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Deformation structures in central Nepal and their engineering geological significance

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ABSTRACTS

Geological maps of the Helambu-Kathmandu area and Kathmandu-Hetauda area with their suitable cross-sections are presented. On the basis of the deformation history, the deformation structures recorded from the field study as well as from the air photo interpretations are classified as continuous and discontinuous deformation structures. All types of discontinuous deformation structures are considered as discontinuities. Discontinuities play decisive role in engineering geology breaking the continuity of the mechanical behaviour of the rockmass at different scales. On the basis of spacing, width, mineral fill and extent, the discontinuities are classified into seven orders. Such classification is essential and appropriate for rockmasses, which are heavily affected by intense tectonic deformation in the Himalaya, the Alps or corresponding orogens. The study area within central Nepal is having many engineering geological problems. Stability of the rock slopes and underground excavations are two major engineering geological problems to deal here with. Significance of the different order of discontinuities in the light of these engineering geological problems are discussed. Orientation of different order of discontinuities is an important parameter affecting blasting, span width, roof support and ground water flow and related problems in the proposed tunnels in the study area. Such structures are also important factor for the stability of the natural slopes and cut slopes.

INTRODUCTION

This paper presents the result of the engineering geological studies in central Nepal from Helambu in north to Hetauda in south. The study area is located from latitude 27°25' to 28°02'N and longitude 85°00' to 85°34'E. Deformation structures are recorded from the field study as well as from the air photo interpretations. Emphasis is given to the deformation structures in following engineering structures:

- About 28 km long free flow tunnel of the Melamchi Water Scheme,
- Proposed alignments of the planned Kathmandu - Hetauda direct link road Project,
- Existing structures of the Kulekhani Multiple Hydroelectric Scheme.

The study area (Fig. 1) is a north-south profile of the Lesser Himalaya between two major regional

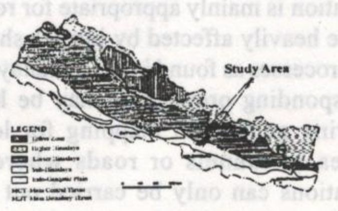

Fig. 1: Location map of the study area with major geologic divisions of Nepal.

thrusts, the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT).

Besides this, the study area also includes the southern part of the Higher Himalayan crystalline basement as well as the northern part of the Siwaliks, including Quaternary sediments of the Kathmandu valley, Chitlang valley and Hetauda Dun. Present study follows the established stratigraphic nomenclature wherever possible. The controversies about the stratigraphic sequence are supposed to be solved on the further progress of the research.

Besides the major regional scale thrusts, about ten large scale faults are mapped in the area lying north of the Kathmandu valley and about eleven considerably large scale faults are mapped in the study area south from Kathmandu. Besides these faults, frequent intraformational shear zones are found along the tunnel alignment as well as the proposed road alignment. Such zones are found at 5 to 20 m spacing and sometimes narrower in the Midland Fracture Zone. Engineering geological problems related to these intraformational shear zones are more severe in the rock units containing sandstone or quartzite and schist or phyllite or mudstone in alternating bands. The 28.7 km long Melamchi Tunnel (HMGN, 1996) and all the proposed alignments of the Kathmandu Hetauda Direct Link Road Project (HMGN, 1993) have to encounter with direct as well as indirect effect of these faults and shear zones. Regional scale, local scale, macro scale and the micro scale discontinuities are so-called weak zones, which are the major channels to release the residual stress and are also the major ground water reservoirs in the mountain aquifers of the study area.

Purpose of the present study is a proposal for a classification of discontinuities depending on spacing, width, mineral fill and extent. This classification is mainly appropriate for rock masses which are heavily affected by intense shearing and folding processes as found in the Himalaya, the Alps or corresponding orogens. It may be helpful for engineering geological mapping for long linear structures as tunnels or roads where detailed investigations can only be carried out at critical points. The major parts of such structures has to be designed and constructed on assumption being obtained from desk studies, field inspections and detailed engineering geological mapping with adequate classification of discontinuities. The mechanical parameters for such projects will be derived from sites with comparable geological structures and where rock mechanical tests were carried out.

GEOLOGY OF THE STUDY AREA

The study area is an about 5 to 10 km wide north-south profile of the central Nepal Himalaya. Lithology of the area varies from granites, variety of high grade metamorphic rocks to sedimentary rocks as well as Quaternary loose sediments. Age of the strata varies from early Precambrian to Holocene. Many controversies and debates are still under discussion about the regional geology of the area, basically about the location and nature of the MCT. The MCT is a tectonic boundary between the Higher Himalayan Crystalline basement and the metamorphic rocks of the Lesser Himalaya, but it is not easily recognisable as a sharp discontinuity in the field. The prominent regionally extending faults of the area are supposed to be branches of the MCT. Table 1 shows the tectono-lithostratigraphy of the northern part, Table 2 is of the southern part of the study area. Distribution of these geological units and major geological structures recorded in the area is presented in Fig. 2 and 3.

On the basis of the tectonic facies, the area is further divided into six units.

- Melamchi Crystalline
- Middle Mountain Fracture Zone
- Shivapuri Injection Zone
- Low grade metamorphic rocks of Kathmandu Complex (Stocklin and Bhattarai, 1981)
- Medium grade metamorphic rocks of Nuwakot Complex (Stocklin and Bhattarai, 1981)
- Zone of sedimentary rocks (Siwaliks)

For each tectonic units, the bulk deformation mechanism is related to vertical depth. Each tectonic facies has mainly three structural levels:

Upper structural level
Middle structural level
Lower structural level

The upper and middle structural levels are part of the so called zone of geological fracturing, which

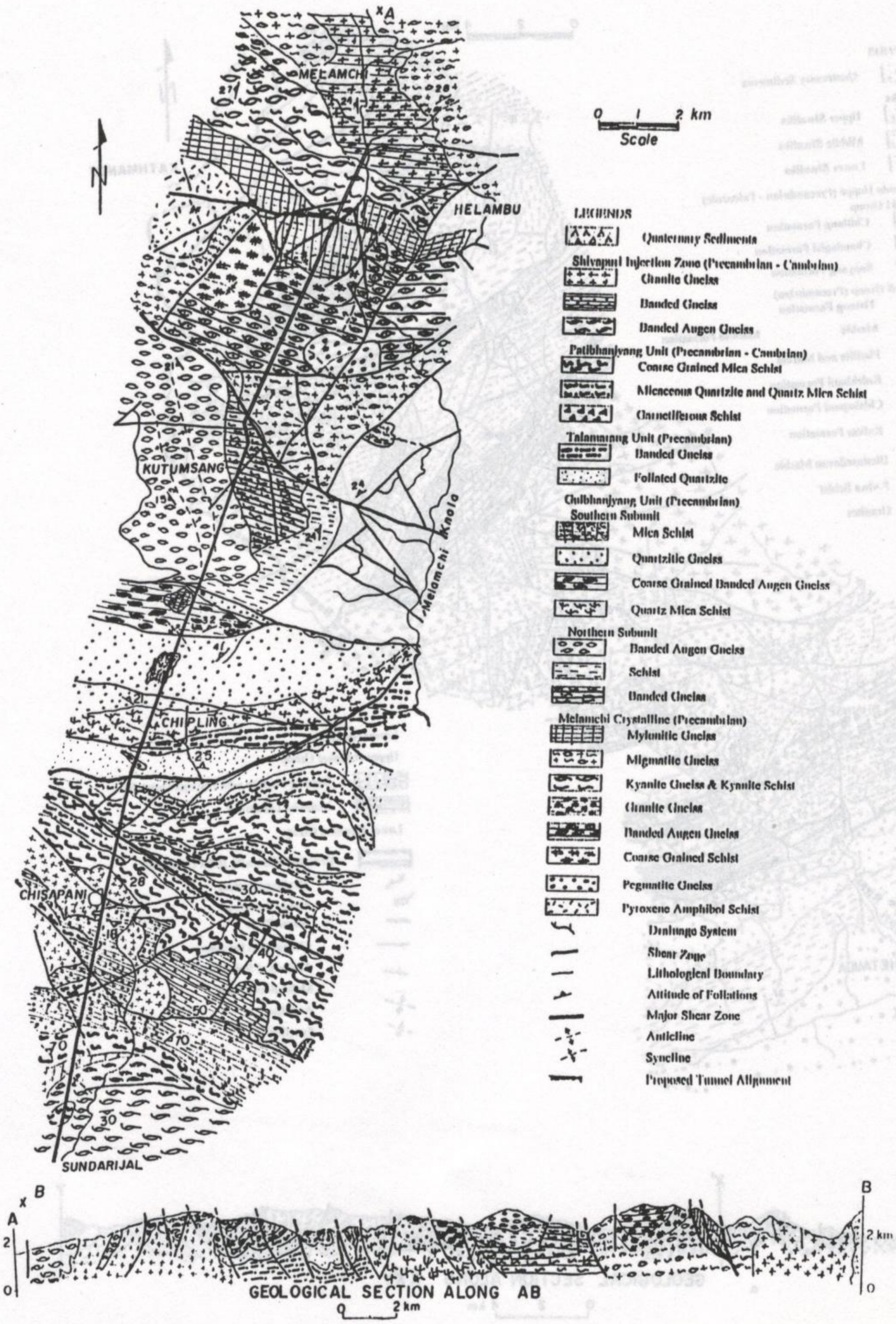

Fig. 2: geological map of Helambu-Kathmandu area.

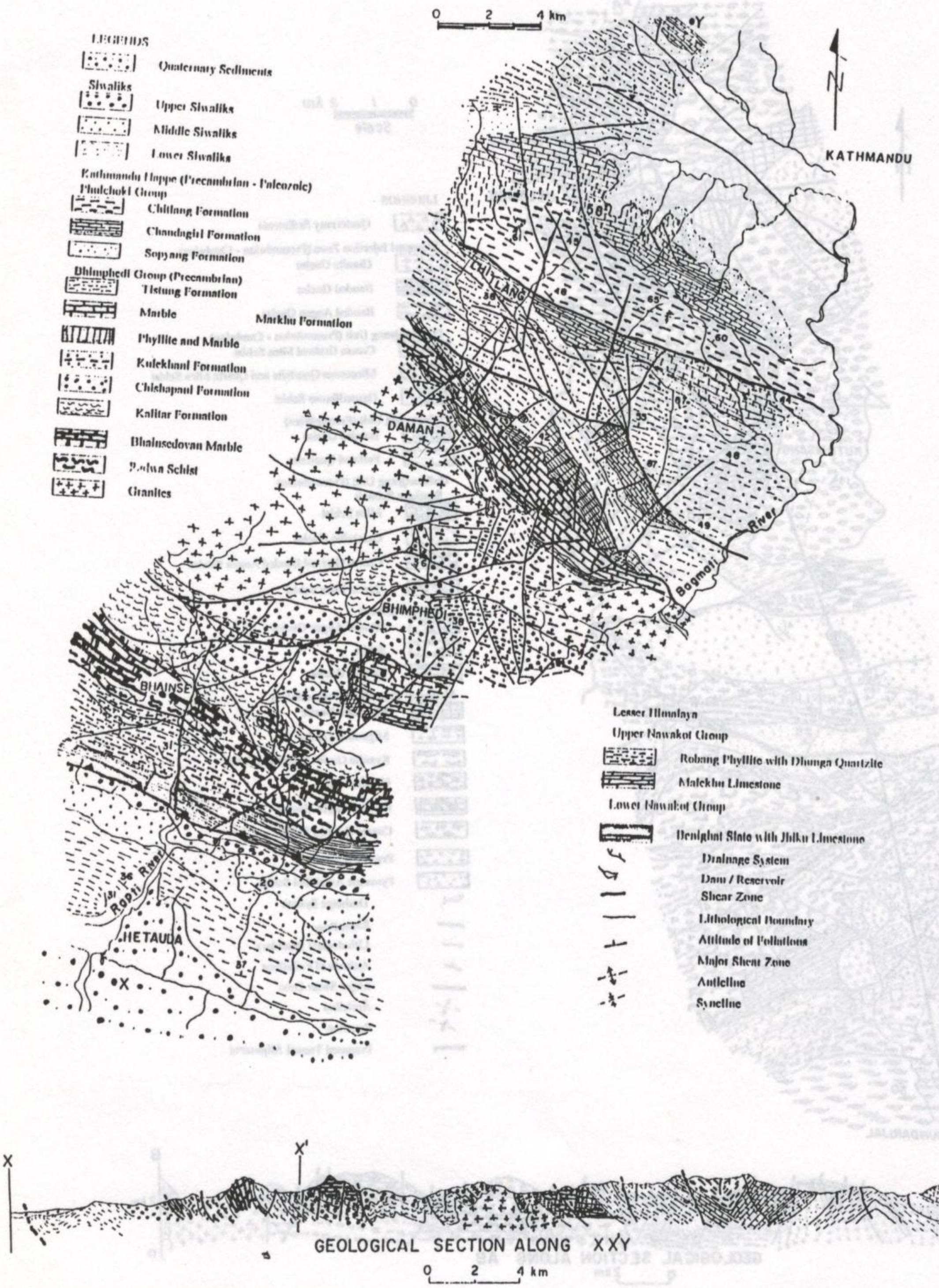

Fig. 3: Geological map of Kathmandu-Hetauda area.

is subjected to high tectonic force. Most of the section of the proposed tunnel is in upper structural level and the planned road is at the top of the upper structural level. Therefore, the role of the existing large scale deformation structures and the influence of pore pressure (in this case mainly joint water pressure) are much more important than the character of the intact rock.

DEFORMATION STRUCTURES

Deformation structures of various magnitudes observed in rocks of the area are the result of high tectonic stress in the Himalayan region and influenced by the lithology and mechanical properties of rocks and atectonic forces (mainly stress release). On the basis of the engineering geological significance, the deformation structures of the area can be classified as:

I. Continuous Deformation Structures (CDS)
II. Discontinuous Deformation Structures (DDS)

Continuous Deformation Structures (CDS)

Resultant structures of following types of deformation are included in this category:

a) Bending (plastic deformation), e.g. folds (major and minor), kink bands,
b) Flattening, e.g. cleavage and foliation,
c) Flow, e.g. various flow structures in high grade metamorphic rocks at a temperature below their melting point,
d) Bending and flattening, e.g. crenalution cleavage,
e) Bending and flow, e.g. boudins, pinch and swell structures, and
f) Combination of bending, flattening and flow, e.g. boudins, mullions, roddings.

The study area has been subjected to plastic deformation in the geological history resulting in many synclines with their subsequent anticlines. The axis of the majority of the folds is striking WNW-ESE. Strike direction of the axis of most of the folds deviates from the general strike of the Himalaya. This is due to local rotational and overthrusting tectonic events and it also depends on respective deformation behavior of the rock mass. The Sindhu Khola anticlinorium and Chitlang synclinorium are of regional significance in the study area. Besides these, about twenty small scale folds are recorded in the study area.

Discontinuous Deformation Structures (DDS)

Resultant structures of following types of deformations are included in this category

a) Fracturing and fault fracturing (brittle deformation) e.g. joints, fissures, extension fractures (veins), shear fractures and faults, and
b) Combination of brittle and plastic deformation, e.g. large scale thrusts and low angle faults, shear zones.

The DDS have a strong influence on the bulk strength and stability of all sort of rock mass. To remove the complexity in significant engineering geological interpretation present work named all types of discontinuous deformation structures as 'Discontinuities'. Discontinuity system of the area is further categorised into seven orders

First Order Discontinuities

These are the regional fracture zones with a persistence of several tens of kilometers. Width of the central shear zone with most hydraulically active core characterised by clay and iron compounds ranges from meters to tens of meters. They have varying internal structures and a very high concentration of the low order discontinuities. Both the central core and branch-like extensions contain closely spaced and interconnected breaks. Such discontinuities contain a very significant amount of clay as they have undergone large and repeated strain. The shear resistance of such discontinuity can be assumed to correspond to the friction angle 15-25°. The central core is with more clay and low shear resistance than the rims. Average orientation of such discontinuities in the area is NW-SE, dipping steeply towards north.

Second Order Discontinuities

These are the prominent local fracture zones with a spacing of a few hundred meters to about a kilometer and extending for several kilometers. Characteristically they are similar to the first order

Table 1: Tectono-lithostratigraphy of the study area north of the Kathmandu valley.

Unit	Sub unit	Main lithology	Geographic distribution	geological age
Recent River terrace	fluvial deposit	Unconsolidated gravel, sand, silt and clay deposits	Flood plains, river bank and channels of the rivers	Holocene
Kathmandu valley deposit	Fluvio-lacustrine deposit	Unconsolidated to semiconsolidated gravel, sand, silt, clay and peat	Kathmandu valley	Quaternary
Shivapuri Injection Zone	Banded gneiss (BGn)	Medium to coarse grained banded gneiss with pegmatite veins and xenoliths of quartzite and mica schist	Shivapuri ridge	Precambrian to Cambrian ?
	Granite gneiss (GrGn)	Medium to coarse grained granite gneiss with clots of tourmaline and Xenoliths of quartzite and mica schist	Chisapani ridge area	Precambrian to Cambrian ?
	Augen gneiss (AgGn)	Medium to coarse grained augen gneiss with pegmatite veins and xenoliths of quartzite and mica schist	Shivapuri ridge	Precambrian to Cambrian ?
Patibhanjyang group	Garnetiferous mica schist (GSch)	Medium to coarse grained, gray, well foliated, garnet bearing quartz-biotite schist with pegmatite veins	Sindhu Khola, Pati-bhanjyang, Thankun-ebhanjyang area	Precambrian to Cambrian ?
	Schist & Quartzite	Fine grained, light gray quartzite with intercalation of medium to coarse grained, gray, well foliated, garnet bearing mica schist	Chipadanda, Patibh-anjyang, Thankune-bhanjyang area	Precambrian to Cambrian ?
Talamarang Quartzite	White sericite Quartzite(SQtz)	Well foliated, sericite bearing white quartzite with intercalation of thin schist bands	Thankunebhanjyang, Chipling, Talamarang Khola area	Precambrian to Cambrian ?
	Migmatites(Ms) and Banded gneiss(BGn)	Fine to medium grained, banded with well developed plane to undulose foliated migmatitic schist and coarse grained mica schist with gneissose bands	North from Chipling and the tributaries of the Talamarang Khola area	Precambrian to Cambrian ?
-- --- -- ---------- ---- ----- ------ -- -- --- --- -- --- **Talamarang Thrust** ----- ---- ------ --- - -- -- ---- --- ---- ----------				
	Mica Schist (Msch)	Medium to coarse grained Muscovite Biotite Schist	Thakani, Chipling, Bhangre khola area	Precambrian ?
	Quartzitic Gneiss (Qgn)	Medium to fine grained, gray to white, high quartz bearing gneiss	Chipling, Chitra, Synle Khola area	Precambrian ?
	Coarse Grained Banded Augen Gneiss (Cgbagn)	Very coarse grained, well foliated, porphyroblastic gneiss with feldspar augen and frequent pegmatite veins	Thodungdanda Bolde Khola area	Precambrian ?
	Quartz-mica Schist (Qmsch)	High quartz biotite bearing schist	along the peak near to Golphubhanjyang	Precambrian ?
	--- --- ---- ------ ---- ---- --- --- ---- ---- ---- ------ Gulbhanjyang Thrust ----- ----			
Gulbhanjyang group	Banded Augen Gneiss (Bgn)	Coarse grained, big porphyriblasts of gneiss in augen gneiss looks mylonitic gneiss	Gulbhanjyang, Jogindanda, Kutumgsang area	Precambrian ?
	Gulbhanjyang garnet-Kyanite bearing Mica Schist (gkSch)	Medium to coarse grained, well foliated garnet and kyanite bearing mica schist with some quartzite bands with frequent pegmatite veins and granite	Thaldanda, Nimadanda, Gohre Khola area	Precambrian ?
	Banded Gneiss	Medium to coarse grained pegmatite bearing banded gneiss	Gohre Khola area	Precambrian ?
---- - ------------ --- -- --- ---- ---- ------- --- -- --- **Gohre - Tadi Thrust** ---- ----- ---- -- --- --- ----- --- --- --- - ------				
	Banded Augen Gneiss (Bagn)	Well foliated banded Augen Gneiss	Manegaire, Lodo-danda, Lamda area	Precambrian ?
	Coarse Grained Schist	Coarse to very coarse grained quartz bearing mica schist	Ribarma Khola area	Precambrian ?
	Migmatitic Gneiss (mign)	Fine to medium grained foliated gneiss with frequent relict fabrics of high grade metamorphic schist and quartzite	Ghopteghyang, Dapkharka, Sineshdanda area	Precambrian ?
Melamchi Crystalline	Pegmatite (peg) and Pegmatite Gneiss (Pgn)	Coarse to very coarse grained high feldspar containing pegmatite and gneiss with frequent pegmatite veins	Sinesh Danda area	Precambrian ?
	Mylonitic Gneiss	Coarse to very coarse grained gneiss indicating the relict fabric of the ductile shearing	Ribal Khola, Sarkathali area	Precambrian ?
	-- --- --- ---- --- -- --- --- --- ------- ---Ribal Khola Thrust --- --- --- --- --- ---- --- -- ------ ---			
	Migmatitic Schist (Misch)	Fine to medium grained, banded, well develop plane to undulose foliated garnet to kyanite bearing schist	Ichok, Helambu area	Precambrian ?
	Granite Gneiss (Grgn)	High alkali feldspar bearing massive gneiss with developed foliation	Melamchi Khola, Melamchigaon area	Precambrian ?
	Kyanit Gneiss Kyanite Schist	Kyanite bearing well foliated gneiss and schist with pegmatite injection	Ribal Khola, Kanyudanda area	Precambrian ?
	Amphibole schist	Pyroxene-hornblende bearing schist	Mangendanda area	Precambrian ?

Table 2: Tectono-lithostratigraphy of the study area south from the Kathmandu valley.

Unit	Sub Unit	Main lithology	Geographic Distribution	Geological Age
Recent River terrace	Fluvial deposit	Unconsolidated gravel, sand, silt and clay deposits	Flood plains, river band and channels of the rivers, Terai plain	Holocene
Kathmandu Valley Deposit	Fluvio-lacustrine deposit	Unconsolidated to semiconsolidated gravel, sand, silt, clay and peat	Kathmandu valley	quaternary
		Siwalik Group (Neogene)		
Siwalik Group (Neogene)	Upper Siwaliks	Conglomerate and sandstone with intercalations of thin mudstone bands	Lal Khola area	Lower Pleistocene
	Middle Siwaliks	Medium to coarse grained pebbly sandstone interbedded with mudstone	Suparitar area	Pliocene
	Lower Siwaliks	Fine to medium grained sandstone interbedded with verigated mudstone	Samari Khola area	Middle Miocene
		----MBT----		
		Kathmandu C omplex		
Phulchoki Group	Chitland Formation	Slightly metamorphosed mudstone and shale, greenish grey color	Chitland area	Silurian
	Chandragiri Limestone	Limestones and impure limestone with some cherty bands	Chandragiri - Chitland hill	Cambrian/ Ordovician
	Sopyang Formation	Slate (slightly metamorphosed shale/ mudstone), calcareous phyllite		? Cambrian
Bhimphedi Group	tistung Formation	Slightly metamorphosed sandstones and mudstone/shale	Bishinkhel, and Kushlechaur area	Early cambrian or late Precambrian
	Markhu Formation	Marble, phyllite and schist in alternate bands with quartzite intercalation	Markhu area around Kulekhani dam	Precambrian
	Kulekhani Formation	Micaceous quartzite, quartzitic schist and schist	Downstream from Kulekhani dam	Precambrian
	Chisapani Formation	White quartzite with intercalations of schist	Chisapani hill	Precambrian
	Kalitar Formation	conglomerate, orthoquartzite, dolomite, schist and garnetiferous schist	Dhorsing to Pandrang and Kalitar area	Precambrian
	Bhainsedovan Marble	Marble	Bhainsedovan area	Precambrian
	Raduwa Formation	Garnetiferous schist	South of Bhainse-dovan area	Precambrian
		---- [Mahabharat Thrust (MT)] ----		
		Nawakot Complex		
Upper Nawakot group	Robang Formation	Robang Phyllite and Dunga quartzites	South of Kamal-matta area	Palaeozoic
	Benighat Slate	Slates and argillaceous dolomite	Between Kamalm atta and Suparitar	Palaeozoic

discontinuities, but the width of the core and rim zone, frequency of low order fractures and clay content are lower. As they have also undergone very large strain and some alteration of feldspar, mica and heavy minerals to clay, the shear resistance is lower. Friction angle should be in the interval 20-25°. Orientation of such discontinuities in the area is parallel to oblique to the first order.

Third Order Discontinuities

Local fracture zones with a spacing of 30 to 150 m and width of few tens of meters to some meters persisting several hundreds meters. They have little or no clay infilling but always interacting low order fractures resulting in higher hydraulic conductivity. Tectonically induced shear zones, on local scale fault zones result in network of long extending low order fractures with smooth surfaces. The friction angle of such zones is expected to be 25-35°. Orientation of such discontinuities in the area is oblique to the first and second order.

Fourth Order Discontinuities

Discontinuities occurring as discrete fractures with an approximate spacing of 2 to 10 m, with persistence of up to some tens of meters. These are the major hydraulically active discrete members of rock located between low-order discontinuities. Such discontinuities are responsible for the major part of the bulk hydraulic conductivity of rock located between fracture zones. They have relatively smooth fracture surface and commonly content of finely fissured or porous fillings implying friction angle lower than that of 3rd order discontinuities. They may have friction angle of 25-30° and very plane chlorite- or clay coated "Slickenside" fracture surfaces which may have a friction angle of only 10-15°. Average orientation of such discontinuities in the area is oblique to the third order. Stability of tunnels and slopes is determined by major long extending discontinuities of the fourth order type.

Fifth Order Discontinuities

Such discontinuities represent about 90% of the visible discrete fractures of the rock between low order discontinuities. Their average spacing is about one tenth of that of fourth order discontinuities and their interaction is poor. They represent weakness and critically high stresses. They do not have significant contribution to the bulk hydraulic conductivity of the rock mass of the area, as either they do not interact significantly or they are healed by pressure solution or precipitation. Such discontinuities may have undergone some shear strain, leading to smoother surface topography than lower order discontinuities. Friction angle may be in the interval of 35-45°. Such discontinuities are extending considerably long, but they are generally random in orientation.

Sixth Order Discontinuities

These are the small-scale fissures and zones or accumulations of weak minerals. They represent zonal enrichment or orientation of low-strength minerals or fine fissures. Such discontinuities are the more or less plane weaknesses which are not conformable to higher order discontinuities. Surface characteristics of such discontinuities are very irregular. So the friction angle should be presumably 40-55° because of their strong dilatancy, if they have not been previously sheared.

Seventh Order Discontinuities

These are the intercrystalline voids and incomplete crystal contacts, serving as embryonic breaks, i.e. "Griffith Cracks". Their role is considerable on the strength and hydraulic conductivity of the intact rock.

Fault system

The Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT) are the major regional scale tectonic boundaries (Gansser, 1964). The HFT is the southern most tectonic boundary between the Siwaliks and the Indo-gangetic plain. The MCT is the oldest tectonic boundary in the region separating the Higher Himalayan Crystalline from the metamorphic rocks of the Midland Group which can be traced on the basis of the beginning of retrograde metamorphism (Le Fort, 1975). Location of the MCT is still under discussion in the study area. Present study has recorded the frequent appearance of garnet to kyanite bearing schist, gneiss and migmatites in the Rebal Khola area and along the trekking route near Thadepati. Additional three major thrusts are recorded from the field study in the area northwards from Kathmandu valley. Besides major large scale thrusts about fifteen faults and shear zones are recorded in this area.

Similarly, south from the Kathmandu valley the Mahabharat Thrust (MT) and the Main Boundary Thrust (MBT) are the major Himalayan thrusts. Besides these thrusts the area is also dissected by about thirty faults resulting in many tectonic blocks. Local faults, weak zones and intraformational shear zones are also frequent. Proposed alignments of the Kathmandu Hetauda Direct Link Road Project have to encounter most of these faults and weak zones.

The joint orientation pattern in relation to the folding has syntectonic relation. Concentration of the joints is greater towards the folding axis and towards the major faults. The axial zone of the syncline indicates the compressive stress and the anticline axis indicates the extensive stress in their joint surfaces. Similarly, the major thrust and the joints have also a syngenetic relation. The axis of the Sindhu Khola anticline is faulted/thrusted. Present studies indicate the faulting successive to the folding and the joint analysis shows their successive interrelation.

Intraformational Shear Zones and Some Atectonic Deformations

Intraformational shear zones are observed frequently in the study area. Such zones are very common in the area having both competent and incompetent rocks in alternating bands. High altitude, steep valley slopes, unfavorable orientation of the foliation or bedding with respect to the natural slopes, deep weathering along the discontinuity planes and ground water activities are the major causes for the formation of large mass movements, creeping or extended rock masses affected by atectonic displacement.

Due to the atectonic deformations the exposures of the same rock at the same tectonic facies give different measurements of strike and dip in the ridge top, midslope, valley side and undisturbed exposures in the river bed. Toppling and other atectonic deformations of the beds in the midslope and the valley sides are more frequent in the incompetent rocks due to the overburden load of the hill and the stress release phenomena. Such phenomena render difficult the interpretation.

ENGINEERING GEOLOGICAL SIGNIFICANCE OF DEFORMATION STRUCTURES OF THE AREA

The study area has many engineering geological problems. Stability of rock slopes and underground excavations are the two major engineering geological problems to deal here with. Influence of the deformation structures is dominant as the:

1. Factor of the constitutive behaviour of the rockmass,
2. Decisive factor and possible source of instability in underground structures,
3. Controlling factor for the stability of natural slopes as well as road cut slopes,
4. Source for the mountain aquifers,
5. Indicator of the paleo- as well as neotectonic stress field,
6. Important parameter for the geomechanical classification of the rockmass,
8. Additional factor for weathering and erosion, and
9. Factor initiating karst phenomena in limestone and marbles.

The mechanical properties and the constitutive behaviour of the rockmass of the area depend on:

1. Deformation history (i.e. physical and chemical condition of deformation),
2. Mineralogical composition of rock, and
3. The deformation structures in the rock mass.

Mechanical properties and the behavior of the rockmass of the area are strongly influenced by the orientation of the discontinuous deformation structures with respect to the imposed loads as well as the spatial distribution of such structures within the rockmass.

Possible source of instability in the planned tunnels of the area are:

1. Adverse structural geology
   - two to six sets of steeply inclined discontinuities,
   - considerably narrow spacing of intra-formational shear zones,
   - axial zone of the folds anticline and syncline
   - frequently observed two sets of foliation,
2. Extreme variation in stress conditions
   most of the part of the proposed tunnels are in the hard rock and the excavation depth vary from <100 m to >1200m which generates the variation in vertical stress due to the load of the overburden,
3. Extreme variation in the intensity and depth of weathering, and
4. Excessive ground water pressure or flow along the major higher order discontinuities as well as along the intraformational shear zones.

Lineations define a very strong anisotropy and control the behavior of rock mass in the tunnel as rock tends to fail as large pencil shaped blocks parallel to the lineation. Foliation controls completely what happens during blasting, and the stability of the roof as well as side walls and the roof bolting. The orientation of the foliation measured in the study area (Fig. 4) seems fair to unfavourable for the tunneling.

Various flow structures observed in the migmatites of the Melamchi Crystalline, Gulbhanjyang Group as well as in Shivapuri Injection Zone formed the inhomogeneity of the intact rock. Pinch and swell structures as well as buddings are the local inhomogineities of the intact rock. They have considerable effect during drilling and blasting of the tunnel. Folds of very small local scale up to the significantly large scale are recorded from the area. Axial zones of the folds are the critical places in tunneling. The intensity of fracturing

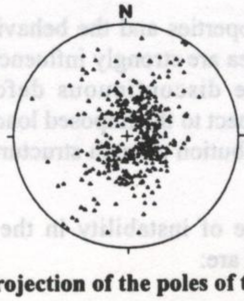

Fig. 4: Projection of the poles of the foliation.

increases towards the axial zone of the folds. Tension fractures are typical in the axial zones of the anticline and the shear fractures are typical in the synclinal axis. Problems related to the ground water are critical in the axial zones of the syncline.

Stability of the rockmass surrounding the underground excavation is likely to be controlled by the through going discontinuous deformation structures namely faults and well developed joint systems. Table 1: Tectono-lithostratigraphy of the study area north of the Kathmandu valley.

Discontinuous deformation structures affect blasting efficiency, limiting the span width, influence the development of the stress distribution surrounding the tunnel roof, and act as aquifer in the planned tunnel. Prominent joints can arrest a blast crack, transmit it without specific direction, reflect it at new angle or abrupt it in a gauge and joint wall (Francis, 1990). Orientation of the discontinuities influence the span width and the stand up time (Hoek and Brown,). Steeply dipping discontinuities are possibly favorable acting as deep piles in the area where the axis of the tunnel is perpendicular to them in contrast. Span width and roof stability of the tunnels depend on the shear strength and nature of joint walls or the gauge layers

Fig. 5: Conditions for tunneling in relation to the orientation of the discontinuities (tunnel diameter up to about 5m).

in the area where the tunnel axis parallel to the strike of the discontinuities. Moderately dipping discontinuities skewed (orienting oblique) to the tunnel axis allow the possibility of failure of the blocks from the roof and side walls.

The proposed classification for the discontinuity systems combined with an appropriate evaluation of the lithology will also offer a suitable tool for the separation of "homogeneous zones" with similar geotechnical properties. Such homogeneous zones are very useful to define areas with similar or equal design and safety concept, excavation, rock support and construction procedure. It will be helpful for the slope stability evaluation and hazard zonation. It also for the preparation of the tender documents, the supervision of the construction and in special cases also for monitoring systems in view of long term operation.

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