Bulletin of the Department of Geology, Tribhuvan University, Kathmandu, Nepal, Vol. 10, 2007, pp. 79–88

Bio-engineering measures for stabilising cut-slopes of Dipayal-Mellekh road, Far Western Nepal

*Gobinda Ojha[1] and Raju Shrestha[2]

[1]*Department of Environment, Tri-Chandra Campus, Tribhuvan University, Kathmandu, Nepal*

[2]*Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, Nepal*

ABSTRACT

The Dipayal-Mellekh road is considered as one of the major infrastructures of the northern region of Doti District as it is only the motorable access. The road extends for about 40 km and is 8 m wide. It passes through six Village Development Committees. This paper describes possibility of using Plantation as a treatment option to safeguard the road and reduce long term maintenance. The study shows that roadside slope instabilities and erosion problems exist in the road alignment due to presence of highly weathered rocks and high cut slope angles. On the basis of slope length, slope angle, material drainage, and site moisture condition, the erosion control measures were suggested. Jute netting with grass lines plantation, site seedling of shrub and trees, vegetated gabion wall, brush layering, palisades, live check dam and fascines are recommended bio-engineering measures for controlling instabilities and erosion problems along the road.

INTRODUCTION

Transportation system offers tremendous opportunities by providing access to remote areas, and allows utilization of land and resources. The transport system with well-designed drainage features can remain stable for years with negligible effect to adjoining areas, if the road is properly constructed (Lewis 2000). Rates of erosion and adverse impact to both aquatic and terrestrial resources increase along the transport system. Steep slopes in mountains reveal marginal safety on roads. In Nepal, bio-engineering measures have been practiced for last 25 years (DRGU 1997). Bio-engineering methods are cost effective (Howell 2002) and the measures include the slope stabilization and erosion control with due consideration to the prevailing condition of the site. The method is used on the basis of local available materials and skills providing benefits through economically useful products. Several agencies have been involved in applying bio-engineering measures for example, Japanese International Cooperation Agency, International Centre for Integrated Mountain Development and Department of Road. Dharan-Dhankuta road, Dharan-Hile road, Banepa-Bardibas road and Muglin-Narayanghat road are some of the examples where bio-engineering measures have been used successfully.

This paper deals with possibility of using different plant species for mitigation erosion and instabilities of slopes to safegaurd the road and reduce long term maintenance. The study area lies in Far Western Nepal, Doti District (Fig. 1). It lies along the Dipayal-Bajhang road between 15+713 km and 28+213 km of Doti District and northwest of Dipayal Bazar from Kasadi to Mellekh.

The baseline survey was initiated in 5th March 2001 by Rural Community Infrastructure Work. The total length of the road is about 40 km and is still under construction. The road begins from Dipayal and passes through six Village Development Committees such as Tikha, Kalikasthan, Banjkakani,

*Corresponding author:
E-mail address: gobindaojha@hotmail.com

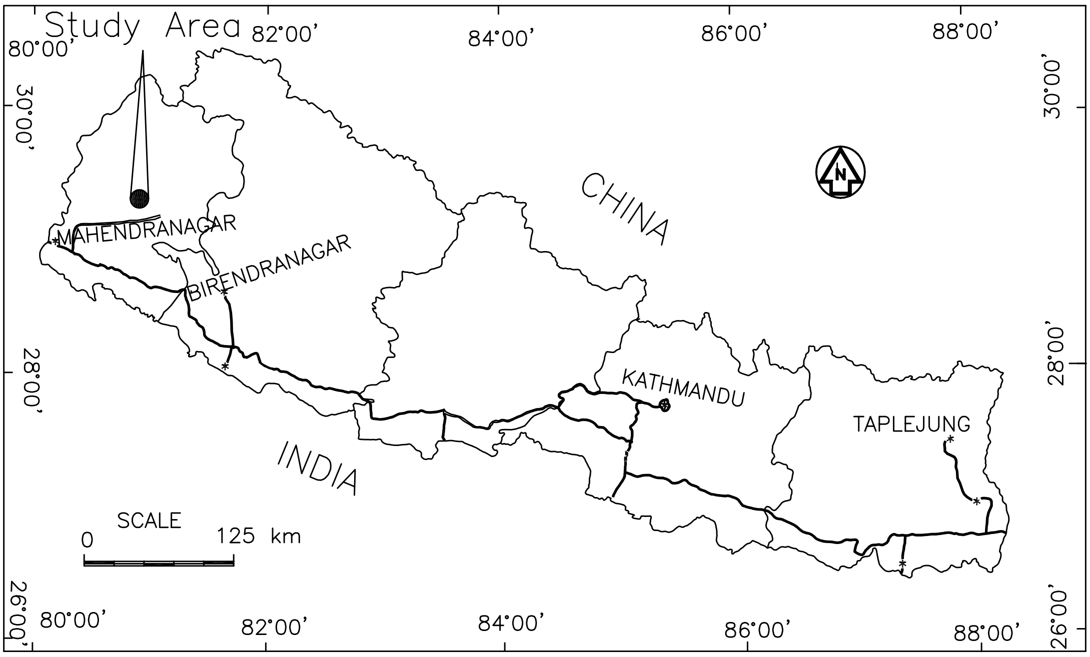

Fig. 1 Location map of the study site

Dahakalika, Khatiwada and Daud.

The road alignment lies in the Lesser Himalaya where metamorphic rocks are distributed. These rocks belong to the Kalikot Formation of the Dadeldhura Crystalline Group and Ranimata Formation of the Lower Nawakot Group (Shrestha et al. 1987). Garnetiferous schist and quartzite are the major rock types of the Kalikot Formation. The beds dip NNE with amount varying from 37 to 74^o. White, massive and fine to coarse sericitic quartzite represent the Ranimata Formation. Quartzite are frequently intercalated with greenish grey laminated chloritic phyllite and occasionally with minor bands of ferruginous quartzite. Some beds of lithic metasandstones are also present. Beds dip towards SW and vary in amount from 32 to 58^o (Fig. 2).

METHODS

During the survey, the engineering geological mapping was carried out along the road alignment, and the unstable sites were recognised. The problems and conditions of sites were determined according to the guidelines suggested by the DRGU (1997). The major criteria adopted were slope angle, slope length, material drainage and site moisture condition. Apart from these, soil samples were analysed and were classified according to Unified Soil Classification System (USCS) (Casagrande 1948). Most of the instabilities were found on the soil slopes and few on the severely weathered rock slopes. Different plant species and plantation methods were proposed considering the above criteria and were based fully on the measures suggested by Howell (2002).

ENGINEERING GEOLOGY OF ROAD ALIGNMENT

Topographically, the road alignment passes along the hillslope faces and ridges of various altitudes. The ascending of the road continues towards northeast through Rol (1306 m) and Mellekh (1940 m). The road alignment passes through flat cultivated land, forest land and steep rocky barren lands. The lower portion of the road alignment passes through steep rock terrain and the remaining portion passes through the gentle slope of cultivated and forest lands.

Generally, the slope aspect is southeast to east. The unstable sites along the road has slope length of less than 15 m. The natural slope and cut slope in the road alignment vary from 16 to 62^o and 35 to 66^o, respectively. Slope less than 40^o are usually covered

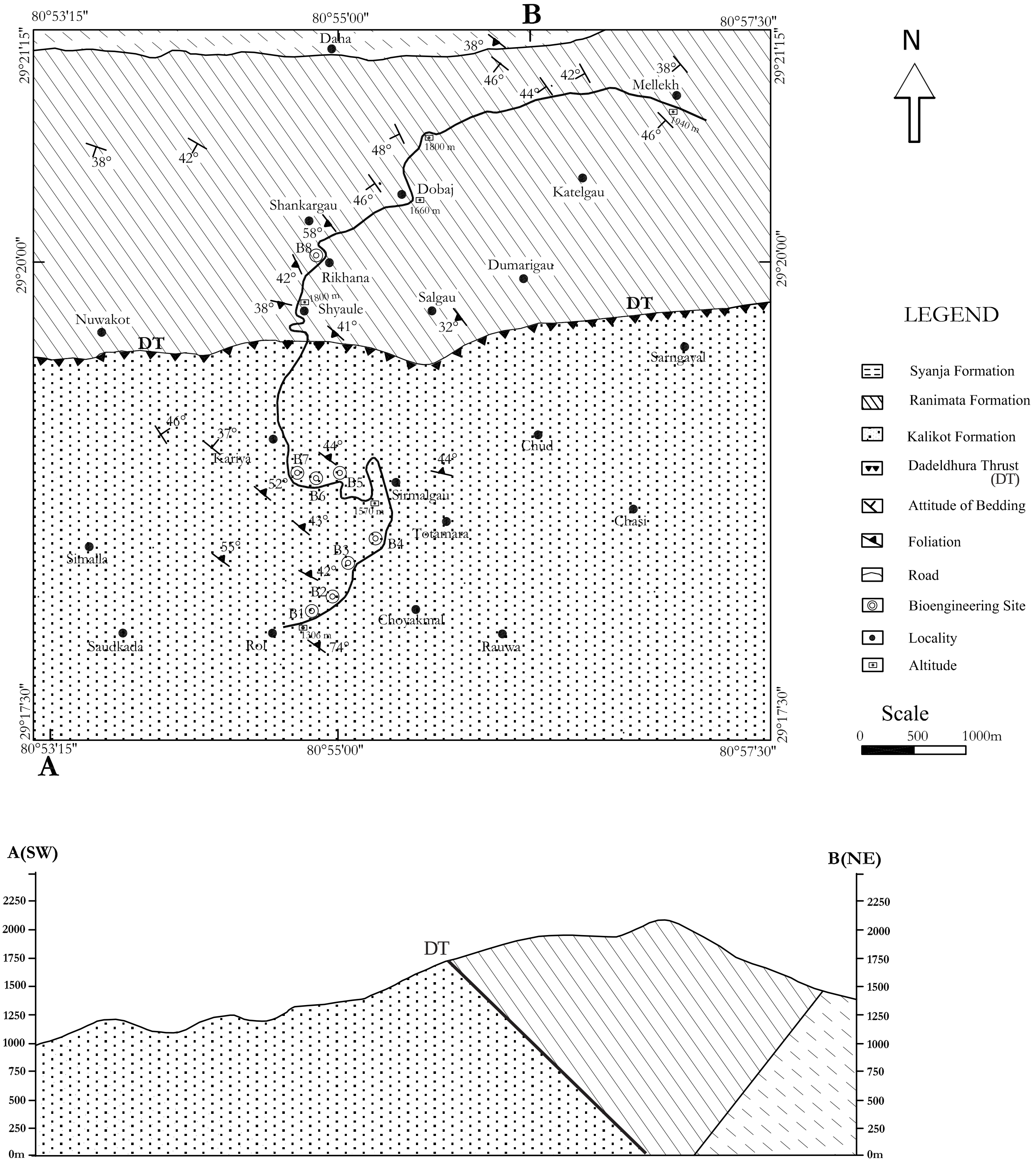

Fig. 2 Geological map and cross-section of study area

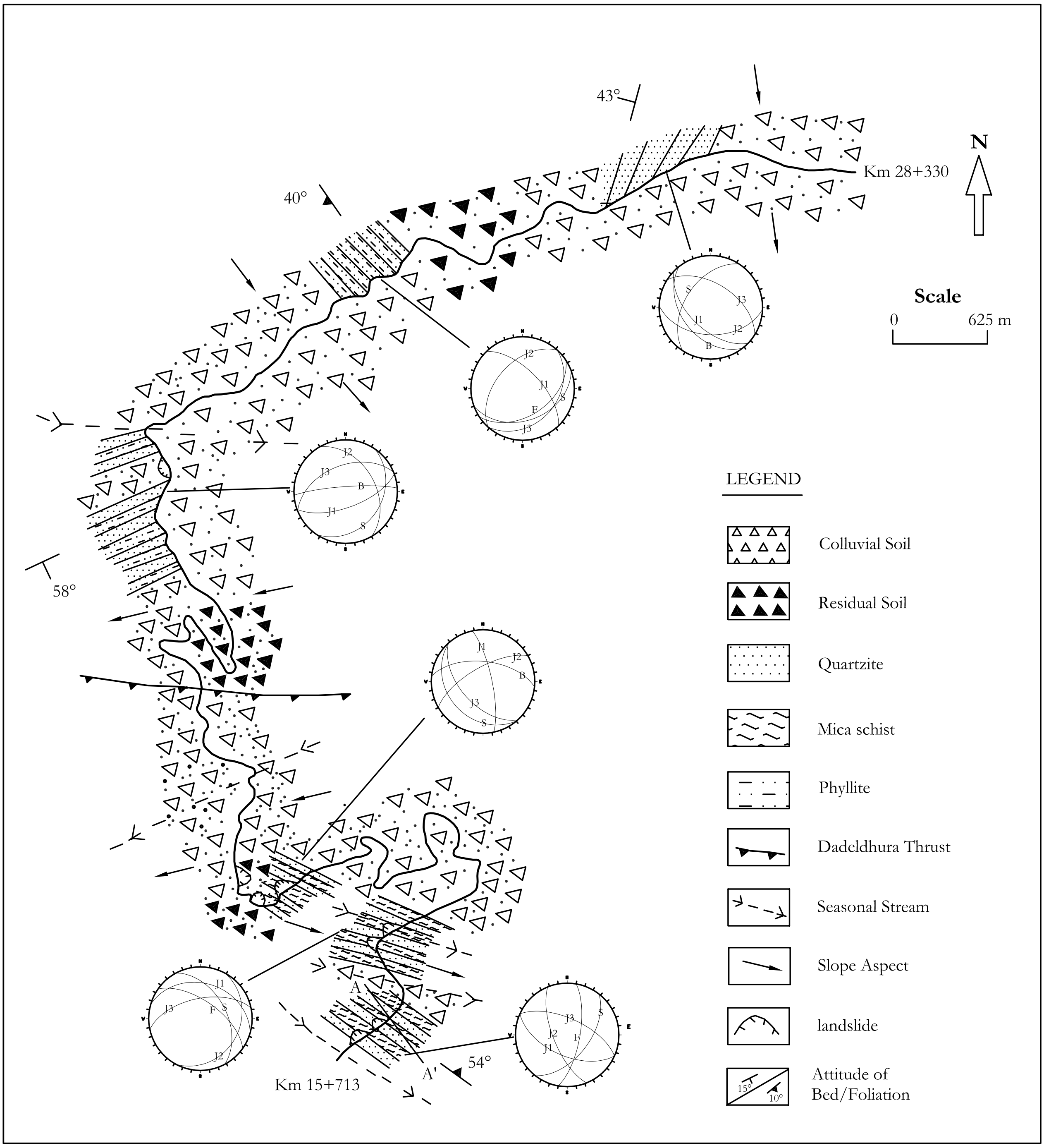

Fig. 3 Engineering geological map of the road alignment

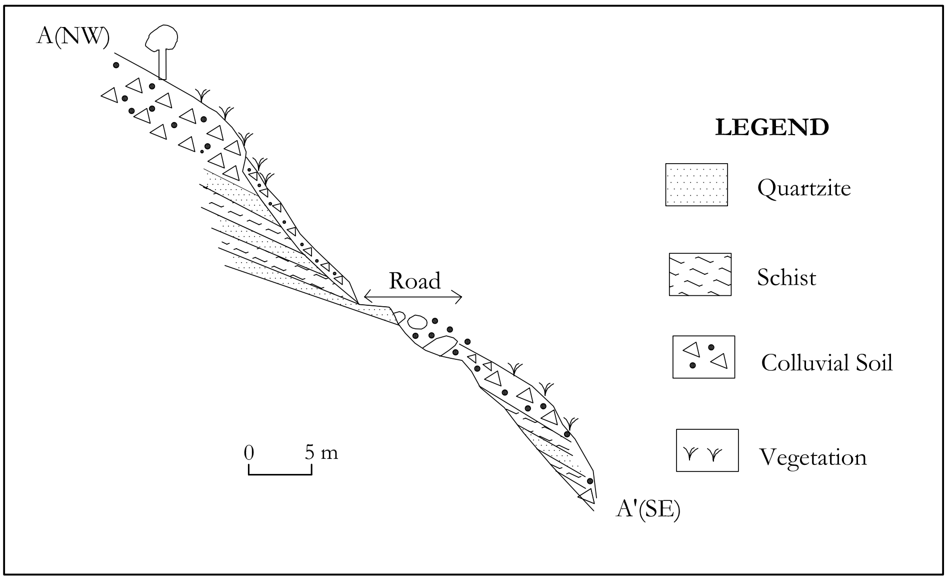

Fig. 4 Schematic cross-section along the bioengineering site B2

by colluvial and residual soil. Most of the colluvial soil have thickness of 1 to 3 m. Residual soil has more than 3 m thickness and is composed of gravelly sand to clayey sand. Garnetiferous mica-schist, quartzite and phyllite commonly outcrops along the road alignment. The rocks are highly weathered and fractured.

The Daduldhura Thrust is the major structure and discontinuities such as bedding/foliation and joints along with this major thrust offer different degree of risk with respect to slope angle and aspect. The discontinuities play role on instability of slopes at different chainages. Bedrocks were measured for discontinuities and their representation in stereographic projection (lower hemispher) has been represented in Fig. 3. Basically three sets of joints and a foliation were recorded. The stereographic projections of discontinuities, foliation and cut slope indicate several structural wedges which are commonly found in bedrocks of the Kalikot Formation lying in the southern part, and are potential because lines of intersection are steeper compared to the friction angles (25-30^{o}) and gentle compared to the slope angles. But the discontinuities of bedrocks of the Ranimata Formation do not form potential wedges as slope angles are gentle.

Several slides are present in the schist and quartzite terrain of the Kalikot Formation and are still hazardous suggesting instabilities in future. The active gully and rill erosion on the colluvial and residual soil surfaces also exhibits high vulnerability of mass wasting.

PROPOSED PLANTATION SITES

Each slope has experienced different degrees of erosion since the construction phase of the road . Cut slopes of road is highly susceptible to erosion because of change in slope amount, aspect, drainage and vegetation. Although some road structures and drainage system may improve stability condition, plantation may provide covering to the slope and reduces direct impact of rain water and surface erosion.

Site B1

The proposed site B1 is located at chainage 16+400 km (Fig. 5a). The site condition is given as below:

Problem: A debris slide of 30 m x 10 m exists and a portion of the road has collapsed.

Bedrock: Weathered mica schist and quartzite

Soil cover: Colluvial silty sand, 1 m thick

Vegetation: Sparse on the upslope of the site

Natural slope: 40 to 60^{o}

Cut slope: 48 to 66^{o}

Slope aspect: southeast

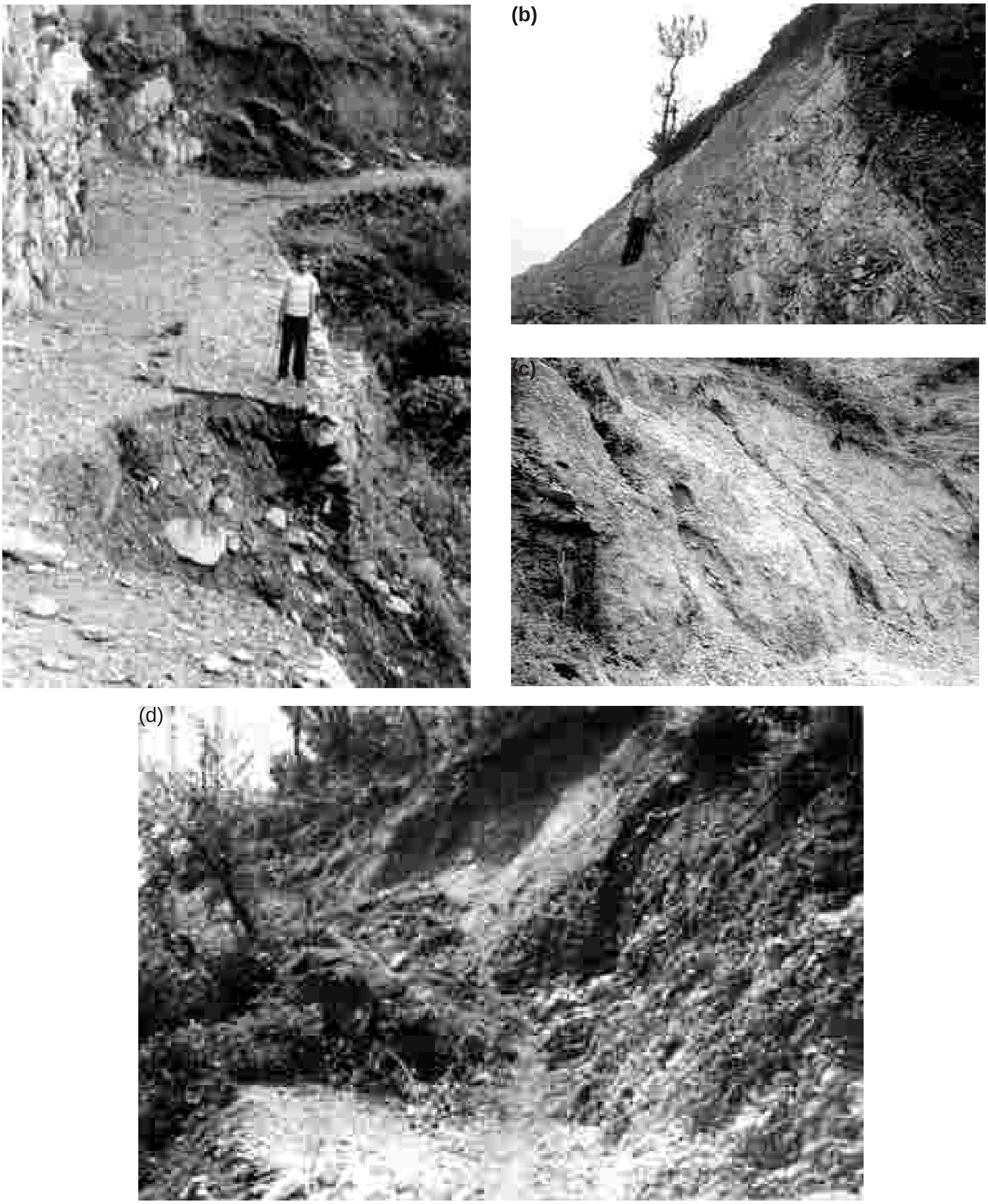

Fig. 5 Photographs showing proposed sites for bioengineering: (a) Site B1 showing damaged road segment; view towards southeast, (b) Site B5 showing steep rock slope containing mica-schist and quartzite bedrock; view towards east, (c) Site B7 showing soil slide with distinct gully erosion; view towards southeast and (d) Site B8 showing debris slide on weathered quartzite and phyllite; view towards east

Slope length: <15 m

Material drainage: good

Site moisture: dry

Considering all the site conditions, the function required are armouring, reinforcing and support the slope. The effective measure is combination of diagonal grass lines plantation with revetment wall. The dry stone masonry wall in the road segment has failed due to improper construction. The proper construction of masonry wall with a line of large trees and large bamboo clump planting can stop road failure towards downslope. Palisades are recommended for protection of rill and gullies. It stabilzes the gully floor by forming a strong barrier and trapping materials moving downwards. *Eulaliopsis binata* (Babiyo), *Neyraudia reynaudiana* (Dhonde), *Arunduell nepalensis* (Phurke), *Cymbopogon microtheca* (Khar) and *Thysanolaena maxiama* (Amliso) are the most suitable grass species and *Erythrina species* (Phaledo), *Pinus roxburghii* (Rani salla) and *Alnus nepalensis* (Utis) are some of suitable tree species proposed for plantation. *Colquhounia coccinea* (Namdiphul) and *Erythrina species* (Phaledo) are suitable plant species for construction of palisades.

Site B2

The site B2 is located at chainage 16+500 km .

Problem: A debris slide of 20 m x 12 m exists. The half of the width of the road is badly affected by erosion due to improper surface drainage (Fig. 4). Tension cracks are developed on downslope of the road. Gullies are active and well developed.

Bedrock: Fractured mica-schist and quartzite

Soil cover: Colluvial silty sand, <1 m thick

Vegetation: Sparse on the upslope of the site

Natural slope: 25 to 50°

Cut slope: 40 to 60°

Slope aspect: southwest

Slope length: <15 m

Material drainage: good

Site moisture: dry

Considering all the site conditions, the function required are armouring and reinforcing the slope. The effective measure is diagonal grass lines plantation and vegetated gabion. The failed road segment may be protected by construction of Retaining wall with tree plantation and proper side drain.Palisades are recommended for protection of rill and gullies. Suitable grasses for the site are *Eulaliopsis binata*, *Neyraudia reynaudiana*, *Arunduell nepalensis* and *Cymbopogon microtheca*. The trees are *Erythrina species* and *Pinus roxburghii*.

Site B3

The site B3 is located at chainage 16+690 km (Fig. 2).

Problem: A debris slide of 15 m x 10 m occurs along with well developed gullies which are dry.

Bedrock: Very fractured mica-schist and quartzite

Soil cover: Colluvial silty sand, <1 m thick

Vegetation: Sparse on the upslope of the site

Natural slope: 25 to 50°

Cut slope: 45 to 60°

Slope aspect: south

Slope length: <15 m

Material drainage: good

Site moisture: dry

The slope is composed mainly of rock, the function required are reinforcing and anchoring the slope, therefore site seedling of shrub/small trees is recommended. The trees will reinforce and anchor the slope.Palisades are recommended to control gully erosion. Suitable species of shrub and trees are *Ingigofera atrotupurea* (Keraukose), Pinus wallichiana (Gobre salla), Pinus roxburghii (Rani salla), *Lantana camara* (Kanda phul), *Vitex negundo* (Simali), *Agave Americana* (kettuke) and Alnus nepalensis (Utis).

Site B4

The site B4 is located at chainage 17+100 km (Fig. 2).

Problem: A debris slide of 12 m x 15 m exists and dry gullies intersect the road alignment.

Bedrock: Highly weathered mica-schist and fractured quartzite

Soil cover: Colluvial clayey sand, <1 m thick

Vegetation: Sparse on the upslope of the road

Natural slope: 30 to 44°

Cut slope: 35 to 50°

Slope aspect: south

Slope length: <15 m

Material drainage: poor

Site moisture: dry

Considering all the site conditions, the function required are reinforcing and anchoring the slope. so, site seedling of shrub/small tree is suitble measure in addition to gabion cascade and culvert to passage the seasonal stream. Live check dams are recommended across the gully. It forms a strong barrier and trap material moving downward. Locally available small trees as proposed in the site B3 are applicable here. The suitable species for live check dams are *Erythrina species* (for vertical support), *Colquhounia coccinea*, *Salix terasperma* (Bains) and *Lantana camera* (for horizontal cuttings).

Site B5

The site B5 is located at chainage 19+660 km (Fig. 2).

Problem: A rock slide of 40 m x 10 m exists.

Bedrock: Weathered mica-schist and weathered and highly fractured quartzite

Soil cover: Colluvial silty sand, <1 m thick

Vegetation: Sparse on the upslope of the site

Natural slope: 34 to 48°

Cut slope: 52 to 57°

Slope aspect: east

Slope length: <15 m

Material drainage: good

Site moisture: dry

This site contains a rock slide (Fig. 5b). The functions required are reinforcing and anchoring of the slope. Therefore, jute netting with site seedling of shrub or small trees is the best solution. This method allows steep, rocky and unstable slopes to be revegetated. The species as proposed in sites B3 and B4 are applicable in site B5.

Site B6

The site B6 is located at chainage 19+790 km (Fig. 2).

Problem: A soil slide of 15 m x 12 m exists and gully erosion is prominent.

Bedrock: Highly weathered mica-schist and quartzite

Soil cover: Residual clayey sand, 3 m thick

Vegetation: Moderate on the upslope

Natural slope: 25 to 30°

Cut slope: 40 to 55°

Slope aspect: southwest

Slope length: <15 m

Material drainage: poor

Site moisture: dry

The site contains thick (3 m) residual soil and a soil slide. The functions required are armouring and reinforcing of the slope. In this site jute netting with random grass lines plantation accompanied by vegetated gabion wall will be suitable. Drainage fascines stabilize rills and gullies, and enable plants to evaporate water (Schiechtl, 1980), therefore these structures are recommended for construction. The grass species which will be favourable for preventing sheet erosion are *Cymbopogon microtheca*, *Arunduell nepalensis*, *Thysanolaena maxiama*, and for vegetated gabions are *Alnus nepalensis* and *Erythrina species*. The recommended species for fascines are *Colquhounia coccinea* and *Vitex negundo* (Simali).

Site B7

The site B7 is located at chainage 19+990 km (Fig. 2).

Problem: A soil slide of 15 m x 10 m exists. Gully and rill erosion was observed (Fig. 5c).

Bedrock: not exposed due to thick soil cover

Soil cover: Colluvial silty sand, 3 m thick

Vegetation: Sparse on the upslope of the site

Natural slope: 24 to 36°

Cut slope: 40 to 45°

Slope aspect: southeast

Slope length: <15 m

Material drainage: good

Site moisture: dry

Construction of brush layers is the effective method. Brush layers armor and reinforce the upper soil layers up to 2 m depth (Lammeranner et al.

2005). These layers form a strong barrier, preventing the development of rills, and trap soil moving down the slope. The suggested species are *Lantana camara*, *Erythrina species* and *Vitex negundo*.

Site B8

The site B8 is located at chainage 23+400 km (Fig. 2).

Problem: A debris slide of 20 m x 8 m exists. Development of rills and soil erosion is remarkable (Fig. 5d).

Bedrock: Highly weathered phyllite and highly fractured quartzite

Soil cover: Colluvial silty sand of 3 m thickness

Vegetation: Upslope of the site is covered by a forest

Natural slope: 15 to 30^{o}

Cut slope: 50 to 60^{o}

Slope aspect: east

Slope length: <15 m

Material drainage: good

Site moisture: dry

Diagonal grass lines plantation with revetment wall at the toe of the slope is recommended. Grass plantation in this way provides a surface cover with good armouring and reinforcement. Palisades are recommended for protection of gullies and rills. Suitable grasses for the site are *Cymbopogon microtheca* (Khar), *Saccharum pontaneum* (Kans), *Thysanolaena maxiama* (Amliso) and *Themeda species* (Katara khar).

DISCUSSIONS AND CONCLUSIONS

The study area consists of mainly quartzite, mica-schist and minorly phyllite. The proposed sites B1 to B7 lie on the Kalikot Formation whereas the site B8 lies in the Ranimata Formation. The road alignment ascends from the sites B1 to B8. The cut slopes are rich in colluvial and residual soils which frequently exceed 3 m. The roadside slope instabilities and erosion problems are due to presence of highly weathered and fractured rocks and unfavourable cut slope aspect and angle. Such cut slopes could have been produced without due respect to the structural analysis of bedrocks before construction of road. Sometimes, engineers can not escape from the instabilities produced from structural wedges formed by the discontinuities present in the rockmass, because they either do not have choice for alternative direction of alignment or they simply neglect potential wedges. For the vulnerable deep seated wedges and lines of intersection, anchoring and other engineering techniques may workout. But for the shallow seated instabilities, engineering works solely may not provide sufficient control over soil erosion and slope wash. Therefore, bio-engineering technique is an economic and environmental friendly solution to stablize cut slopes along the road alignment.

In the unstable cut slopes, slope length is less than 15 m and slope angle is greater than 45^{o}. Material drainage condition in most of the cases is good with dry moisture condition, except in the sites B4 and B6 where drainage is poor. considering these criteria, diagonal grass plantation is suitable in sites B1, B2 and B8, while jute netting with random grass line plantation and vegetated gabions is suitable in the site B6. Because the sites B3, B4 and B5 have thin soil cover and are mostly composed of fractured bedrocks, site seedling of shrub and small trees are suitable. Brush layering is an another way for preventing surface erosion (rill and sheet erosion) in a very thick soil covered slopes such as in the site B7. Palisades, fascines and live check dams are recommended for protection of gullies and rills. These stabilize the gully floor by forming a strong barrier and trapping the debris moving downwards. Palisades are used upto 60^{o} slope having good material drainage to protect deep and narrow gullies. For poor material drainage and slope of upto 45^{o}, fascines should be used. Live check dam should be used in any gullies upto slope of 45^{o}.

Grass species such as *Eulaliopsis binata* (Babiyo), *Neyraudia reynaudiana* (Dhonde), *Cymbopogon microtheca* (Khar), *Saccharum pontaneum* (Kans) and *Thysanolaena maxiama* (Amliso), *Arunduella nepalensis* (Phurke) and *Themeda species* (Katara khar) are suitable for the proposed road alignment. The species like *Eulaliopsis binata* (Babiyo) and *Neyraudia reynaudiana* (Dhonde) are suitable upto 1500 m (for sites B1 and B2), but other grass species are suitable upto 2000 m (recommended for all the grass planting proposed sites).

The suitable shrub species and trees are

Ingigofera atrotupurea (Keraukose), *Vitex negundo* (Simali), *Agave americana* (Kettuke), *Coquhounia coccinea* (Namdi phul), *Lantana camara* (Kanda phul), *Salix terasperma* (Bains) and *Erythrina species* (Phaledo). The latter three species are suitable for brush layering.

ACKNOWLEDGEMENTS

Authors are thankful to R. P. Pathak Geo-Environmental and Social Unit, Department of Roads for providing necessary materials and comments. Authors also thank R. Shrestha and R. P. Dhakal for their helps during desk works.

REFERENCES

Casgrande, A., 1948. Classification and identification of soil. Transaction of the American Society of Civil Engineers, 901p.

DRGU, 1997. Bio-engineering information. Rate analysis norms (interim), standard specifications (interim), list of species and supporting information. Department of Road Geo-environmental Unit (DRGU), Nepal Government, Ministy of work and transport, Second edition.

Howell, J.H., 2002. Roadside bio-engineering site handbook. Department of Road, Nepal Government and Department of International Development, United Kingdom. 160p.

Lammeranner W., Rauch, H. P. and Laaha G., 2005. Implementation and monitoring of soil bio-engineering measures at a landslide in the Middle Mountains of Nepal. 159p.

Lewis, L., 2000. Soil bio-engineering. An althernative for roadside management; A practical guide. 44p.

Schhaffner U., 1987. Road construction in the Nepal Himalaya.The experience from the Lamosangu-Jiri Road Project.International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, 67 p.

Schiechtl H.M., 1980. Bioengineering for Land Reclamation and Conservation. University of Alberta Press, Edmonton, 404p.

Shrestha, S.B., Shrestha, J.N. and Sharma, S.R., 1987. Geological map of Mid-Western Nepal (Scale 1:250,000). Department of Mines and Geology, Kathmandu.