the proposed Nathpa dam site has been prepared. Slope angles have been calculated at 130 points and suitable class intervals have been chosen. This map reveals a simple slope pattern. The slopes in the entire area range between 5-55 degrees. In this valley topography, the slope angle increases, as one move upward from the valley bottom. While in the south facing valley side, slope rises gradually from valley bottom (25-40 degrees) the eastern part of the north facing side has less inclination as compared to its western part, which rises abruptly from the riverbed (40 degree).

Slope category: Slopes depending upon their inclinations have been categorized into nine (Demek, 1967) and eight (Kertesz, 1979) different types. Six slope categories have been identified in the study area.

Areas occupied by different slope classes have been statistically analyzed (Table 2). Figure depicts the relative areas occupied by slopes of different inclinations.

Table 2: Frequency table, slope categories

S. No.	Class Interval (in degrees)	Frequency (Number of grids)	Relative Frequency	Cumulative Frequency	Relative cumulative Frequency
1	<10°	5	4.88	5	4.88
2	10°--20°	11	9.84	16	14.72
3	20°--30°	33	28.92	49	43.64
4	30°--40°	40	35.24	89	78.88
5	40°--50°	21	18.42	110	97.30
6	>50°	3	2.68	113	99.98

The total surface covered by the study area is 134622sq.m. Approximately 65% of the area is covered by slopes ranging between 20° to 40°. Slopes of 30° to 40° are most frequent and constitute approximately 35% of the area. Area with slope angles greater than 40° constitute 20% and those with angles between 10° and20° constitute 10% of the area. Areas with angles less than 10° constitute 5% of the area. Since 80% of the area has slope varying between 25°

and 55°, the zone is susceptible to landslide and need further analysis.

Mechanical strength:

Mechanical strength of rocks was determined by means of Schmidt Rebound Hammer test, which determines the uniaxial compressive strength. The uniaxial compressive strength can be computed from SHV by using the equation,

UCS= 7.752SHV - 213.349 (Irfan and Dearman, 1978)

The data has been tabulated in table 3:

Table 3: Results of Schmidt rebound hammer test

(A) Rock type: Quartz Biotite Schist (Dry density = 2.43)

S. No.	SHV	Compressive Strength (M Pa)
1	23	28.5
2	22	27.2
3	25	32.6
4	24.5	30.5

(B) Rock type: Amphibolite (Dry density = 3.1)

S.No.	SHV	Compressive Strength (M Pa)
1	36	90
2	33	72
3	34	80
4	33.5	78

Rock type: Augen gneiss (Dry density = 2.9)

S.No.	SHV	Compressive Strength (M Pa)
1	30	58
2	32	64
3	32.5	67.5
4	32	64

Structure: The entire sequence of rock formation exposed in the area under study has undergone major deformations due to numerous tectonic movements taken place during orogeny of Himalayas. This process have rise to development of thrusts, faults and folds. Nature of bedrock and its deposition, particularly sloping foliation planes and joints planes constitute another frequent cause of landslide. Sometimes these discontinuities are so arranged that they separate number of blocks of the bedrocks, which are left free to move in downward direction. This process of slope failure leads to rock slides or rock falls.

Jeori-Wangtu Gneissic complex, to which belong the rock types exposed in the study area, constitute the northern limb of Dras syncline. The rocks of this complex have undergone deformation whereby primary structures in the form of bedding and compositional banding gave way to secondary formed foliation in newly rock types (Schist, Gneissose schist and gneisses). The attitude of foliation varies with strike changing from N70ºW to N70ºE and average dip being 35º-55º à N. At Negulsari and Sholding Khad, the general attitude of foliation as NW-SE/35º-65ºàNE. At Sungra, the general attitude is E-W/35º-50ºà N.

The overall rocks at dam site area have foliation, striking N75ºW-S75º E and dipping 45º- 55ºà N. The foliations are dipping towards valley side exhibiting thereby typical dip slope topographical feature. These steeply dipping formations are highly jointed and at places shattered and fissured in nature. These schist bands and set of joints are dipping towards the river, are vulnerable for sliding. The foliation

joints are at 1 to 2m spacing or even less at places. Some of the foliation joints which are associated shearing contain gauge. These joints are quite open and widely spaced as shown in the photograph. The opening varies from less than 1mm to 30mm. However, some of these joints are quite open and their widths vary from 30-50cm. the foliation joints from the major plane of failure, on left bank. Similarly a southerly dipping joint with strike S80°E-N80°W and dipping 30°-40° into the valley from the plane of separation on the right bank. They are simple cases of wedge or planner failure where, the southerly dipping joint or foliation joint in association with following set of joints (release surfaces) cause failure. The foliation plane joint in its continuation from the left bank, dip into the right bank slope. The wedge forming joint sets show mark of seepage marks, which though not wet during the period of investigation, must be becoming active during rainy season. These seepage points are more numerous in discordant pegmatite vein.

The overall picture emerging out of lithological and structural study is that the richness of mica content, crushing and major shear planes has made these slides very problematic and unstable. The weathering of gneisses and crushing of country rock along shear zones have produced micaceous clayey material, which swells on wetting and provides lubricated surface for the sliding material during the rain.

The landslide on the left bank is reported to have been triggered during heavy downpour in the area in monsoon season of 1989. Large quantity of water percolated in to the overburden material and ingress of this water into weak formations is considered to be the major factor initiating the process of slope failure. The steeply dipping rock formations, which are considered prone to landslide due to presence of a number of intersecting joint planes, have also been considered to have contributed to a great extent in creating the instability of the said hill slope in the form of wedge failure. Since, both insitu bed rocks and overburden materials forming the hill slope are found involved in the slope failure process, the slide as a whole therefore, can be classified as rock – cum – debris slide type of landslide. The various planner features and their attitudes have shown in the structural map prepared (figure: 3). The structural and geological details along with

stabilization considerations of both banks are shown in the cross-sectional diagrams (figures: 4&5)

Seismicity: the study area comes under seismic zone IV as inferred from seismic zoning map of India. It has been found that the value of peak acceleration in this region is 0.6g. Though this magnitude of the earthquake in itself is not very large enough to induce landslide in the hill slope but tend to promote the landslide potential as initiated from geological and hydrogeological factors. Both geological factors and seismic activities tend to promote each other for inducing landslide in the cut slope in residual soil and weathered rock. This region has in past, been subjected to earthquake tremors, which have played a great role in the configuration and carving of the present topography. The Kinnaur earthquake of magnitude 7 on the Richter scale, which occurred on 19th January 1975, rocking some parts of Kinnaur and Lahaul-spiti districts of Himachal Pradesh, caused considerable loss of life and property. This earthquake, which is considered to be due to release of strains accumulated along Kaurik fault, brought about lot of changes in tectonic- magmatic history of rocks and structures present in the vicinity and activated a series of land slides in the region.

Human Factor: Indian Space Research Organization (ISRO), on the basis of careful examination of satellite imageries of river basins in Tibet, deciphers that the floods of August 2000 were result of human activities from China. ISRO scientists pored over multidate satellite data to investigate the causes of the flash floods. Around 25 satellite imageries were analyzed. These pictures showed the presence of huge water bodies or lakes upstream in Sutlej basins before the flash floods took place. However, these lakes disappeared soon after the disaster struck Indian Territory. This probably indicates that the Chinese had breached these water bodies as a result of which lakhs of cusec of water were released into Sutlej river basin. ISRO has even pin pointed this lake at latitude 30.15^{0} North and longitude 94.50^{0}

East. The Nathpa Jhakri Hydroelectric Project was worst hit. Water entered the turbine section of the 1500MW multicrore project, setting it back by more than three years apart from heavy financial loss.

Preventive and remedial measures: Hill slopes, whose formation consists of jointed rock beds dipping into valley or where large number of boulders is present, form sources of rockslide and rock falls. The study area, which though made up of moderate to highly fractured gneissic and schistose rocks, form a stationary hill slide. The transition from a stationary hill side to an active slide could be contributed to the following reasons:

1. Construction of double formation road on the same slope.

2. Use of blasting material.

3. Interference with water reseme of the destabilized slope.

Keeping in view of the various observations made during inspection, which has been discussed above, the following suggestion can be made for the stabilization of effected hill slopes.

1. The widening of the road should be stopped immediately.

2. Loading of the slope uphill side of the national highway should be avoided and the slide material should be damped away from the slop involved in the slide.

3. The percolation/ingress of the water into overburden material/joint planes is considered to be major factor for creating the instability. The water, therefore, shall have to be intercepted before it flows down to slide portion. Constructing a catch water drain all along the upper periphery of the slide may do this.

4. It is also suggested to construct flexible retaining structures by providing wire crates at the base of the crown.

5. Asphalt mulch treatment should be tried to stabilize the slope adjoining the cultivated lands to check further erosion.

6. Local vegetation should be grown to act as effective binding material and to check downward movement of loose material.

7. In order to pin down the unstable insitu bedrock exposed along the affected hill slope with underlain stable bedrock, it is suggested to provide widely spaced rock bolting along with low pressure grouting.

8. The toe cutting at the base of Sutlej should be checked in order to minimize the movement of slided mass.

9. All the loosely held big boulders lying along the hill slope removed by resorting to control blasting and this should be done before implementing the above recommendations.

10. Considering the conditions existing in the area, the use of geogrid is recommended to effectively check the rock fall.

Stabilization measures

Reinforcement in the form of plug, rock bolts and cable anchors are required to prevent sliding. These measures however, should be preceded by certain preliminary measures which include,

(i) Removal of the overburden loose material to a minimum extent and,

(ii) Toe retaining wall with adequate drainage arrangement.

Rock bolts are being used in the right bank in order to stabilize the southerly dipping joint planes. The strength, numbers and spacing of the bolts and anchors are decided according to the magnitude of the disturbing force and estimated value of shear parameters along joint planes.

Conclusion

Landslides are common phenomena in the mountainous terrain and are of major concern among natural disasters, which frequently strike the life and property. Himalayan region has become a perennial source of landslide or other mass movement activities and this very fact has drawn the attention to the importance of problem, strategy of remediation, protection and preservation. In the planning of developmental schemes in such terrain, existing instabilities of the slope should be taken into consideration so that the scheme may be executed with minimum disturbance to the environment of the area.

The geology of the area of study comprises of Wangtu gneissic complex, which comprises of banded, augen and porphyroblastic gneisses with thin schistose and thin sheets of pegmatite and amphibolite. The terrain is sparsely vegetated and at many places valley has exposed rocks. The gneisses show four sets of joints and two of which, one of each bank, deep into the valley at an angle less than the slope face. The other joints behave as "release surfaces" which together with joints dipping into the valley induce planar failures in insitu rocks, which is confirmed by stereographic evaluation of slope instability. Occurrences of landslides are more common where slope angle and relative reliefs are very high. Landslides are very prolific along NH-22 highway Road construction is the most important anthropogenic cause for slope failure. Hence proper geotechnical investigation must be carried out before laying the road network. Suitable remedial measures such as shear plug, rock bolting, and cable anchoring can be made to prevent landslides.

While natural factors can be taken care off using more advanced geotechniques the threat caused by human beings is a matter of political resolution between the parties involved across the international boarders, particularly in view of heavy flooding on 1st August 2000.

Nathpa Jhakri Hydroelectric Project   Nagarjunasagar and Bhakra Dams

Class Notes on Dams 1 Class Notes on Dams 2 Class Notes on Tehri Dam

-