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Engineering geological study of the Kali Gandaki 'A' hydroelectric project area, western Nepal Lesser Himalaya

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ABSTRACT

The Kali Gandaki 'A' hydroelectric project area lies in the Lesser Himalayan Zone of the Syangja district of western Nepal. The rocks are characterised by highly deformed, thick sequences of the clastic rocks belonging to the Andhi Khola Formation and the carbonates of Darsing Dolomite, both belonging to the Kali Gandaki Supergroup. The dark bluish grey, brecciated and highly fractured dolomite is exposed on the abutments of the proposed diversion dam site area. It also forms steep cliffs to the north of the dam site. The contact between the dolomite and the overlying phyllite is a tectonized zone. This contact exposed along the exploratory adit and test trenches gives evidence of a fault dipping steeply towards the east. The phyllites exposed along the proposed headrace tunnel alignment and in the powerhouse site are variable in composition and rock strength. At the powerhouse area thin bands of limestone are intercalated in phyllites with sheared contacts. The headrace tunnel alignment makes acute angle with the foliation along most of the length and some sections passes parallel to the foliation. An inferred fault at about 1 km chainage, shear zones with varying thickness and a syncline at about 4 km from the intake portal are the main geological structures along the tunnel alignment which have to be carefully dealt with during the design and construction phase of the project.

INTRODUCTION

The Kali Gandaki 'A' hydroelectric project area is located in the Syangja district of western Nepal (Fig. 1). The project is a simple run-off-river type with a 44 m high diversion gravity dam on the Kali Gandaki River. The dam is proposed at about 500 m downstream from the Andhi Khola (a tributary of the Kali Gandaki River) and Kali Gandaki confluence. It diverts the water flow into an open cut desanding basin through which a 157 m long power conduit conveys the flow along a 5925 m long tunnel (7.4 m diameter) to a powerhouse cavern. The water is finally discharged into the Kali Gandaki River through three 134 m long tailrace tunnels (Fig. 1). The installed capacity of the project is 144 Mw with a daily peaking capability during dry season and the project will generate annual energy of 840 Gwh (Norpower, 1992; Kali Gandaki 'A' Associates, 1993, 1994). Field investigation during the detailed design phase was made to collect basic data to complement the investigations carried out during the detailed feasibility study to better define the geological/geotechnical conditions at different hydraulic structure sites.

GEOMORPHIC FEATURES

Geomorphologically, the Lesser Himalayan Zone is divided into the Mahabharat range, lying just to the north of the MBT and the widely depressed Midland Zone further to the north. The project area lies in the Midland Zone consisting of the calcareous and phyllitic rocks. The rocks are normally weathered to various degrees. The Kali Gandaki River and Andhi Khol are the main drainage systems that shape the area. The Kali Gandaki River flows north to south forming a deep and narrow valley up to the Andhi Khola confluence and then turns to E-W making a long loop. The streams on both east and west facing slopes show the dendritic drainage pattern. In the project area three levels of river

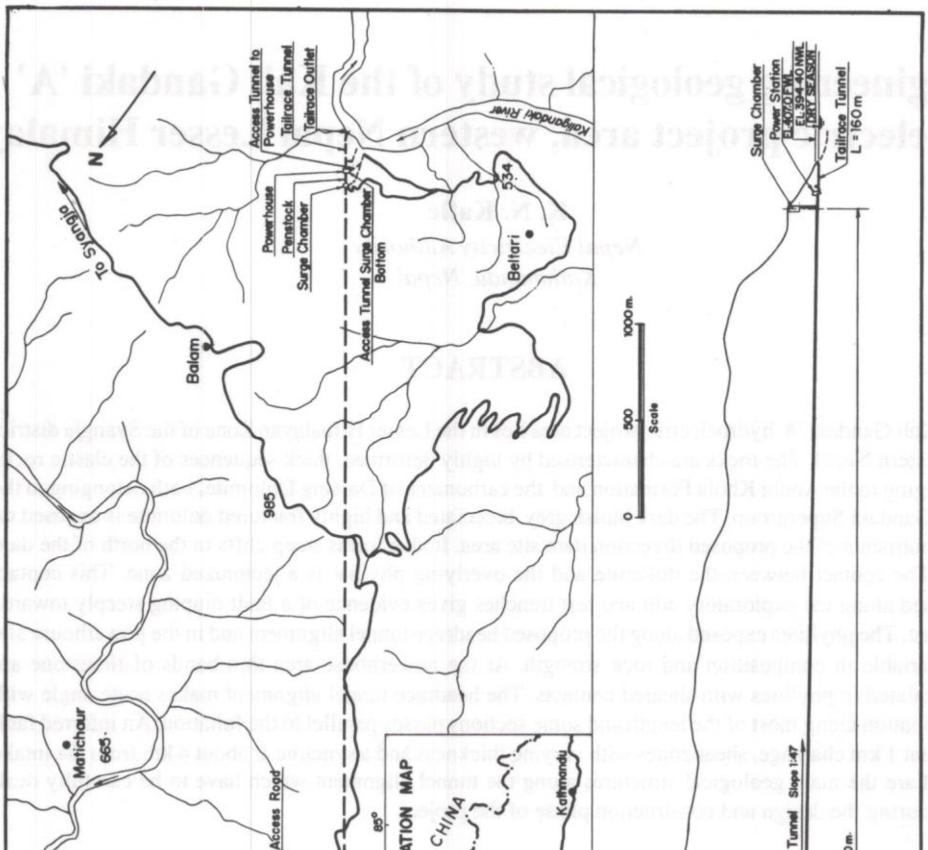

Fig. 1: Location and the general plan of the Kali Gandaki 'A' Project area.

terraces are recognised along the Kali Gandaki River. They are: the lower, intermediate and higher level terraces. The hill slopes are generally populated and most of the area is covered by cultivated land. Solution features such as solution channels, minor caves and holes are present in the headworks and powerhouse area.

The mass wasting processes are quite common in the project area and are grouped into three categories: viz., (i) rock falls and toppling failures, (ii) shallow slides and/ slope wash in soil, and (iii) deep-seated rock slides. The rock falls and topplings are quite common in dolomites especially at the dam-intake area. The second process is commonly observed in the whole project area. The deep-seated rock slides are observed only in the phyllitic rocks along the Kali Gandaki River. The existing large slide scars on the sheared, weathered and folded phyllites seem to be related to the E-W running Barigad Fault exposed on the south loop of the river.

GEOLOGICAL SETTING

The project site lies in the Lesser Himalaya of western Nepal. A 4-6 km wide Kali Gandaki depression zone forms the topographically lowest part in the area. It is bounded by the Andhi Khola Fault in the north and the Barigad Fault in the south. The Barigad Fault divides the Kali Gandaki Super Group into the inner and outer belts. The rocks found in this east-west trending depression zone lying between the Malunga village in the south and Pindi Khola in the north belong to the Kali Gandaki Supergroup of Sakai (1986). This supergroup is subdivided into four units, viz., the Belbas Slates, Syangja Beds, Darsing Dolomites, and Andhi Khola Formation in the ascending order (Sakai, 1986).

Geology of the Project Area

The project area is occupied by the Darsing Dolomite and Andhi Khola Formation of the Kali Gandaki Supergroup of Late Precambrian to Early Palaeozoic (?) age (Sakai, 1986). The dolomite is cherty in nature and is highly jointed and brecciated. It is a cliff forming rock. The formation is well exposed on the proposed diversion dam abutments, downstream of intake area and in the desanding area. The N-S trending joint set is the most prominent one. The rocks have a general NNE to SSW trending strike and dip gently towards southeast or northwest. An open fold is exposed on the slopes of both the banks and an east plunging anticline is anticipated in the foundation and intake area (Fig. 2). The contact between the dolomite and the overlying phyllite is not exposed on surface. However, the sheared, shattered, slickensided, closely jointed and tightly folded carbonaceous phyllites found inside the adit, in the trenches and core loss sections in different boreholes give evidences of a tectonic contact between the two rock units.

The headrace tunnel and the powerhouse cavern lie in phyllite of the Andhi Khola Formation. The phyllite is varying in composition and is anisotropic in character. In the upslope of the intake area, phyllite is pervasively sheared and difficult to recognize its sedimentary structures and foliations. From Mirmi to Jaipate village, the rock is more slaty in character with intercalatation of thin limestone bands at few places. From Jaipate village to the powerhouse site, sheared, tightly foliated talcose phyllite intercalated with thin (0.5 to 3 m) bands of limestone is observed. The headrace tunnel makes an acute angle to the foliation along most of its length and some sections will probably pass parallel to the foliations (Fig. 3).

The general trend of the phyllite from intake to Jaipate village is about E-W and dips towards south. The phyllite in the powerhouse area generally trends along the N-S direction and dips gently towards west forming a synclinal structure near Jaipate village (access road intersection). The exposed phyllite along the tailrace alignment is calcareous and moderately jointed. Some isolated thin (1-3 m) bands of limestone are present in the phyllite. The foliation generally strikes N-S and dips 20-60° towards west.

The major structures like the MBT and the Barigad Fault (BF) are about 20 km and 0.5-1 km south respectively from the powerhouse site. As these faults are far from headworks sites, the adverse impact due to these faults on the structures are considered to be not serious. However, the impact of the BF on the powerhouse area stability can not be overlooked.

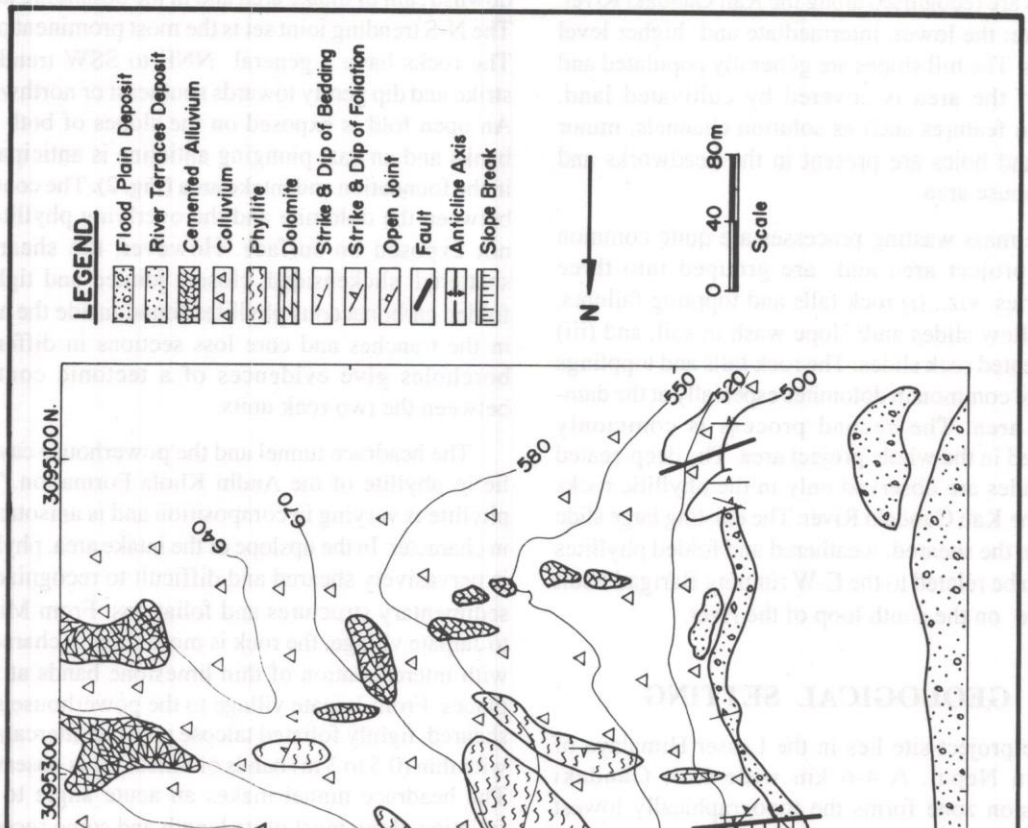

Fig. 2: Geological map of the headworks of the Kali Gandaki 'A' Project.

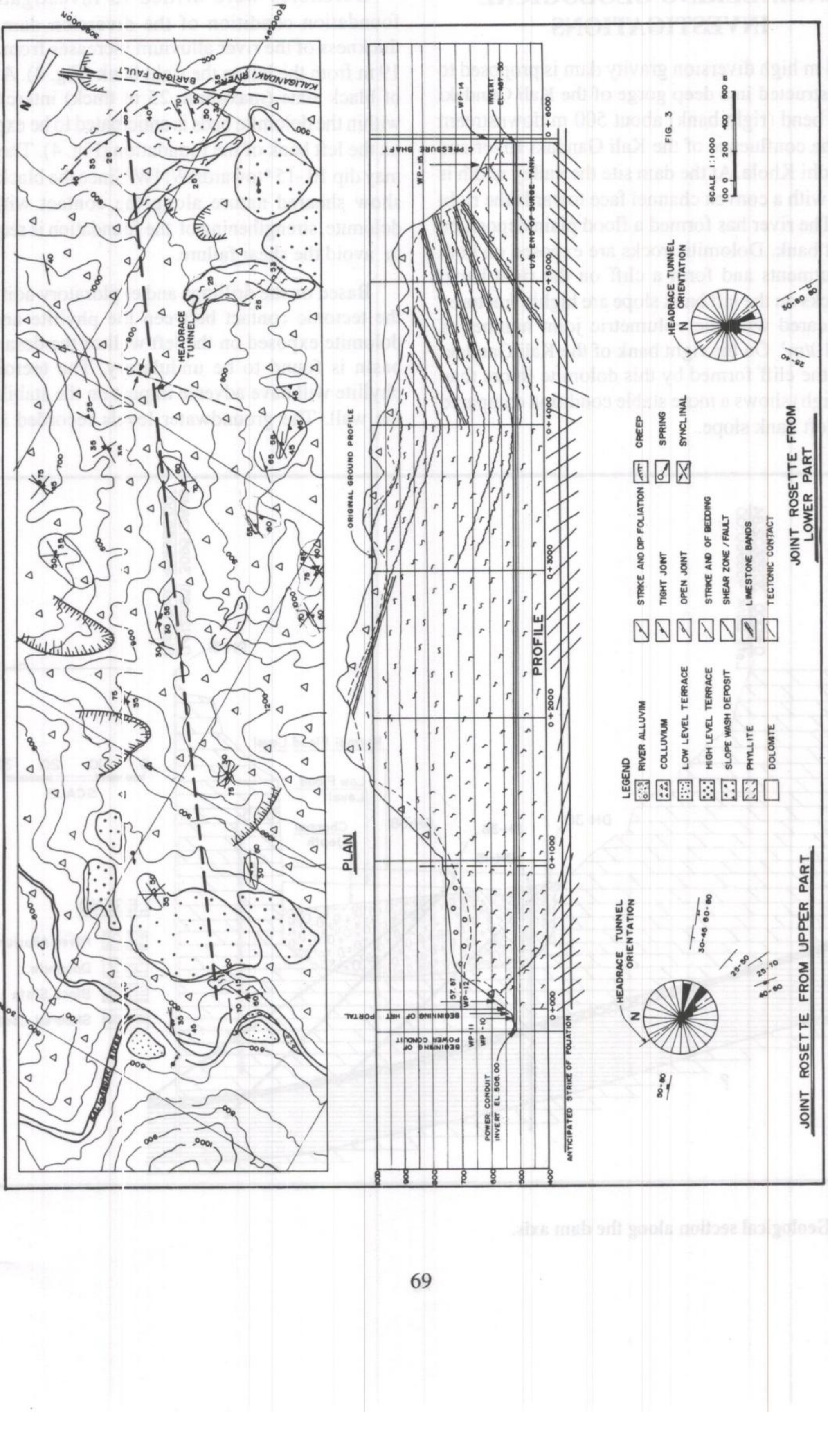

Fig. 3: Geological plan and profile along the headrace tunnel.

ENGINEERING GEOLOGICAL INVESTIGATIONS

The 44 m high diversion gravity dam is proposed to be constructed in a deep gorge of the Kali Gandaki Valley bend (right bank) about 500 m downstream from the confluence of the Kali Gandaki River and the Andhi Khola. At the dam site the valley width is 110 m with a convex channel face towards the right bank. The river has formed a flood plain deposit on the left bank. Dolomitic rocks are exposed on both the abutments and form a cliff on the right bank. The rocks on the left bank slope are highly fractured and sheared with the volumetric joint number of about $10/m^3$. On the right bank of the Kali Gandaki River, the cliff formed by this dolomite (more than 40 m high) shows a more stable condition compared to the left bank slope.

Boreholes were drilled to investigate the foundation condition of the diversion dam. The thickness of the river alluvium increases from 15 to 19 m from the left to the right bank (Fig. 4). A layer of black slate (maximum 25 m thick) intercalated within the dolomite beds is anticipated to be exposed on the left bank of the foundation (Fig. 4). The beds may dip 10 - 15 °towards WNW. Since the black slate show sheared nature along the contact with the dolomite, strengthening of the foundation is required to avoid the shear failure.

Based on the drillings and exploratory adit data, the tectonic contact between the phyllite and the dolomite exposed on the left wall of the desanding basin is found to be undulatory. The tectonized phyllite will have adverse impact on the stability of the wall. The groundwater levels recorded in the

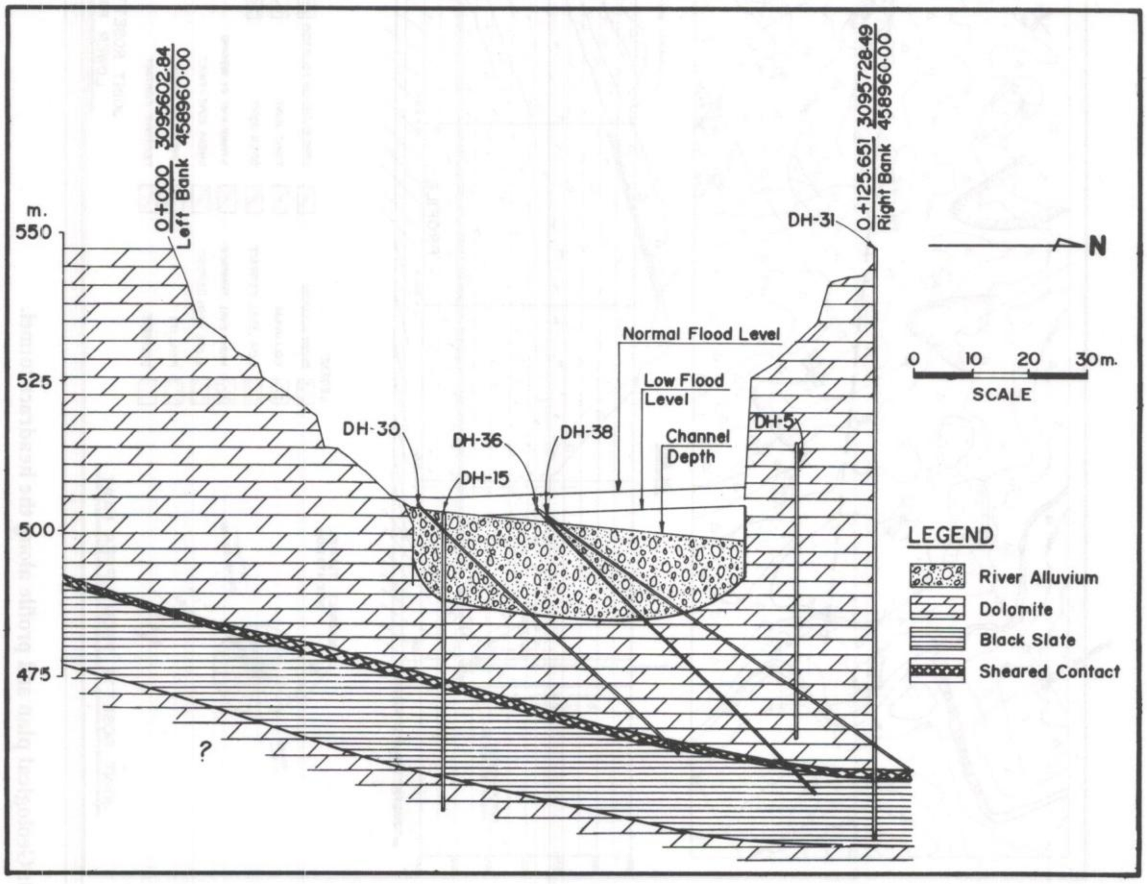

Fig. 4: Geological section along the dam axis.

boreholes show the effluent flow which may reduce the shear strength in cut slopes. Artesian condition is found in deep drill holes in the dolomites. The dolomite in the farther depth is intercalated with bands of black slates The idea to put powerhouse deep inside the dolomite as proposed in the detailed feasibility study was found to be unfavourable. Now the structures are proposed to be placed at a shallow depth to avoid the artesian condition.

In the power conduit section, the slope is covered by thick colluvium and the rocks encountered are of poor quality phyllites. The slope being unstable, necessary measures are required to stabilise it. The power tunnel inlet portal located at the toe of the convex slope is covered by thick colluvium (more than 10 m thick). The presence of a deep gully adjacent to the portal may cause stability problem.

The phyllite in headrace tunnel is characterised by variable composition and rock strength. The rocks vary from weak chlorite and talc rich schist, fissile carbonaceous slate, calcareous shale to strong, massive sections with apparent high content of silica and calcareous materials. The headrace tunnel cuts the rocks making an acute angle with the foliation along most of the length, and runs parallel to the foliation in some sections. In general, the tunnelling condition along most part of the tunnel is not favourable considering the orientation of the foliations in the rock. In such cases, both shear and buckling failure may occur. The perennial springs along the tunnel alignment may add inflow of groundwater into the tunnel.

The slope stability in the powerhouse site is mainly influenced by joints dipping towards the Kali Gandaki River Valley and those across the foliation planes. The main joint sets that strike N-S and NW-SE may cause wedge failures.

CONCLUSIONS

Based on the detailed geological and engineering geological studies of the project area, the selection of the dam site, powerhouse site and the tunnel alignment were finalised. The project area is charcterized by the presence of fair to good quality dolomite and poor to fair quality phyllites. The geological and geotechnical conditions of the selected sites in general may be considered as reasonably favourable. The enginnering geological/ geotechnical conditions of the tunnel alignment were assessed form the data collected from about 400 to 600 m above the actual tunnel level. Shear failures together with wedge failures are anticipated due to the presence of N-S and NW-SE striking joint sets. The perennial springs along the tunnel alignment may pose water inflow problem in to the tunnel.

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