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Landslide Investigation and Prevention Practice in Nepal

Tiwari Binod* and Marui Hideaki**

Abstract:

Almost all countries of the world inspite of how advanced the country is bare the panic of natural disaster in any of its crucial form. As it is impossible to stop such disaster completely, the attempt should be made to reduce such disaster by mutual sharing of the experience of each country. Due to this reason, UN designated the 1990's decade as International Decade for Natural Disaster Reduction (IDNDR) and is observed on October each year.

Being a mountainous country with steep slope and fragile geology, Nepal is frequently suffering from various types of disaster. Among the total disaster occurring in the country, loss due to landslide and flood is very high. Such disaster in Nepal is not only the problem to Nepal but it is associated with South-Asian disaster as almost all the rivers flow towards the Bay of Bengal via major cities of India. Therefore the flood and sediment related disaster in Nepal always threaten India and Bangladesh too.

In association with the above mentioned problems and in line and way to contribute one major step in IDNDR, the government of Japan sake hand with the government of Nepal to establish Water Induced Disaster prevention Technical Center (DPTC) in Nepal. The main objective of the project is to cope with major water induced disasters through technology development, training for manpower development and establishment of database.

Nepal has diversified topography while moving from south towards north. Although more than 70% of the total loss of property is due to landslide and flood only, landslide investigation prior to the infrastructure development is not common. Remedial measures to the existing landslides are also being applied haphazardly and with thorough/quick surface investigation only. In this context, DPTC is contributing a major step in the concept of landslide prevention work after investigation, using Japanese technology modified at local condition. As the disaster events, especially in the form of landslide is increasing, Nepal should have to change its conventional landslide prevention practice to the appropriate one. This paper deals with the prevailing landslide investigation and prevention practices in Nepal and usefulness of the modified Japanese technology alongwith the possible suggestions to be considered to boost up the landslide prevention strategy of the government of Nepal.

Keywords : landslide, Nepal, investigation, prevention, geology, topography, precipitation, disaster, highway, extensometer

*新潟大学大学院自然科学研究科博士課程前期
**新潟大学積雪地域災害研究センター

1. Introduction:

Natural disaster is a common phenomenon, which hit various parts of the world without pre-notice and ruins the beautiful infrastructures made by the hard effort of human being. Although such disaster occur in any of its crucial forms like flood, landslide, debris flow, typhoon, volcano, earthquake etc., the ultimate effect of it is to remain the panic to the human being and the development activities. It is impossible to stop such disastrous events of the nature, despite of how rich and advanced the country is; but only the way is to be familiar with its nature and to avoid the disaster. The nature of such disaster depends on various factors like geographic location, topographic condition etc. So, various countries individually have different types of dominant disaster events. Frequent typhoons, earthquakes, volcanic eruptions, landslide, debris flow, flood, for example, are hitting Japan, whereas Nepal, being a landlocked country, does not have typhoons and volcanic events. So, various parts of the world, being affected by the natural disaster each year in any of its form have to be gathered and united each other to share the experiences on disaster events and the developed technology so that disaster events will be minimized to make safe world and clean environment. Due to this reason, United Nations have designated the decade of 1990's as International Decade for Natural Disaster Reduction (IDNDR) and is celebrated worldwide on October by sharing the experience of each other.

Nepal, being a under developed mountainous country is also being hit by various types of disaster events each year, destroying lots of lives and properties and pushing a country further backwards. This fact necessitated the strategy on identifying the cause of these disasters and possible alternates to minimize them. Frequent disasters hitting the country are landslide, floods, debris flow supplemented by intermittent earthquake and other minor disasters too. An effect of water induced disaster is considerable in comparison to other. Considering this aspect and in line and way to contribute one major step in IDNDR, the Government of Japan decided to co-operate the Government of Nepal to establish a project called Water Induced Disaster Prevention Technical Center (DPTC) in Nepal. The main objective of the project is to cope with major water induced disaster through technology development, training for manpower development and establishment of database. The project is playing a major role in water induced disaster mitigation of the nation.

Considering the past disaster events in Nepal, the main disaster responsible for huge loss of life and property are landslide and flood. During 1995, about 28% of total loss of life and 74% of total loss of property was due to landslide and flood only. So, if the damage due to it can be minimized, huge part of loss of life and property can be saved. As most of the Nepalese river flow towards Bay of Bengal , confluxing with various big rivers of India like Ganga River, sediment accumulated and flood disaster in this form will indirectly affect an environment of India and Bangladesh too. So, unless the Nepalese rivers and catchments will be treated, occurrence of South Asian Disaster can not be ignored. The important arterial

highways of Nepal used to be blocked for several hours by landslides during monsoon, causing hindrances to the public life.

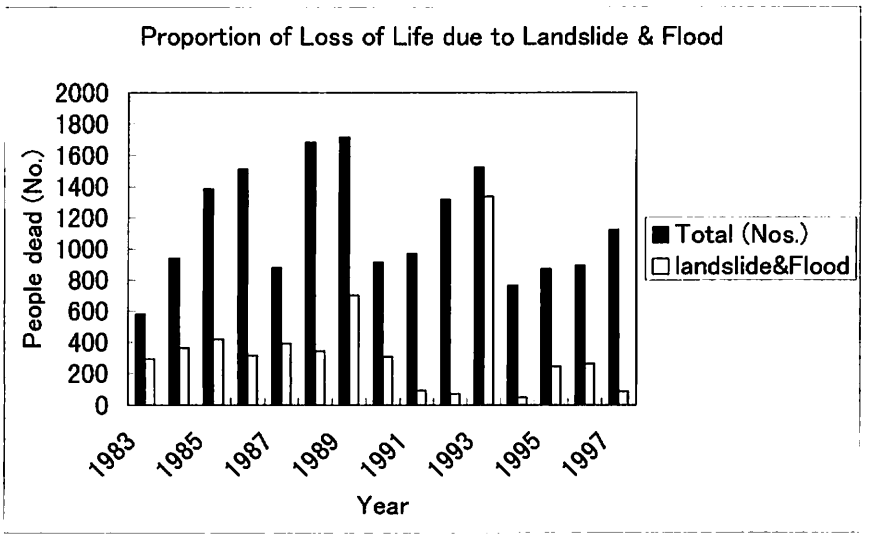

Figure 1 : Proportion of loss of life due to landslide and flood only

The total population of Nepal according to population census 1991 is about 18.5 million with an average increasing rate of 2.08% against lower economic growth rate. Although total area of the country is about 147000 sq. km., area above 4000m. altitude is very cold and has a very less population density. Only 7.8% of the total population are living in mountainous region whereas 45.5% and 46.7% lives in hill and plain (Terai) area respectively. So, the major population is concentrated within very narrow central and southern belt. Such activities resulted to extensive spread of farming new lands, specially farther and farther from their villages to the marginal lands for cultivation as well as fodder and firewood, destroying more and more shrubs and forests. Common agricultural practices in the slope steeper than 30° and unlined irrigation channel over the steep slope is obviously inviting the landslide in major hill slopes.

The chapters explained hereunder are self explanatory to understand the causes of excessive landslides in Nepal.

2. 0 Topography and Geology:

The topography of Nepal varies drastically from low lying areas of the Gangetic plain with an altitude less than 100 m. in the south to Himalayas with an altitude of 8848m. in the north within a short horizontal distance of 90-120 km. Such gradient is responsible for the induction of frequent landslides in Nepalese hills. The flat plain with an altitude ranging 100-400m. covers almost 17% of the country where no landslide problems are encountered. Among the rest 83% land, 60% of the total land, existing at an altitude ranging several hundred

meters to 3000m., covers lesser and mountain area. This part is very sensitive for landslide occurrence, characterized by its steep slope and fragile nature. A remaining part includes middle and lesser Himalayan belt, having less population density.

Although it is very small country, Nepal has diversified geological pattern. In general Nepalese hills are geologically very young and as a consequence very delicate and fragile. The kingdom of Nepal lies in the central part of the Himalayan range and covers nearly one third of the total range. About 83% of the total land lie within the mobile belt. Being a tectonically active zone, resulted with the movement of Indian and Eurasian plate, uncountable discontinuities have been formed. Clearly visible several thrust lines divide the whole country into 5 main geological regions. The rock and soil type in each region is specific and differs from others. The southernmost Terai region bounded by Himalayan Frontal Thrust in north, is a active foreland basin of the Himalayas and consists of coarse sediment in the north and finer sediments like silt and clay in the south. The second geological zone consists of geologically young, immature and fragile Siwalik zone, which is composed of generally soft and loose north dipping sedimentary rocks like sandstone and mudstone in alternate layer, siltstone, marls and conglomerate. The zone north to a Siwalik i.e. Main Boundary Thrust is lesser Himalayas ranging up to Main Central Thrust in the north, forming a major geological and physiographical zone of Nepal Himalayas. Majority of the hill population of Nepal lives within this zone. Lesser Himalayan zone is mainly represented by the low-grade metamorphic rocks like slate, phyllite, schist, limestone and dolomite, deeply weathered, highly fractured and traversed by a large number of major and minor thrusts and faults. The fourth zone i.e. higher Himalayas, ranging from Main Boundary Thrust in the south to Main Central Thrust in the North, is essentially made up of low-grade metamorphic rocks like various kinds of gniesses, schist, quartzite and marbles along with granite at some regions. Beside these four distinct geological regions, some of the inner mountain valleys belong to Tibetan-Tethys zone of the Himalayas, mostly composed of fossiliferous sedimentary rocks like shale, limestone, sandstone etc.

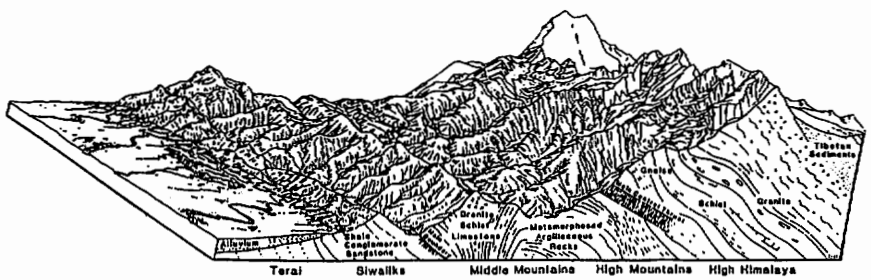

Figure 2 : Physiography of Nepal

3. Climate and Precipitation:

The climate of Nepal is dictated by her location with respect to the latitudes, variation in the altitudes and by the location of individual geo-physical units within the country. Southern part of Nepal has tropical climate whereas the mountains of the midland exhibit sub-tropical climate along the river valleys to warm and cool temperate climate as one goes higher in elevation. Himalayan part has temperate to alpine type climate. Over 80% of the precipitation take place from May-August. The intensity of rainfall is also very high so that 100mm per day is common. The distribution of summer monsoon rainfall is determined by the distance from the Bay of Bengal, origin of north-westerly moist seasonal winds as well as the location of the place with respect to the Himalayan Mountain Ranges to a north, a leeward area in general. The winter monsoon, responsible for about a yearly mean of 500mm. of precipitation in the greater part of the country, originates in a Mediterranean and carry very less moisture by the time it reaches Nepal. This clarifies the winter snow line is at about 2500m.

4. Distribution of Landslide:

The distribution of landslide in Nepal is highly influenced by topographical, geological and climatic condition. As already mentioned, immature Siwalik region and densely populated Lesser Mountain area are highly suffered from landslide problems. In the northern part of the country, having altitude greater than 4000m. has alpine form of hazards, which includes topples, ice/rock avalanche, ice/rock fall, debris slide and glacier lake outburst flow. As the population growth rate is high in comparison to the economic development, the densely populated lesser Himalayan region, has no alternate except to destroy the forest area to accommodate the new population. Besides, infrastructure development without specific consideration to future disaster leads an increase in landslide phenomenon in this region. To link the road network to most of the district headquarters and major cities and towns, the alignment should have to pass through a Siwalik hill which lead in destroying of forest cover and disturbance to immature geological formation resulting in the invitation of landslide. Western part of the country is more prominent to landslide rather than the eastern part as the monsoon reach this part quite late than the eastern part. Besides, distribution of the landslide is varied according to geomorphological condition. The lower Siwalik formation with alternate layer of mudstone and sandstone dipping towards valley is more susceptible to landslide than the other ones. Many highways, constructed without special consideration to this phenomenon are being suffered from numerous landslide occurrences. Besides, the landslides are concentrated densely along the geological discontinuities, especially along Main Central Thrust (MCT), Main Boundary Thrust (MBT) and other major local thrust/fault lines.

Mainly almost all of the mountainous arterial roads are suffered from landslide problems. Most of the roads have no way rather than crossing the geological boundaries like MBT, MCT, HFT etc. to connect the important obligatory points. This resulted in excessive landslides

among which some are uncounterable chronic ones. The following are the main highways of Nepal suffering from huge landslide problems.

Prithivi Highway: This is the most important highway connecting Kathmandu with Pokhara. This is the only highway, which has access to Kathmandu from western and eastern Nepal. If this highway will be blocked, nothing can be transported to Kathmandu. 200m. long Prithivi Highway runs along the bank of Trishuli and Marsyangdi rive along its major part both of which are main tributaries of Gandaki, the longest, river of Nepal. So, the highway used to be blocked at various locations during monsoon and immediate maintenance is necessary. Jogimara landslide is one of the chronic landslides along this highway, which used to push down at least one passenger bus during the monsoon in the past. This problem is solved by the excavation of loose debris and construction of trapping retaining wall at foothill side and concrete retaining wall at the riverside. Still there are several challenging landslides along the highway, most of which are induced in artificially disturbed lime stone belts. The MCT crosses the highway around Belkhu area where a bridge was completely washed away by the huge debris flow disaster in 1993. Besides, the highway crosses various local faults along its course.

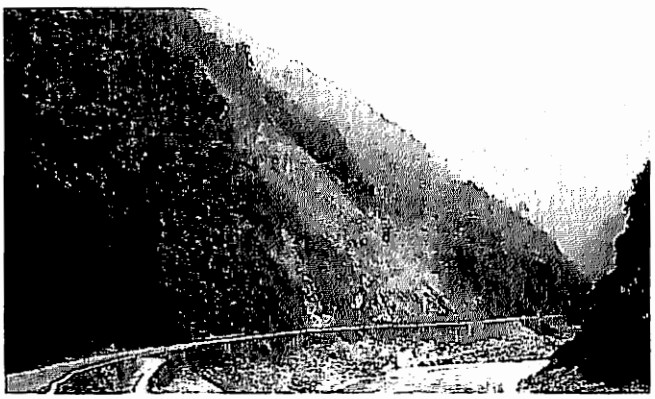

Photo 1 : Jogimara Landslide, a chronic one in the past

Tribhuwan Highway: This road was only the road to connect Kathmandu with east and west before the construction of the Mugling-Narayangadh Road. This was first constructed as access road to Kulekhani Hydroelectric Project, an oldest Hydroelectric Project in Nepal. As this is ridge road, it has less hydrological problems but the extensive numbers of switchbacks to reach the ridge induced several landslides. It crosses both MBT and MCT in very short interval several kilometers down from Bhainse dovan. So, this part is very fragile and is being suffered from frequent landslide and debris flow problems. Along its course, it crosses many local thrust lines where prominent landslides can be found.

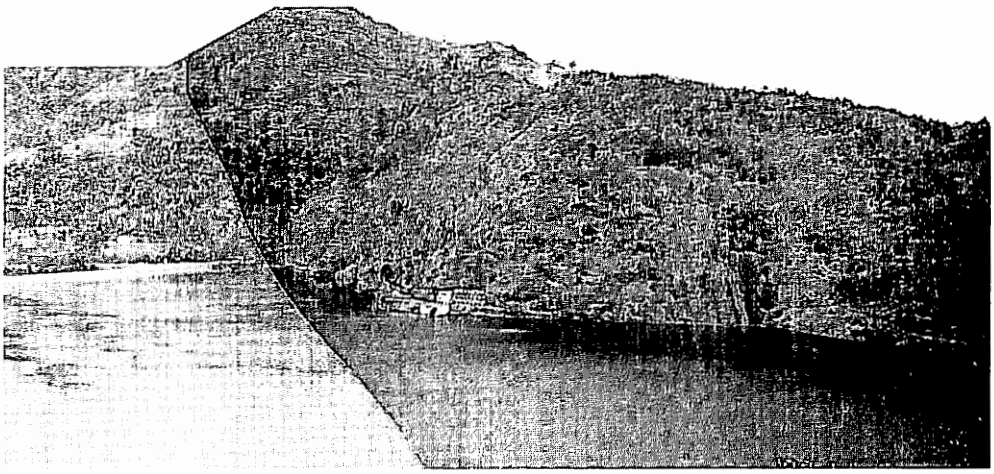

Photo 2 : A potential landslide that was threatening Kulekhani dam

Araniko Highway: This is 115 km. Long main highway connecting Kathmandu with China. After its construction, it has suffered from frequent disasters like glacier lake outburst flood of 1981, heavy flood of 1985 and 1987 which completely destroyed the main highway course as well as Sunkoshi Hydro-electric Project. Since then and enhanced with earthquake of 1988, the highway is suffered from various landslide and debris flow problems. Although many of the big landslides have already been controlled, still many hazardous zones are to be treated yet. Many villages along this road are established on the ancient debris fan. There are 38 major landslides within 52 to 115 km. road sector among which landslide at Ch. 53, landslide at Kothe are very dangerous landslides upto Barabise (Ch. 87). Kothe landslide may induce landslide damming in future after heavy precipitation as it is slided from both banks of the Sunkoshi River. The zone after Barabise upto Kodari is really vulnerable and has suffered from plenty of landslide events. During the monsoon of 1996, the highway was fully collapsed at various sections and was intensively damaged at Ch. 80, Ch. 98, Ch. 103 and Ch. 108. Larcha

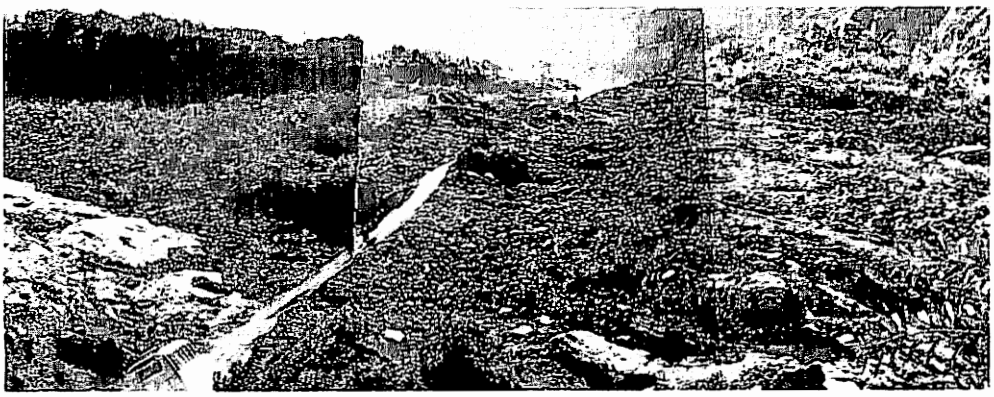

Photo 3 : Landslide at Ch. 98 of Araniko Highway

bazaar, lying at Ch. 108 was fully swept out , killing 22 people due to the huge debris flow induced due to landslide damming at upstream around the MCT. The MCT line crosses at 2 locations i.e. Ch. 53 and at western part of Tatopani bazaar. Therefore, big chronic landslide at Ch 53 is the output of such geological condition, strengthened by stream bank cutting.

Kathmandu-Trishuli Road: This road, joining the 70 km. distance between Kathmandu to Trishuli was first constructed as access road for Trishuli Hydro-electric Project. This is strategic road to connect Somdang, which is another border to China. Many fault lines also cross the road sector. The MCT is crossed by the road at about km. 48., which induced heavy landslide. Besides, there are many local faults along which frequent landslides can be observed. The landslide at 19 km. is the prominent one, which was first triggered due to the earthquake of 1942 and activated many times due to hydrological as well as artificial causes like road cutting. The collapse of this 110 m. long landslide may affect a lot in the economy of the northern sector, but is almost stabilized after the intensive investigation work. As the slide is passed by the local fault line, dense landslide geo-morphology can be seen along the fault line.

Photo 4 : Landslide at 19 km. along Kathmandu- Trishuli Road

Pokhara-Baglung Road: This is 72 km. long highway connecting Pokhara with northern town Baglung. As this road is also running northwards, frequent landslides encountered on the way create disturbance to thorough traffic. The big landslide at Lumle is creating havoc to the road managers as the whole hillside is converting to landslide. This landslide starts from the folded joint of phyllite and ends at the stream several hundreds meter downstream. Besides this, several landslide topography at off-road right bank of the stream can be observed which might be dangerous in future.

Photo 5 : Lumle landslide induced due to hydrological and geological cause

Sidhartha Highway: This is one of the major highways suffering from severe landslides. 270 km. long this highway runs from Pokhara to Sunauli, a Nepal India border. Pokhara-Syangja sector of this highway has several potential landslide zones among which some are already slided. At Ch. 86 of this highway, there is big landslide, a part of which has already, been slipped. This landslide was mainly induced by stream under cutting of Andhi khola after road cutting in ancient debris deposit. There are several close faults near Tansen and at Tansen-Butwal sector of this road. At Kerabari, the road crosses the MBT which induce several chronic landslides along the road sector. After that the road crosses along the Siwalik formation the dominant rock of which is alternate layer of sandstone and mudstone. There are several landslides along the road where the rock dips towards river/road resulted due to leaching of mudstone towards river after contacting the water. Jhumsa landslide, 10 km. before Butwal is one typical example for this phenomenon. Landslide damming in 1981 caused heavy loss in this road sector.

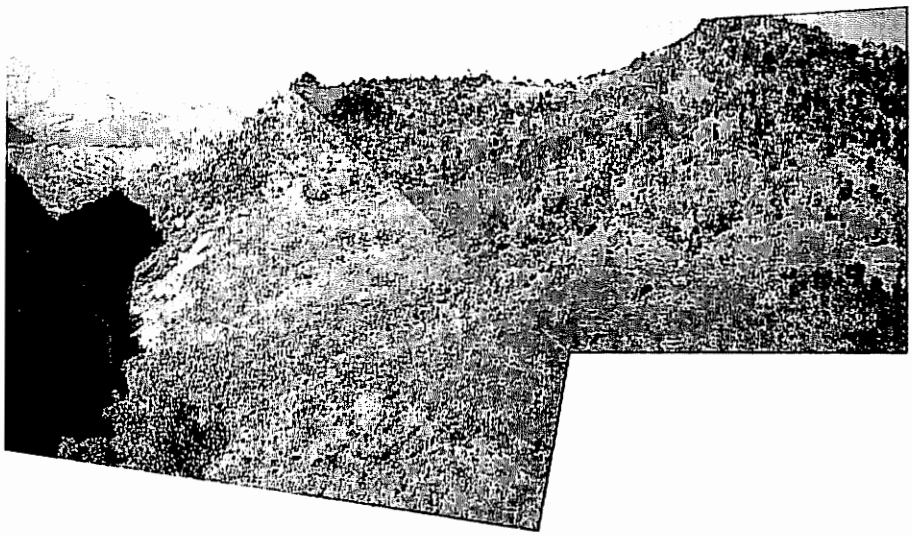

Photo 6 : Landslide at Sidhartha Highway that was induced due to road excavation at old sliding area

Mechi Highway: This is the arterial road running from southern flat land Charali upto

Photo 7 : landslide at 62 km. along Charali-Ilam Road

northernmost district headquarter of Taplejung in the east. This is very important from traffic as well as communication point of view. This road is separated into 3 sectors viz. Charali-Ilam, Ilam-Phidim and Phidim-Taplejung Sectors. Each sector has specific landslide problems. At 20 km. along Charali-Ilam road, there is huge landslide and the road is already settled by 50 cm. MBT is passing from upper part of this area which is the main reason of slide. The landslide is further enhanced by poor surface drainage. Likewise, there is big landslide at 62 km. of the same sector. Although the landslide is sliding repeatedly resulting in the alteration of the road alignment, the late monsoon precipitation at 1994 collapsed 63 m. of the black topped road length. Clear crown scar was visible which gave the concept of crown excavation that was done without delay. Although the traffic was stopped for initial some days inducing havoc to the northern side, the traffic was smooth thenafter. The landslide is induced due to geological causes as well as due to chemically contaminated ground water. After careful investigation and implementation of prevention works like series of check dams, well surface drainage network, drainage boring works and plantation, the slide is within the controllable limit now. As the prominent fault line is passing from the landslide vicinity, the whole area after the Mai River seems to be unstable. At Ilam-Phidim sector, there are several chronic landslides. Landslide at Chureghati is one typical example. Road is settled by about 10 m. leaving the side drain at the top. This is also the geologically induced one supported by stream under cutting. The MCT is crossing at around Lalikharka near Phidim where sign of landslides can be seen on the road. Several chainages of Phidim-Taplejung road sector are also suffered with landslide occurrence. Land mass movement at Ch. 18 along the Phidim-Taplejung sector, known as Bharapa landslide is one of the prominent one. This landslide was reactivated after the earthquake of 1988 although was induced long ago as the road is passing through the geologically faulted area. The movement was further enhanced by the stream under cutting of Hewa khola. Besides, the road is suffered from net like landslide features at Amarpur area

i.e. Ch. 48 to 58 and after Kabeli River as MCT crosses the road once again around this part.

Dharan-Dhankuta Road: This is a 52 km. part of Jogbani-Terathum Road, which is main connector from India at Jogbani to northern district of eastern Nepal, Terathum. The 52 km. long road was once supposed to be most expensive road sector in Nepal as it is fully supported with slope protection works along its length. Inspite of these efforts, the earthquake at 1988 ruined the road completely by inducing many slides and debris flow. MBT line passes through the road sector some km. down of Bhedetar. Series of landslides can be observed along the road sector there. The upper hill above Ch. 48 is crossed by MCT. This gave instability to the whole hill, inducing a incredibly big landslide along the road sector. As the solution is not so easy for this deep-seated landslide, the prevention work is still not started yet. Other landslides are more or less treated. Near Tamor Bridge, the huge debris flow at 1993 buried a bridge, which could not be cleared off yet.

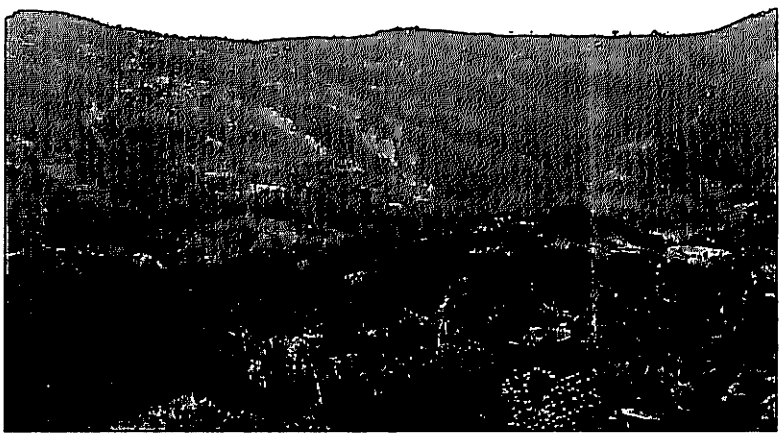

Photo 8 : Huge chronic landslide at 48 km. along Dharan-Dhankuta Road

East-West Highway: This is longest as well as most important highway of Nepal, stretching in 1028 km. from Mechi River at eastern border upto Mahakali River at western border. This highway runs through the flat Terai land along almost all of its course except some locations where it crosses Siwalik ranges. While it crosses Siwalik, it is suffered from various types of landslides. It runs through Siwalik range while it reach Pathlaiya-Butawal sector. There is chronic landslide at the Right Bank of Rapti River a little before Manahari. This was really big landslide induced due to stream under cutting as well as geological reason. It is tackled now by the construction of retaining wall and 11 concrete spurs to divert the stream flow. The total cost was found to be more economical than diverting the alignment itself to have a new road of 4 km. length. There are plenty of landslides along Narayanghat-Butawal sector while the alignment crosses Siwalik hill. These landslides are more or less tackled by retaining wall construction as well as extensive bio-engineering work. The newly constructed Highway

Bridge at Tinau River, upstream of Butwal bazaar, was collapsed before inauguration due to the landslide in 1978. While the alignment crosses Siwalik area from Sibagadh upto Bhalubang, there are typical landslides induced at Siwalik rock i.e. alternate layer of mudstone and sandstone. These features are prominent along the river bank where the dip of the rock is towards the river.

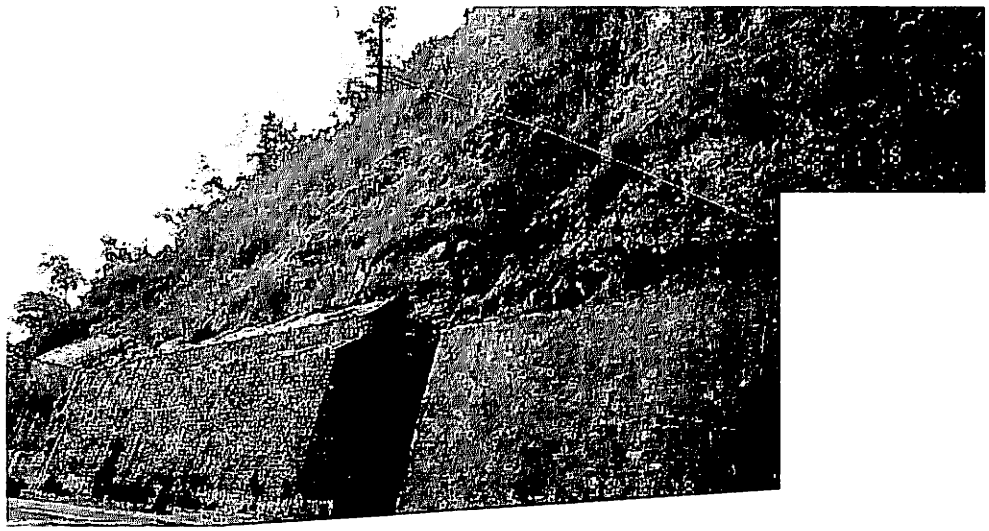

Photo 9 : landslide at the bank of Rapti river on Hetauda-Narayangadh Sector

Photo10 : landslide at right bank of Tinau River which collapsed the highway bridge before inauguration

5. Main causes of excessive Landslide:

Many of the landslides in Nepal are induced due to poor geological as well as topographical conditions. But these causes are enhanced highly by artificial causes, which are fully the responsibility of the human being and their unplanned development activities. In brief, following are the main causes for excessive landslides in Nepal.

5. 1 Natural Causes:

a. *High Relief or steep slope:* Almost 83% of the total Nepalese land lies in hilly region having relief liable to frequent slope failure under heavy precipitation. Again, the slope steeper than 60° are also common where rock fall are prominent. The relief of the country, combined with other factors increases the frequency of landslide.

b. *Unstable/fragile geology:* Because of the presence of heavily weathered and fractured (due to intense folding and faulting induced by seismic and plate tectonic activities) rock, the landslide cases have been increased. Excessive development of weak rock such as Phyllites, slates and schist and presence of calcareous interlayer in these rocks which lead to porosity and void formation due to leaching and dissolution are also the causes of excessive landslides in Nepal. Besides, the country is famous for high current rivers and streams, which unfortunately undercut the toe of the slope and induce serious landslides.

c. *Concentrated Precipitation:* The concentrated heavy precipitation is also the cause of excessive landslides. During the latest big disaster event at 21 July 1993, heavy rainfall continued from 19 to 21 July 1993 in Central Nepal. The daily rainfall up to 540mm. was also been recorded at that time. Such heavily concentrated rainfall combines with steep cross gradient and fragile geology to cause excessive landslide during monsoon period.

5. 2 Anthropogenic Causes:

Almost 60% of the total landslide events in Nepal are induced due to various anthropogenic reasons as described hereunder.

a. *Deforestation:* Intensive deforestation has been taken place in most part of mountain in the last decade making the slope more vulnerable to landslide occurrence. A rapid increase in population resulted in to the encroachment of marginal land for cultivation, firewood, timber and fodder. These factors have increased the surface runoff and head and toe erosion, giving rise to landslides. The young Siwalik hill is so fragile that there is a saying "once the forest cover of this region will be destroyed, it is extremely difficult to re-grow it". The deforestation has massively been done in the same Siwalik hill for various purposes including infrastructure development.

b. *Improper land-use:* For sustainability of the people, agricultural practices in steep slope are common which induced lots of serious effects due to pounding of water and removal of vegetation cover. Besides, unlined irrigation channels have been constructed through steep slope, making the slope more vulnerable. Unplanned paddy cultivation in steep slope is also practiced. Removal of vegetative cover is also increased due to the overgrazing by cattle.

Quarrying for construction materials and mineral values make the rock near quarry site fragile. In fact no land use regulation is made and practiced/enforced to the public.

c. *Unplanned Infrastructure Development:* In the past very formal geological investigations were made for the development/planning of the infrastructures which resulted in passing of highway or irrigation channels along the fault lines creating chronic landslide events. There is no alternate rather than passing the highways from steep and fragile Siwalik and Lower Himalayan belt. But due to lack of proper care on future landslide induction during the construction, such highways have to bear the regular maintenance problem after one or two years of construction. In addition, dumping of spoil to anywhere or making an unplanned spoil bank created illusion to the planners thinking it to be the original ground after its consolidation. An unlined channel construction through potential active landslide or road cut in the toe of ancient landslide deposits were common in the past which induced severe landslides.

d. *Lack of Public Awareness:* Due to illiteracy and lack of government effort to provide sufficient awareness to the local people on the cause and effect of such catastrophic events, the problems are increased. Due to the lack of knowledge, overgrazing, over-quarrying of slopes, improper drainage management, unplanned paddy cultivation in steep slope, construction of buildings in hazardous area, blockade of road side drain for irrigation purpose etc. are carried out which further induce the disaster events.

6. Landslide Investigation Practices:

In past no landslide investigation practices have been made during the development of infrastructures, which resulted on development of chronic landslide cases. Landslide investigation practices have been started these days by few organizations i.e. Department of Roads (DOR), Water Induced Disaster Prevention Technical Center(DPTC) etc. either for the stability of road sector or for the research to find appropriate method. Now most of the infrastructures like highways, irrigation channel, hydropower etc. are well investigated on its geological and environmental factors during planning phase with available sources of maps and aerial photographs along with site survey. But main problem during the investigation is lack of up to date maps and aerial photographs. The latest aerial photographs of whole country were snapped during 1989 with few photographs after 1993. Likewise, topographical maps of 1958, with recently prepared maps of eastern and central development region are available. The planning should have done with such instrumental restrictions. On site and desk study of engineering geological structures and land use pattern is being done with best possible skill to identify possible unstable slopes and safe quarry locations. Not much efforts have been made in the investigation of active landslides due to the cost involvement on it. Rather, a prevention work is directly

applied with some preliminary formal investigations. Even in these circumstances, few projects of DOR and DPTC are trying to investigate several landslide situations with the under mentioned techniques. DOR has taken several specific landslides of some projects under investigation for post construction results whereas DPTC has undertaken 4 model landslides in the country along with the study of several other landslide cases to workout for most appropriate investigation and prevention techniques for developing countries like Nepal. Various types of extensometers have been installed in the landslide area to examine the amount of surface movement. For this purpose, DOR has applied the straingauges whereas DPTC has applied various types of automatic extensometers like drum type extensometer, wired bed dislocation meter, guide line tilt meter etc. imported from Japan in high cost and has tried to modify it in to very cheap human based /manual extensometers by extensive research so that it will be sustainable to be applied in any area and by any agency. For this purpose two alternates have been found appropriate using wooden planks and posts. A 1/500 - 1000 scale topographic map is being prepared for the landslide and surrounding area along with cross-section at several locations. Several moving posts are being installed there and are being measured with reference to some

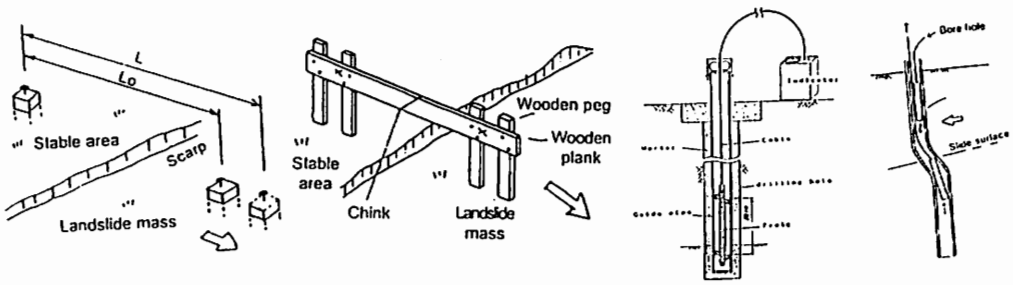

Figure 3 : Two types of Manual extensometers, Guideline tiltmeter and simple sliding surface detecting method as automatic's alternate

stable area. This has been utilized for the block division of landslide and identification of landslide mechanism. This technique is found to be appropriate, sustainable and reliable in developing countries. DPTC is applying simple tiltmeter to find the potential ground fluctuation and to compare the effect of precipitation and ground water on the ground fluctuation. Effort is made in this stage to make the investigation sustainable and simple. So, DPTC has installed manual rain gauges in all model sites to compare the effect of rainfall on other parameters like ground water rise, displacement and potential ground fluctuation. Due to the lack of transportation networks in hilly area along with expertise and budget as well, it is tried to find out the possible slip zone with one drilling only or without drilling. In this stage, data analysis and interpretation of various cases has been tried to estimate the tentative depth of deepest slip zone, comparing other factors and with careful analysis of one drilling hole only. Both DPTC and DOR are installing piezometers in their investigations to depict the condition of ground water. DPTC is trying to find out the effect of precipitation on ground water fluctuation and

the latter's effect on displacement, so that proper warning can be made in advance. Geomorphological maps with emphasis on mass movement parameters are being prepared for the landslide to identify the general cause of landslides. These investigations are being made to identify the cause and extent of landslides so that appropriate countermeasures can be applied. In other organizations and small projects, countermeasures are being applied with thorough surface investigations only because of several social and economical problems.

7. Remedial measures adopted:

Remedial measures could not be applied in all landslides except some major landslides in the road sector. Even the applied remedial measures consist of traditional methods and applied without proper investigation except some specific projects. Regardless of the slip zone, retaining wall at uphill and downhill side of the road are constructed to stop the slide for short duration which sometimes have negative /adverse effect. The prevailing remedial measures applied in highway sectors are gabion retaining walls, masonry retaining walls, surface and sub-surface drainage, anchorage work, river structural works and bio-engineering works. Specially, drainage and anchor works are applied in few projects only whereas gabion retaining walls are common. In this context, DPTC has undertaken several landslide area as its model sites and continue the first phase prevention works using various techniques after 2 years investigation.

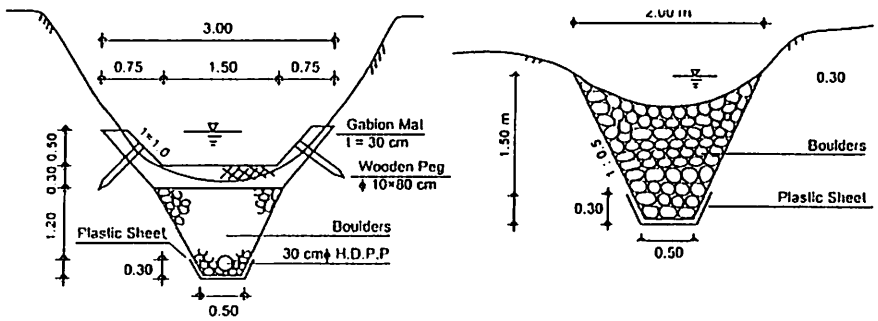

Figure 4 : Various types of surface drainage works tried to reduce the construction cost, utilizing local material

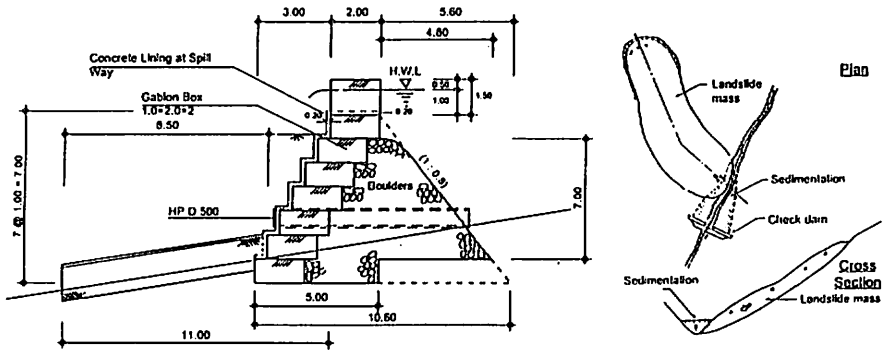

Figure 5 : Consolidation dam applied to act as toe loading at the foot of landslide block.

The model sites are typical landslide areas in eastern, central and western part of Nepal and possible sustainable and appropriate countermeasures are being applied there to see The result and for further improvement if any. These model sites are also being utilized for demonstration site to the engineers of the country while providing training. Due to lack of expertise, equipment, technology and budget, drainage well works and drainage tunnel works are not being applied yet. Very effective consolidation dam and a surface drainage structures made of local material are being tried and found to be appropriate for the developing countries.

8. Possible Improvements Necessary:

Massive improvement is necessary on the landslide prevention strategy of Nepal. The landslides juxtaposed during road construction should be tackled and minimized at first step. Then the off-road landslides should be tackled. Following are the things that can immediately be started to reduce the disaster due to landslides.

- Extensive establishment of raingauges and timely publication and circulation of the rainfall data.
- Preparation of revised and small scale topographical, land-use and geological map as well as regular aerial photographs.
- Interpretation of the existing aerial photographs and maps to prepare the hazard map for slope instability which should be utilized by the planners during infrastructure planning like highway, irrigation etc.
- Detailed hazard assessment during the planning phase of the project and proper care to be taken against un-avoidable locations.
- Safe and environment friendly construction practices and use of minimum possible explosives.
- Application of bio-engineering treatment immediately after hill cutting/filling works.
- Proper management of road side and cross-drainage, a main causes of road slide.
- Application of countermeasures in the existing slides with proper investigation rather than application of retaining wall without or with thorough/quick surface investigation, which is responsible for post construction degradation of slope stability. Monitoring by simple extensometers and moving pegs are sufficient to find the extent of slides whereas topographical, geo-morphological and land-use maps help in depicting the major causes of the slides.
- Most of the landslides and fatal debris flow disaster are found to be happened in previous consolidated debris deposits due to the disturbance to static balance by any reason. So, landslide/debris flow data base system should be established with proper location, strength and stream index number.
- Most important aspect is people's awareness against the actions liable to the landslide like improper paddy cultivation practice on uphill steep slope, over-quarrying of slopes, poor

water management, deforestation and so on. Such actions can be reduced by providing knowledge to the people by public awareness programs like exhibition, posturing, documentary, training etc. Paddy cultivation in steep slopes can be replaced by horticulture.

- Training to the technical manpower on the safe construction practices and that to the policy makers on the adverse effect of haphazard planning.
- Allocation of the responsibility of landslide data base keeping system to a single organization and support of other institutions on its functioning.
- Preparation and enforcement of land-use regulation and plan.

9. Conclusion:

Although Nepal has adverse natural condition against the stability, adverse action by the inhabitants has induced much of the instability problem. The lack of co-ordination among the inter-disciplinary department against disaster is the main cause to increase the problem further. Due to lack of people's awareness against disaster, huge loss of life and property is being experienced each year. In this context, Japan has developed its technology on landslide prevention and prediction strategy but the exact carbon copy of technology is almost impossible due to imbalance in economic standard of two countries. So, considering landslide investigation and prevention practices in Japan or other advanced countries, the modified sustainable approach is vital for the landslide prevention in Nepal. Besides, the non-structural measures like hazard mapping, people's awareness in various forms and proper co-ordination of various organizations in disaster mitigation is other important aspect. In addition, training is necessary to the field level staffs and policy makers (who always hesitate to spend time and money for investigation, saying it to be unproductive). There is no deficiency of manpower but every thing is happened due to the lack of willing and power. The sustainable concept being developed with extensive research in Nepal can be applied in the developing countries which has similar limitation of fund and expertise.

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