7. Mountain Risk Engineering (MRE)

Background

Three decades of mountain road building in Nepal, carried out with funds and technological assistance from seven countries (America, China, India, Japan, Russia, the U.K., and Switzerland) and multilateral agencies, such as the Asian Development Bank and The World Bank and HMG Nepal's own resources, have produced about 4,000km of mountain roads traversing the Siwalik, the Mahabharat, and the Himalayan ranges. Varying standards and technologies applied on these roads and the impacts from them on the socioeconomic and engineering-geological environment have generated a vast wealth of experience whereby Nepal could be called both a museum and a library of mountain roads.

While there may be uncertainties concerning the satisfactory economic impacts so far from many of these roads, the experiences from them have clearly contributed to the development of awareness and mountain specific approaches to road development in mountainous regions, not only in Nepal but also in other mountainous regions of the world, especially in the developing countries.

Engineering-geological considerations, having been pursued since 1979 in Nepal and reinforced by growing environmental concerns during the last decade, are now being vigorously adopted and institutionalised. The Eighth Five-year Plan for the transport sector in Nepal is witness to this.

The International Centre for Integrated Mountain Development (ICIMOD) from 1988 to 1992 has:

i) produced a Mountain Risk Engineering Handbook,

ii) developed an MRE training curriculum, and

iii) conducted MRE training for about 35 engineers and geologists from the Hindu Kush-Himalayan Region.

MRE Handbooks, although developed from experiences with mountain roads, especially in Nepal, are a first step towards synthesising, integrating, and bringing together the essential elements of mountain-specific infrastructures in a comprehensive manner. Specific practical applications for other infrastructures, such as canals, can be followed. However, a simplified version has to be prepared in order to extend the basic principles and concepts to local people for use in low-cost participatory programmes at village level.

MRE Definitions and Concepts

MRE is defined as the science and art of engineering mountain infrastructures, giving due regard to the natural and human processes and tolerable risks to and from infrastructures (Deoja et al. 1991).

Risk assessment has been treated differently by different persons and agencies. The Geotechnical Control Office, Hongkong, expresses hazards and risks in terms of the instability score (potential or failure) and consequential score (risk to life in the event of failure), based upon formulae developed from discussions and calibrations from trial and error methods. Slope ranking is carried out by using the total score, which is the sum of the instability score and the consequence score. Romana slope classification by SMR (Slope Mass Rating) is based on empirical relationships, which involve Bieniawski's (1979) rock mass rating and adjustment factors for dip direction and dip amount for slope and joint and the adjustment rating for the blasting method. Wagner et al. (1988) have used subjective ratings for various natural factors. A hazard map is produced through overlaying a slope map, geological map, and a morpho-structural map. These methods, or maps, provide indications of relative hazards but are silent on predictions of both physical or monetary loss and the time dimension of the occurrence of the damaging phenomenon. Einstein (1988) has suggested a systematic and formalised technique of risk assessment, using assessments of probabilities. An expert system for hazard and risk assessment has been proposed by Thapa et al. All of these techniques, however, use experience-based subjective judgements to varying degrees to arrive explicitly or implicitly at the probabilities of occurrence or rating. While it is possible to treat a given site within small areas with rigorous engineering-geological investigations, field and laboratory tests, and deterministic and relative hazard and risk analyses, these are justified mainly for important and high cost structures on a specific site and normally at the detailed design stage (post feasibility stage) of a project. Linear infrastructures, such as roads and irrigation canals, however, do not normally justify rigorous investigations and analyses, for reasons of both cost and time, at the pre-feasibility stage or at the feasibility stage of the project cycle. Nevertheless, investment decisions at pre-feasibility and feasibility stages require some indication of the likelihood of occurrence of a damaging phenomenon and associated loss of life and property over specified time periods. Comprehensive, simple, and rapid assessments, based upon desk study and walkover checks, are necessary for pre-feasibility and feasibility studies, which would then identify the specific locations requiring rigorous investigations and analyses for the detailed design stage of the route identified from the feasibility studies.

Hazard and Risk Assessment

Risk, as defined by Varnes, is a function of hazard, element at risk, and vulnerability. Einstein defined hazard as "the probability that a particular danger occurs within a given period of time" and risk as "hazard times potential worth of loss".

Table 29 illustrates hazard and risk calculations based upon subjective ratings for various factors of instability, as discussed in the MRE Handbook.

These calculations are intended for use in route selection so that risk mitigation is primarily through avoidance of risks, and residual risks are minimised by adoption of physical mitigation measures within the limits of resource availability and the analysis period. For simplicity, only one time occurrence of hazard, immediately after the construction of the structure, is considered.

Posterior probabilities require updating, e.g., Bayesian updating, which requires many more statistics. Rainfall events and earthquakes are assumed to be the main triggers of landslides. However, earthquakes have not been considered in the method presented here. Prior probabilities are obtained by rating on a 0 to 1 scale for the various attributes and multiplying the total rating by the rainfall factor This is based upon the assumption that, no matter what the existing condition may be, landslides do not occur if there is no trigger. The total rating for the state of nature and the existing danger may be treated as the probability for a threshold value of rainfall.

Table 29: Ratings for State-of-nature (Ps), Dangers, Hazards, and Risk Calculations

Attributes	Description/Measurement	Rating
1. Slope angle, degree	0-5, 6-15, 16-75, 76-35, 36-45, 45	0, .05, .1, .14, .12, .1
2. Relative rellet, metre	0-50, 51-100, 101-150, 150-200, <200	0, .03, .06, .09, .12
3. Drainage	simple, active, very active	0, .04, .08
4. Groundwater condition	dry, wet, flowing, very active	0, .04, .09
5. Land use/Vegetation	thick vegetation, moderate, sparse, barren or cultivated land	0, .03, .06, .09
6. Fault	150m, 51-100m, <100m on both sides	.16, .08, .04
7. Soil type	Alluvium, colluvium, loose alluvium, talus, till, and debris and moraine	0, .04, .06-.08, 1-.12, .08-.1, .1-.12
8. Soil depth	(1m, 1-3m, 3-10m, >10m	0, .06, .12, .08
9. Syncline/Anticline	50m, 60m, >100m	.04, .02, .01
	50m, 60m, >100m	.08, .04, .02
10 Rock type	massive resistant, soft, interbedding of soft and hard rock	0, .02, .04, .06
11. Weathering grade	fresh, moderate, high, complete	0, .02, .04, .03
12. Joint spacing	>1m, 51-100cm, 10-50cm, <10cm	0, .03, .04, .06
13. Orientation of discontinuities	Slope oblique to joint/bedding up to 30 degrees, dip slope of joint ± 20 degree, dip slope of bedding/foliation + 20 degree	.04, .06, .08
Danger Classification		
Old landslide	small, medium, large	slope length <10m, 10-15m, >50m
Recent landslide	small, medium, large	slope length <10m, 10-15m, >50m
Dormant landslide	small, medium, large	slope length <10m, 10-15m, >50m
Landslide due to river bank undercutting	small, medium, large	Mt > 100m from road, Mt 50-100m, Mt >100m Depth <0.5m, .5-2m, >5m
Debris flow	small, medium, large	
Rainfall Factor		
	Mean annual 24 hr rainfall, mm	Rating
Average annual rainfall, of		
1000	<50, 50-100, 101-140, 141-170, >170	.3, .5, .8, 1, 1
2000	<80, 81-120, 121-140, 141-170, >170	.4, .6, .8, 1, 1
3000	<130, 131-150, 151-190, 190	.5, .8, 1, 1
4000	<160, 161-190, 191-220, 221-260, >260	.6, .9, 1, 1, 1.
Road Damage Factor		
Type of Likely Failure	Soil Rock, Soil+Rock	Type of Likely Failure Soil Rock
Minor slide (1-3m deep)	.2 .3	Minor undercutting .3 .1
Medium slide (3-6m deep)	.5 .6	Medium undercutting .5 .2
Major slide (>6m deep)	.9 1	Major undercutting .9 .5
Minor debris flow	.2	
Medium debris flow	.4	
Major debris slide	.9	
Hazard and Risk Calculation		
Hazard for State-of-nature	= Rating for State of nature (Ps) x Rainfall factor	High Hazard = >0.6
Hazard for danger	= Ps + (1-Ps) x Rainfall factor =>1	Medium Hazard = 0.31-0.6
Risk, km (R_1)	= Hazard x Length of road likely to be affected x Damage factor	Low Hazard = 0-0.3
Risk, monetary value	= R1 x per km cost	

The state of nature is a description of the existing conditions in otherwise stable areas, and danger is the existing landslide or mass movements. The ratings in Table 29 are subjective ratings for hazard at threshold values of rainfall for the state of nature. Hazard for lower values of rainfall can be obtained by multiplying this value by lower values (on a scale of 0 to 1) for rainfall. The type of likely failure has to be judged from information on the state-of-nature and dangers such as depth of soil, rock type and structure, groundwater table, and type of existing failure. Hazard for dangers (existing failures) is treated like the one for rainfall at the threshold value and is equal to the $Ps + (1-Ps) \times Rainfall$ factor. Risk is obtained by multiplying hazard by the length of the road likely to be affected times the damage factor (% of road likely to be fully damaged should the likely danger occur).

Whatever method is employed for risk assessment for alignment selection for mountain roads, it is very essential for engineers and geologists to have a knowledge of geological processes, theories of instabilities, and the skills to analyse the instabilities. The subject background provided in the MRE Handbook, Volume I, provides a body of basic knowledge from which engineers and geologists can be provided with the background to improve and develop their own methods appropriate to specific situations.

It must be remembered that assessment of risks to a particular road is not only dependent upon the natural hazards but also upon the hazards from the standard and sequence of constructions of the road elements designed. Therefore, a knowledge of road geometries, cross-section design, traffic levels, cost trends, alternative designs, and rigour of designs at different stages of the project cycle is necessary.

MRE Application in Nepal

The Eighth Five-year Plan for the road sector in Nepal has stipulated a policy for adopting mountain-specific engineering-geological techniques for mountain roads. The policy also provides for the institutionalisation of Mountain Risk Engineering and Environmental Units in the Department of Roads.

The Thankot-Naubise Road Rehabilitation Project and the Arniko Highway Rehabilitation Project in Nepal are carrying out slope stabilisation and river training works following techniques recommended in the MRE Handbook. Rehabilitation of road sections, damaged in the 1987 floods, of these two roads is going to cost about 217 million rupees.

Plates 16 to 24 present properly engineered slope stabilisation techniques in Nepal. It should be noted that these techniques appear heavy and expensive, but they are definitively less expensive than rehabilitation of poorly-designed, hastily constructed, and costly structures, especially when high traffic roads are closed.