The Indian Landslide Scenario, Strategic Issues and Action Points

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The Indian Landslides

Landslides are among the major hydro-geological hazards that affect large parts of India, especially the Himalayas, the Northeastern hill ranges, the Western Ghats, the Nilgiris, the Eastern Ghats and the Vindhyas, in that order. In the Himalayas alone, one could find landslides of every fame, name and description- big and small, long and short, quick and creeping, ancient and new. The northeastern region is badly affected by landslide problems of a bewildering variety. Landslides in the Darjeeling district of West Bengal as also those in Sikkim, Tripura, Meghalaya, Assam, Nagaland and Arunachal Pradesh pose chronic problems causing all kinds of losses. There are landslides in the Western Ghats in the south, along the steep slopes overlooking the Konkan coast. Landslides are also very common in the Nilgiris, characterized by a lateratic cap, which is highly landslide prone.

India has a sensational record of catastrophes due to landslides, unique and unparalleled. The Darjeeling floods of 1968 destroyed vast areas of Sikkim and West Bengal by unleashing spate of landslides, causing considerable death and destruction. These landslides occurred over a three-day period with precipitation ranging from 500 to 1000 mm in an event of a 100-year return period. The 60km mountain highway to Darjeeling got cut off at 92 places resulting into loss of lives and total disruption of the communication system. Yet another landslide tragedy of an unprecedented dimension was the great Alaknanda Tragedy of July 1970 in Uttaranchal State that resulted from the massive floods in the river Alaknanda, upon breach of a landslide dam at its confluence with river Patal Ganga. A few years ago, the Malpa rock avalanche tragedy of 18 August 1998, hit the newspaper headlines as it instantly killed 220 people and wiped out the entire village of Malpa on the right bank of river Kali in the Kumaun Himalaya of the state of Uttaranchal.

Landslides in the southern India revived public imagination when the Amboori landslide of 9 November 2001 in the State of Kerala killed 23 people. In the avalanche valley of the Nilgiris, majority of landslides do occur in a loose cover of debris consisting of boulders. The major landslides in the Nilgiri hills are the Runnymede landslide, the Glenmore slide, the Conoor slide and the Karadipallam slide. In the recent times, casualties and damage due to landslides have increased in the Nilgiri hills. During October-November 1978, 90 people died. Snow avalanches have also been matter of great concern especially in the higher Himalayas and have humbled even ace mountaineers.

The economic losses due to landslides and avalanches in India are enormous and recurring, not to speak of strategic setbacks to the developmental plans.

Severity of Landslide Problems

How does one measure severity of a landslide? When a small landslide kills people at the bottom of a slope, does it become severe? On the other hand, does a huge landslide in wilderness which kills none, classed as severe? While we identify indicators and develop a suitable scale to measure severity, for sure, both cases are serious. There are some slides which are stable at sometime of the year and problematic some other time. The degree of trouble from a seasonal landslide is known to swing from zero, in dry weather, to an alarming level of hazard in the monsoon period. One simple but incomplete index of judgement could be the speed of landslide movements. Statistically speaking, landslides that moves at snail's pace (Creeping Slopes), let us say on the Eastern Himalayan slopes, record movements of the order of 5 cm in a decade for

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slopes less than 35$^{o.}$. For slopes between 35^{o} and 75^{o} , creep movement may approach 1 m in a decade. Typically movements of landslides fall in the range 1-4 cm per day. Most hazards are however associated with high speed landslides including mudflows, debris flows and debris-avalanches, which acquire speeds as high as 3 to 50 m/s. These invariably take place in the company of heavy rainfall or earthquakes, or both. Take for example the devastating debris flow in the year 1880 on the slopes of Sher-Ka Danda hill in the Nainital district of Uttaranchal. It was so swift that it traveled about 1 km in 30 seconds, killed 150 people and swept away 'Victoria Hotel', Naina Temple and other buildings and filled a part of the Naini Lake. Similarly, the flow slide of Kuekhola trestle point, (Bhandari, 1977), generated large movements in a few minutes completely destroying the huge retaining wall, the road formation, and the rope way trestle platform.

Another indicator of landslide severity could be magnitude of slope movements. The author has documented a number of examples of exceptionally large movements. One of the landslides on the north Sikkim moved down by 13 m and moved out by about 26 m. Similarly, on the National Highway 31 (Mile 9), a stretch of road sank by 5 m and moved out by 15 m in 1963. Some corrective measures were provided but the road sank again by 18 m, Bhandari (1982). Most of landslides are rendered more severe when coupled with rockfalls. Slope instability problems seem to compound when landslides involve multi-tier failures involving e.g. debris flow or mudflow in the slope cover, deep seated movements on boundary shears, soil falls at the rear scarp of the landslide, and rock fall directly hitting the road formations, culverts, bridges and the traveling public.

Yet another indicator of severity could be the volume of the landslide mass displaced. Suddenness of a landslide, its recurring nature and history and its momentum dynamics are other factors of great significance in deciding on the degree of severity of a landslide.

It is important that in India we develop and adopt a well considered scale to measure composite index of landslide severity, to influence management investments.

Man as the agent of Change

Who is responsible for the alarm (which is rightly being raised) in the areas affected by landslides? Let us take with the Himalayan example, and ask the question- why the Himalaya today faces the greatest danger of landslides? Himalaya's immature geology, meandering rivers, snow bodies, climatic variations, cloudbursts, flash floods etc., have always been there. For centuries, formidable snow avalanches did hurtle down the slopes in the higher Himalaya as they do now. If at all, the natural changes in the basic system have been, at best, marginal spread over a span of time.

The real chaos on slopes came when the man entered the scene. Vast areas of Western Sikkim, Kumaon, Garhwal, Himachal Pradesh, Kashmir and several other hilly regions fell to his axe and were robbed of the protective vegetal cover to less than 30 per cent as against twice as much considered desirable. Lopping of trees for fuel or fodder, overgrazing, increased domestic and industrial consumptions of timber were chiefly responsible for deforestation. For example, close to the India- Bhutan border near Phuentsholing (Bhutan) and Jaigoan (India), spurt of human settlements has increased the number and frequency of Landslides, over the period of past few decades. Deforestation did add to the fragile geological environment and adverse climatic conditions to cause degradation of inter bedded quartzite and phyllites. The slopes without vegetation could not be expected to hold soil cover together and widespread erosion was the natural consequence.

According to one estimate, nature takes nearly 1000 years to produce a few centimetre of top soil but destabilizing forces of nature in the mountainous areas wipe away millions of cubic metre in just one second! The rate of erosion in the catchment area of the Himalayan rivers has increased five-fold in the geological time scale; the present rate being upwards of 1 mm per year.

According to Valdiya, rivers are carrying incredibly large amount of sediment at the rate of 16.5 hectare metre per hundred sq. km of the catchment area per year, leading to rapid siltation of reservoirs and lakes. Satellite photographs taken in 1974 dramatically reveal that eroded debris carried by the Himalayan rivers have created a new landmass over 50,000 sq. km in area, extending about 700 km into the Bay of Bengal.

As the pressure of population rapidly grew, more and more of human settlements, roads, dams, tunnels, water reservoirs, towers and other public utilities were added. The network of roads in the Himalayan region is today well over 50,000 km. Some of the roads exist even at altitudes as high as 5,000 metre surrounded by mountain ranges such as Kanchenjunga (8,586 m). Khardung La at 5,600 m is perhaps the highest motor road in the world. Due to the inclement weather and extremely low temperatures (-40^{o}C), it is open for just three months in a year. The 434 km hill road from Srinagar to Leh has cut down the time of journey from 16 days to 2 days but not without creating problems of landsliding. A 300 m long stretch of mountain road, 18 km east of Srinagar (Garhwal) in the valley of Alaknanda is also badly affected by landslides involving limy quartzite and slate. North Sikkim highway too is bristling with landslide problems of a bewildering variety and so are the roads in the State of Jammu & Kashmir.

Construction of roads requires imaginative planning and methodical construction but when engineers work against time, they may not even have the basic data on geological formation, topography, drainage pattern etc. and as a result, some of the hill roads begin with landslides as witness to their inauguration functions. Let us not forget that every kilometre of road when constructed may bring about a stress relief equivalent to about 1-2 lakh tonne of rock mass and if the road cuttings are not properly protected, landslides and rock falls become imminent adding about 1,000 tonne of land loss per km annually. At many major landslide locations, the debris clearance may well be of the order of 4,000-5,000 tonne annually. The author's experience in North Sikkim and Garhwal clearly reveals that on an average there are 2 landslides every sq.km. And we tend to add one more every 6 sq.km. The mean rate of land loss is to the tune of 120 m^2 per km^2 per year and annual loss of land is about 2,500 tonne for every sq. km of area. (Bhandari et al. 1985).

Likewise, a number of dams have been built in the Himalaya including the mighty Tehri Dam on river Bhagirthi. The Dam projects over the Ganga and its tributaries in the hills alone exceed two dozen. Apart from the fear of reservoir induced seismicity, the implications of such constructions include large scale deforestation, huge excavations, resettlement problems, and consequent threats to life and property. A number of tunnels are also being made. Microwave, TV, Transmission Line and other towers are also dotting the hilly areas. Quarrying and mining, for example, in the Doon Valley, Jhiroli (Almora) and Chandhak (Pithoragarh) have inflicted heavy damages to slopes and to the associated environment.

Influxes of tourists into the hilly region have brought about tremendous pressure on land due to construction of new buildings and tourist complexes including aerial ropeways and other utilities. For water storage, underground water tanks are being built without any special instructions or precautions despite considerable bad experiences of slope instability from similar tanks, as at Mussoorie in Uttaranchal and Shimla in Himachal. Some of the constructions are coming up on old landslide masses without adequate pretreatment and investments on hillside stability, compounding the problem. Our rich cultural heritage and monuments are also under severe threat due to landslides and slope instability.

The time has come when the planners will have to recognize the problems of hilly regions, out of the box far beyond the norms of routine practice and the authorities would have to ensure that no plans are cleared unless adequate provision is made for adequate investigation and protective measures. This is what is meant by mainstreaming of disaster mitigation in the development process.

Uncertainties due to extremes of Variations

Uncertainties due to extreme of variation create a fascinating and complex Landslide scenario, especially when in league with human intervention. Take, for example, the Himalaya. It displays fantastic variations of geology, geomorphology, climate and vegetation across its mighty sweep. The southern side of the Himalaya is humid with luxuriant flora whereas the northern side is arid, barren and wears the look of a desert. If one were to decide to climb up the Himalaya, the very start will be with sweltering heat. Then one would encounter rather damp zone with abundance of exotic vegetation, then one will find the grassy highlands with the purest air to breathe. The real climbing would normally begin thereafter at an altitude of 4000 m or so. Thus, after passing through the tropical and the sub-tropical climates, the climbers enter an arctic like region, stepping into the world of snow and ice. What a variety all in one journey?

The temperature variations add to the variety. In Trans Himalaya, including the region of Ladakh, temperature during summer never exceeds 30^{o} C and in the winter season, it may fall to as low as -43^{o}C as at Dras. The rainfall variations are also astounding. On the one hand in the eastern Himalaya, rainfall is to be measured in metre whereas on the other hand, in places like Ladakh total annual precipitation seldom exceeds 10 cm. It is largely due to glacier melt that irrigates terraced fields.

It is important that we take advantage of the extremes of variation in understanding the whole range of landslide problems in their varied dimension. That should be a national programme.

Rainfall, Cloud Bursts and Land sliding

The experience suggests that reactivation of old landslides invariably takes place following heavy or prolonged rains. For the first time landslides, however, the action is usually so long delayed that the connection between rainfall and landslide appears tenuous. In such cases it is conclusively established that to name rainfall as 'the cause" would be as wrong as blaming the dynamite that rocked the building, when fuse was detonated, as the cause, although the dynamite, the fuse, the match and the man behind the blast that rocked the building, must all share the blame as co-partners!. Most landslides have multiple causative factors.

Rainfall particularly in the Sikkim Himalaya is often punctuated by flashes of cloudburst. A cloudburst comes with the speed of thunder, lasts for a few minutes to as long as three hours at a stretch of time, and usually leaves behind a trail of devastation worse than inflicted by the combined effect of rainfall in the same area, for the rest of the season. Rainfall record of the Teesta Valley for the period 1891-1965 speaks of rainfall intensities exceeding 250 mm in 24 hours, repeated more than 40 times! Taking the mean annual precipitation as 5000 mm for the Teesta Valley, the Event Coefficient (Ce = precipitation record of the event/mean annual precipitation) can be calculated. Thus event coefficients (Ce) do range between 0.06 and 0.36 which are remarkably high values from any standards, and are usually associated with landslides' on the lower side of the scale and landslide disasters on the higher side of the scale. Admittedly, conclusions derived from study of 'event coefficients' alone, without cognizance of rainfall records prior to the event and without knowledge of landslide history of the area may be deceptive. However, the fact remains that 'cloud bursts' of intensities exceeding 1000 mm in 24 hours (Ce> 0.2) trigger mass movements practically in any circumstances, and for 0.1<Ce <0.2, probability of mass-movement is pretty high. For Ce<0.1, biunivocal (unequivocal) relationship between rain and slides does not seem to exist.

The search for a relationship between 'incidence' of a landslide and 'rainfall' seems practical although it is many times more scientific to look for a relationship between the rainfall, piezometric pressure across the critical surface of sliding and the incidence of a particular landslide. A geotechnical engineer, in a great majority of cases, 'knows' neither the 'critical surface' nor the 'pore-pressure' on it. On the other hand, rainfall observations are inexpensive, simple and common, (Bhandari (1984). The difficulty arises when, like newspaper reporters, professional begin to lean on rainfall figures to explain why the landslide.

Earthquake Induced Landslides

Reports of earthquake-induced landslides surface virtually after every earthquake in hilly areas. There are professional papers on landslide that occurred due to Uttarkashi and Chamoli earthquakes. There is a report on evidences of earthquake induced Landslides in South Andaman Island after great earth quake 26th December 2004 (Malik et. al 2005). The magnitude 7.6 Muzzafarabad earthquake of October 8, 2005 triggered hundreds of landslides and rock avalanches. Translational and rotational landslides, shallow rockslides and debris flows have been reported (Owen et.al. 2006).

This is the most neglected and the least studied subject that calls for the greatest attention. Unless earthquake-induced landslides are mapped, landslide hazard zonation maps will remain incomplete on the unsafe side. Naturally any attempts to do hazard and risk assessment without the knowledge of earthquake induced landslides will be open to question. By the same logic, investments to retrofit buildings may turn futile. The subject is dealt with in greater detail elsewhere, Bhandari (2006).

Importance of Visual Observations in Landslide Studies

With the path- breaking advances in space technology and remote sensing, it is now possible to map landslides with a good degree of accuracy. Ground studies, however, remain indispensable for scientific interpretation, analyses and treatment of landslides. Visual observations are inexpensive and play a very vital role in landslide studies. India needs quality teachers to make that happen.

A landslide is a generic term that embraces a wide variety of slope failures and mass movements. The morphology of a typical landslide depicting the three essential elements namely (a) subsidence at the head of the landslide (b) heave at the toe of the landslide and (c) distortion of the landslide mass, is all too familiar. In a well developed landslide, the slide movement is known to occur on discrete boundary shears. The landslides, which move long distances or those that occur repetitively, do develop highly polished and slicken-sided slip surfaces at its basal and side boundaries. Such a slip surface often carries both the visible and invisible signatures of the moving mass. In many cases, the signatures on rocks would be quite obvious to the human eye, especially on side shear boundaries. Many such details and sensivities are missed out in remote sensing.

When landslide boundaries are well exposed, very little investigation is necessary to elucidate the boundaries required to under the slide dynamics. In other cases, the first thing an investigating eye will look for is the comparison between the geomorphology of a slope surface *before* and *after* the landslide. Here again, there are straightforward cases in which slope deformation is too dramatic and conform to generally recognizable slope behaviour. Likewise, the landsliding on the well-developed planar surface, for instance in stratified rock masses, is usually easy to explain. The difficulties, however, arise in dealing with cases where although land subsidence is clearly seen but the visual evidence of landslide features, such as the lateral shift, is lacking. In such cases, surface subsidence needs careful study to arrive at a distinction between *subsidence* and *landsliding*. Also there may be cases in which evidences of downward and outward movements of a landslide are easily mapped but determination of the slide boundary is not easy. The procedure requires the best of ocular geomorphology, and much more. A trained eye is often able to classify situations by comparison of slopes *before* and *after* a slope failure.

Let us consider landforms generated by some well-known landslide types. A small observational effort in study of landforms can yield big diagnostic gain. The observed back-tilting of slipped masses at the head of a landslide serves as a strong pointer to a rotational slide. The message becomes unambiguously clear when trees or electrical poles located in the head region of the slide show visible backward tilting. There are cases in which tilting is absent and instead a graben is seen in the landslide head region. If so, one could rule out the possibility of rotational failure and look for a possible non-circular or a composite failure surface. Sudden change in the geometry of slip surface, driven by the geology of the area, is typical of such failures. There are cases in which a failed slope breaks into a myriad of pieces. The heterogeneous character of the slope mass, complex distribution of shearing stresses and non-uniform mobilization of shearing resistance at the slide surface are some of the inferences that follow the study of the failed slope profile.

Such training in reading simple landforms is indeed pre-requisite to reading of more complex landforms, for instance, landforms arising from the interaction between two or more landslides. Often the failure may start as individual landslides but upon neglect or progression, combine to generate bigger landslides. The growth of such interacting landslides may be facilitated by discontinuities and shear zones, especially if present in proximity. An interesting situation arises when the lower-end of the higher landslide places a sudden load on the head of the landslide immediately below. Such a suddenly placed load may kick off motion in the lower landslide in turn, destabilizing the upper one. The head loading, when sudden, develops excess hydrostatic pressures in the head region of the lower landslide, Hutchinson and Bhandari (1971)

Those who disregard these ground realities in stability analyses will doubtless endup with wrong conclusion and consequently with expensive and yet ineffective landslide remediation packages. The point at issue is therefore how to bring about transformation in our approach from adhocism to holistic, multi-disciplinary study of landslides.

Face and Place Value of Landslides

Lush green slopes with an old landslide will easy dodge an investigator and give a false indication of safety. Similarly, in a dry weather, even a major repetitive slide would deceptively look stable. Surface looks of slopes are therefore not trust-worthy, a fact to be always remembered.

Landslides will have to be understood interms of the context and situation in which we observe them at different times of the slope history. Here are some examples:

- Old landslides dormant for decades or centuries, including those which are known to be dormant for decades under a thick cover of vegetation, without showing any signs of instability or activity.
- Old landslides which are known to be dormant for decades but are feared to activate due to neglect of slopes, ongoing developmental activities or such other reasons.
- Landslides only a few years old, but with no recurrent activity observed since then.
- Old landslides, which appear to be dangerously big, but their activity levels remain unstudied and their slope history is unknown.
- Recent Landslides with clear evidence and/unquestionable potential for repetitive activity and enlargement.
- Known Landslides, sporadically treated with partial/inadequate/temporary/ non-engineered remediation.
- Recent small landslides, with evidence of self-healing.
- Landslides, old or recent, under effective (engineered) control.

The Current Status of Landslide Studies in India

Landslide investigations

A typical landslide investigation includes macro-geomorphological mapping of the associated area, its large scale location specific mapping with special attention to topography, geology, geomorphology, seismo-tectonics, surface and subsurface drainage characteristics, landuse and land management. Mechanics of the landslide is often unclear and its analyses incomplete without systematic geotechnical, meteorological and seismic characterization of slopes including mapping of micro-geological details, evaluation of seismic site effects, and study of the environmental impact of (haphazard) urbanization. Elucidation of landslide boundary shears, monitoring of piezometric pressure and its buildup and dissipation, measurement of time dependent surface and subsurface displacement patterns, mapping of exposed shear zones, slip surfaces, surface cracks, land subsidence and heave, and behavioral studies of buildings and other structures also form an integral part of the landslide investigation. Reconnaissance surveys and preliminary landslide studies logically leads to identification of the locations for representative soil and rock sampling and decision on the simulated stress path to determine total and effective shear strength parameters. The ensuing stability analyses could be deterministic, probabilistic or both. Only after the results of such stability analyses are available that one could prescribe control measures to fix a slide.

There is not even a single case of landslide study in India to date, which can be called scientific, systematic and comprehensive. In a great majority of cases, there is hardly any connection between the report of a landslide investigation and engineering design of control works. For a landslide study to be scientific, it is important to go significantly beyond mapping geology and naming probable causative factors and design control measures merely based on the so called past experience. Pinpointing of primary and triggering factors and their inter-connection, delineation of slide boundaries and understanding of sliding mechanism, determination of representative shear strength parameters, estimation of pore pressures and their variations with time, and stability analyses are the pre-requisites to design of remedial measures. For a study to be systematic, choice of equipment, types of tests and test procedures must be judicious. And for landslide study to be comprehensive, it must necessary trace the landslide history of the slope and relate the investigations and analyses to the demands of current and the future land uses. Modernization of the tools and techniques of landslide investigation and creating a pool of trained professionals are most essential. Considerable investments are necessary in adding modern equipment for insitu and laboratory determination of shear strength parameters which in turn would require investments in undisturbed sampling especially of shear zones and slicken-sided slip surfaces, and sample management. Basal boundary shears are often difficult to establish and therefore investments on inclinometers, slope indicators and deflection tube torpedoes are necessary to define the plane of sliding. Uses of photographic techniques for rockfall investigations are common elsewhere in the world and deserve to be adopted in India. Remote sensing devices for study of rapid motion landslides and their run-out effects also need to be introduced.

Most landslides being the result of poor slope and sub slope drainage, hydrological studies of the catchments associated with landslides are essential. In the areas of complex landforms and landslides with water streams, springs and ill defined overland flow; radioisotope studies may be necessary well beyond the confines of the catchment under investigation.

For the ultimate objective of an investigation to be achieved, the coupling between study of landslides through remote sensing such as by satellite imageries and ground surveys of the very landslides should be logical and strong. Landslide Investigation without remote sensing is often blind. By the same logic, landslide investigation without ground studies and validation is lame.

Common landslide vocabulary involving standardized definitions and landslide classification systems are yet to be developed for uniform application in landslide studies across the country.

Landslide Hazard Mapping

The first small scale landslide hazard map of India was published by BMTPC in October 2003 and released on 30 January 2004. The strategy and the approach to landslide hazard mapping used were based on the current state-of-the art, taking fullest advantage of the enormous amount of information and data on Indian landslides, mostly published and some unpublished. The available thematic factor maps of India were used in hazard mapping on a GIS platform. A high degree of match was found between observed and predicted landslide hazard. The National Remote Sensing Agency of the Department of Space of the Government of India published two volumes of Atlas on Landslide Hazard Zonation. The Atlas, Volume 1 refers to the State of Uttaranchal and Volume 2 to the State of Himachal Pradesh. The pilgrim routes were targeted in mapping to a scale of 1:25 000. The above initiative spearheaded by NRSA was a team India effort in which a number of institutions participated. Notable among them are Wadia Institute of Himalayan Geology, Dehradun, Central Building Research Institute, Roorkee, Remote Sensing Application Centre, Lucknow, Remote Sensing Application Centre, Shimla, Defence Terrain Research Laboratory, Indian Institute of Technology, Roorkee, Advance Data Processing Research Institute, Hyderabad, Indian Institute of Remote Sensing (IIRS), Dehradun, Regional Remote Sensing Service Centre, Dehradun, Space Application Centre, Ahmedabad and G.B.Pant Institute of Himalayan Environment and Development, Srinagar

The reliability of the maps was questioned in the first S.P.Nautiyal Memorial Lecture, Bhandari (2002), chiefly because of the procedural deficiencies in integration of factor maps that led to a poor correspondence between the mapped and the observed landslide hazards.

Geological Survey of India has covered about 41694 sq km and 3448 line km of road corridors through landslide hazard mapping on macro scale (1:50000 / 1:25000), and the balance of 6550 line km is in its current plan. It has mapped nearly 10000 km along the hill roads to a scale of 1:50 000 and 1: 25 000. An inventory of Landslides of Northwest Himalaya has already been published in 2005 and further work is in progress. For all this work to be of practical use, the maps will necessarily have to be user friendly , for different target groups at a large enough scale.

Central Building Research Institute, Roorkee has carried out landslide hazard zonation in parts of Alaknanda and Bhagirathi valleys as also in the Darjeeling Himalayas and in east and south districts of Sikkim. Besides above, landslide inventories have been prepared for major highways of Garhwal and Sikkim Himalayas and a database has been developed for Rishikesh- Badrinath road. Central Road Research Institute has also developed a database on Indian landslides as a part of natural disaster knowledge network in late 2000 and early 2001.The database includes more than 200 landslides investigated by CRRI since early 1960s.

Landslide Remediation Practices and Technology Needs

Landslide Control in India continues to move on the traditional lines. In most cases, an attempt is made to fashion the landslide remediation packages to suit specific landslide sites. A typical landslide package usually consists of a combination of slope dressing and treatment, surface and subsurface drainage and provision of restraining structures (such as nailing, bolting, and anchoring). In special cases, such as for example at Sher-ka-danda hill in Nainital and Khunni Nallah, prestressed anchors are in use. Reinforced earth applications are nowadays quite common. The other courses adopted to avoid landslides are tunneling, bridging the landslide-affected area or re-routing. Border Roads Organization is the premier agency in the country to manage landslides and is also the repository of experience on technological developments.

Bolting, anchoring and tie back solutions have all been mastered by agencies dealing with Civil and Mining Engineering problems in India. Numerous successful examples of stabilization of problematic slopes and landslides, open cast mines, tunnels, road cuttings, wharf and retaining structures, etc., bear ample testimony to the great potential the reinforcing technologies hold. It is, however, somewhat disappointing that the technological interventions for landslide control, in many cases, have not always been quite sensitive to the real needs of the specific sites. There are examples where slopes were reinforced when simple remedial measures such as drainage would have done the job. There are also cases in which prestressed anchors where used although simple nailing or bolting would have been enough.

In many cases, the ready availability of a technology at any given time and place had driven its choice at the expense of better-suited technologies. On the other hand, instances are not wanting to demonstrate that judiciously chosen technologies based on scientific analysis have made perceptible difference to the success of a landslide remediation programme.

Technological Innovations in India in the area of Landslide Control have been very few and far between. If at all any, they have come more by the sheer weight and length of our experience, and by trial and error, and importation of technology, than by our sense of creativity.

The technologies for slope treatment such as the Asphalt mulch technique of vegetative turfing and jute and coir netting were first developed by the Central Road Research Institute in the late seventees and the early eighties. CRRI also promoted the technology of subsurface drainage using horizontal drains to synergise with surface drainage measures. The first application of horizontal drains in India was in the stabilization of deep-seated landslides in the Nilgiri hills. G.B. Pant Institute at Almora has also contributed immensely to slope stabilization by vegetative turfing.

Construction of gabion walls as an element of landslide remediation package is common in India. Central Building Research Institute was perhaps the first to experiment with Netlon Technology at the slopes of Laltibba in Mussoorie in the eightees. It is also credited for developing the innovative technology of anchored drum diaphragm wall, Bhandari (1984). The first portable hand-operated slope-stitching machine by use of short piles was developed and used at the site of Kaliasaur landslide in Uttaranchal in the early eighties.

Bioengineering is another re-emerging way of improving slope stability. The use of bioengineering methods is not new to India although what we practiced was not known by this name. The technique dates back to 12th century China, when brush bundles were used to stabilize slopes. In the early 20th century, similar techniques were used in China to control flooding and erosion along the Yellow River. In Europe, especially Germany, bioengineering methods have been used for over 150 years. Documented use of bioengineering in the United States dates to the 1920s and ’30s. Stream bank stabilization, timber access road stabilization and slope restoration were common applications. After World War II, with increased access to earth-moving equipment and the development of new structural slope stabilization and erosion control methods, bioengineering practices all but disappeared. In the last 20 years bioengineering has been recognized as a re-emerging technique to provide erosion control, environmentally sound design and aesthetically pleasing structures.

Advantages of bioengineering solutions are its low cost and lower long-term maintenance cost low maintenance of live plants once established, improved strength over time as root systems develop and increase structural stability and environment friendliness. The limitations include short installation season, limited availability of right kinds of plants and paucity of trained labour where needed.

There could be a number of competing landslide remediation packages to fix the same landslide and all of them may be equally sound, technologically speaking. The traditional way has been to pick the least expensive package without regard to the technology deployed or to the implementation time. For example, letus say that a slide can be stabilized either by use of anchors or simply by improving drainage. The preference among the two should go to the latter, even if the costs tend to be little higher. Anchoring with bad drainage continuing would not remain effective in the long run whereas improved drainage of a slope may render it durable stability.

The Indian slope stabilization practices need an urgent review and modernization.

Slope Instrumentation, Monitoring and Landslide Prediction

The first landslide instrumentation initiatives were taken by the Central Road Research Institute in early 1970s, Bhandari (1980). Hydraulic standpipe piezometers were used for pore pressure measurements. Electrical resistivity method was used to determine slip surface of landslide at Snowdon in Shimla. Water level indicators were used to monitor relative ground subsidence and a crack cum tilt measurement device was developed and used for measuring progression of crack widths and tilts of structural members in buildings affected by landslides.

Central Building Research Institute at Roorkee was first to establish a landslide-monitoring laboratory equipped with the latest equipment at that time. Most of the landslide instrumentation related to monitoring of pore water pressures and surface and subsurface displacements. Several innovative devices were gradually added to supplement EDM observations. The first General Report on Prediction of Landslide Behaviour through Instrumentation for Indian landslides was presented at the third International Symposium on Landslides held in New Delhi, (Bhandari (1980)). The first state-of-the art paper from India on "Simple and Economical Instrumentation and Warning Systems for landslides and other mass movements", presented at the Fourth International Symposium in Canada, introducing the whole range of instruments for landslide monitoring, (Bhandari (1984)).

Prediction of Landslides based on time-dependent displacement behaviour of slides was examined and pitfalls in the application of tertiary creep model of landslide forecasting was examined (Bhandari, 1988). The model did not find acceptability because much of the damage due to slope displacements usually occurs well before the state of tertiary creep is reached.

Early Warning against Landslides

Early warning against landslides based on the rainfall as an indicator has been very common. Continuous monitoring of rainfall at the site of a known landslide, estimation of infiltration, overland flow and evaporation, linking rainfall with consequent pore pressures and displacements and related stability analyses provide powerful clues to the possibility of a landslide.

Not even a single early warning system has so far been installed on any of the landslides in India. Centre for Disaster Mitigation and Management at Vellore has developed several schemes of Early Warning against Landslides, ready for implementation. The scheme for early warning against rockfalls and rapid motion landslides is based on wire fence actuated signals. For landslides of repetitive kind, multiple indicator approach is utilized. The first time slides are difficult to predict for early warning and requires further research on priority.

Integrated GPS and IT & C based real time monitoring hold a great promise as tools for early warning against certain types of landslides. The advantages GPS are that it is capable of measuring deformations to sub-centimeter level, it requires no line-of-sight between the observation stations unlike other conventional sensors and it enables continuous monitor of deformations even during unfavorable weather conditions. Satellite Radar Imaging (SAR) and the Global Positioning System (GPS) are being pursued vigorously to tap their latent potentials. One might also exploit air-borne system of SAR, Synthetic Aperture Radar, for relief support and damage assessment. Contrary to space based SAR's; the existing technology provides an adequate resolution in airborne applications. The required frequency of observation could be ensured by mobilizing aircraft globally over potentially affected areas. It is possible to achieve adequate performance with about 30 aircraft equipped with satellite links, operating from the existing airfields.

The applications of GPS are bound to multiply. During the late eighties, GPS technology offered new possibilities for tectonic geodetic surveys. For example, in 1986, GPS measurements were performed in the K2 Area. In 1991, a GPS network for monitoring the movements of the earth with the possibility of detecting the relative movements between the different blocks of Himalayan Orogeny was established at the behest of the European Economic Community, Scientific Commission. The new work covers an area between Trisuli and Arun Rivers in longitude 85^0 to 88^0, while in latitude it lies between the Indo-Nepal border and the Zangbo River in Southern Tibet (26^0 30' - 31^0 15'). The measurements taken in 1996 were to be pursued every 5 years so as to detect the shifts of the points.

Sokobiki have reported GPS observations at Neuta landslide in Kochi, Japan. The survey which began in December 1991 is one of the first practical project of this kind taken in Japan. From the results of measurement by GPS, it was concluded that the precision for sloping distance is within one cm, and for each vector component or for each height, is within 2 cms. From the result of observations conducted during 1991-93, the annual horizontal displacement of Neuta region was found to be 45 mm. It was also concluded from the results of three years of GPS observation that GPS is an adequate tool for observing the landslide movements and landslide surface features. It is expected that GPS surveying would be (a) developed further to facilitate quality monitoring in a cost effective manner, and (b) coupled to real time early warning systems. One case study in Alpines indeed proves the GPS technology can coupled with real time telemetry. For this purpose a GPS based continuous monitoring system of landslide motions measurement has been developed. A few stations are used to define a reference frame and have therefore to be placed in stable terrain such as bed rock. The remaining stations are the monitoring points situated in the deformation area. Each station consists of a GPS antenna, GPS receiver and data transmission unit.

For early warning, it is not enough to develop schemes of instrumentation and measurement suited to specific situations but the red light levels (thresholds) will have to be determined for different situations, without which decision making will be a nightmare.

Landslide Education

There are, as of today, no exclusive educational courses or training programmes on Landslides. The considerations of slope instability in general and of landslides and landslide disasters in particular are embedded in traditional courses on Geology, Geotechnical Engineering, Earth Sciences and Highway Engineering. Engineering Geology. What is being taught is seldom being related to native Indian problems.

Since certain class of landslides could be predicted and most landslide disasters could be averted by the prepared communities; landslide awareness, education and training should become integral part of landslide disaster mitigation strategy. Blending of landslide education with educational curricula, institutionalization of specialized education on landslides by research and conduct of community awareness programmes deserve high priority. Self-education programmes on Landslides could be particularly helpful for in-service professionals. Centre for Disaster Mitigation and Management at Vellore Institute of Technology, Vellore begun to promote self-education through knowledge based products such as CD-ROM. The first CD-ROM on learning to live with Landslides was released by CDMM at VIT on 9 January 2006.

Standardization related to Landslides

All the following BIS standards related to landslides are dated and need urgent revision, and enlargement of the scope of standardization itself.

- IS 14496 (Part 2): 1998 Guidelines for preparation of landslide-hazard zonation maps in mountainous terrain.
- Part 2 Macro Zonation
- IS 14458 Guidelines for Retaining Wall for Hill Areas
- Part 1 Selection of Type of Walls
- Part 2 Design of retaining/breast walls
- Part 3 Construction of Dry stone walls
- IS 14680:1999 Guidelines for Landslide Control
- IS 14804:2000 Guidelines for Siting, Design and Selection of Materials for residential buildings in Hilly Areas
- National Building Code (NBC) 2005.

Documentation of Indian Landslides

Indian landslide studies have been published and are being published chiefly in journals and proceedings of the national and international conferences. The first major initiative to pool the case records and papers on Indian landslides was made jointly by CBRI and CRRI by hosting an International Symposium on Landslides in India in 1980. Eversince, the event has been institutionalized by the International Society of Soil Mechanics and Geotechnical Engineering as a four-yearly event. Three volumes of the Proceedings of the above Symposium plus Indian Papers contributed to the subsequent International Symposia held in Tokyo, Switzerland, Norway, New Zealand etc provide a wealth of information on Indian landslides.

Research, Development and training related Issues

- Standardized Uniform Landslide terminology, classification System, hazard zonation mapping scales and methodology, and rigorous procedures of ground validation.
- Scientific Methods of landslide hazard, vulnerability and risk assessments.
- Scientific approach of integrating Landslide hazards into multi-hazard mapping.
- Studies on earthquake- induced and earthquake-triggered landslides.
- Methodology of landslide damage assessment
- GIS based hazard, vulnerability and risk assessment
- Deterministic and Probabilistic stability analyses of complex natural and manmade slopes and landslides
- Scientific Design of surface and subsurface drainage systems and field evaluation of their efficacy
- Innovative technologies for mechanized construction of complex subsurface drainage networks
- Introduction of sound geotechnical investigational equipment and procedures for slope characterization

- Quantification of environmental degradation, cost of loss of land and agriculture produce and of traffic delays
- Retrofitting and Protection of heritage buildings in landslide prone areas
- Development of instrumentation and slope monitoring for early warning including early warning thresholds and criteria
- Study of landslide dams and management of consequent threats
- Fashioning landslide rescue operations to their typology

Strategy for Development

The cry for Integrated Mountain Development on one hand and eco-vandalism in our mountains, the other hand, has brought to focus the need for eco-technology to co-exist with its all powerful and awesome first cousin market-technology. While for 'eco-technology' the supreme consideration is man, as it seeks to protect and preserve all forms of life and strongly calls for restoration of interdisciplinary development ethos.

For our fragile mountains to be saved from the ever increasing negative impact of slope instability, the experiences of past must be consolidated, the available body of information and data should be synthesized, a powerful data base should be created, the entire mountain range in general and the problematic unstable slopes in particular should be mapped and classified to meet diverse landuse requirements. Construction and development activity should be appropriately regulated with in-built provision for simultaneous implementation of protective measures, short and long term interests should be safeguarded through systematically launched and strictly monitored scientific studies, old constructions should be appropriately strengthened and maintained, forest cover and vegetation should be restored, drainage measures should be augmented and a national network be established not only to give premonition of impending disasters but also to oil the machinery for implementing protective works for relief with speed and efficiency.

Operational Issues

- Integrating landslide concerns in development of Multi-hazard Disaster Management Plans at different levels.
- Creating Network of knowledge based institutions dealing with landslide studies for effective implementation of national landslide agenda
- Innovation in the Management of multi-institutional multi-disciplinary teams
- Switchover from piecemeal remediation of landslides to onetime (simultaneous) and holistic implementation of control measures
- Management of change from outmoded technologies of landslide remediation to state-of-the-art technology based landslide control.
- Private sector and Insurance sector participation in environmental protection of slopes.
- Establishment of Disaster Knowledge Network (a network of networks) and national clearinghouse of information
- Embedding landslide mitigation measures in development plans
- Landslide education, public awareness and local capacity building
- International linkages, cooperation and joint initiatives (for examples-under SAARC)

Administrative Issues

- Introduction of progressive landslide project implementation and monitoring guidelines and writing of handbooks and Manuals for adoption.
- Streamlining of procedures for speedy funding of priority/fast track projects
- Switchover from conventional bureaucratic benchmarking and project progress evaluation to peer-centric progress review, evaluation and mid-course correction.
- Seeding the concept of landslide prevention, and opportunity costs in administrative management of landslides

Financial Issues

- Criteria for disbursement of funds for servicing different areas of landslide mitigation
- Building costs on preventive action and long-term maintenance of major problematic slope development budget.
- Creating techno-financial regime for landslide project implementation
- Disbursement of landslide mitigation funds to non-governmental agencies and organizations

Legal Issues

- Techno-legal regime for introduction of sound slope protection, planned urbanization, regulated landuse and environment friendly land management practices
- Zero tolerance against deliberate environmental violence and unhealthy construction practices
- Law governing new constructions on problematic slopes and in the landslide prone areas.

Vellore Declaration 2006 on Indian Landslides

Some of the well known landslide experts, after an interactive roundtable meeting held at the Centre for Disaster Mitigation and Management at Vellore on 16 March 2006, made the following specific recommendations to NDMA, DST and other agencies, for expeditious implementation:

1. The National Disaster Management Authority should accord even higher importance than at present to landslide studies and declare landslide disasters as a major area of recurring concern to a large cross section of Indian population especially those living in the Himalayas and Himalayan foothills, the North Eastern Region, and the Western Ghats. Such formal recognition will not only give fillip to reliable hazard, vulnerability and risk assessment in the hilly areas but would also help protect from landslides, India's rich cultural heritage and places of pilgrimage, strategic and lifeline buildings, roads and communication systems. Unlike earthquakes, many types of landslides could be avoided or prevented and catastrophes averted through instrumentation, vigil, healthy slope management practices and landslide education.

2. Encouragement, support and adequate funding should be provided by State Disaster Management Authorities, the Department of Science and Technology, the Border Roads Organization, the Geological Survey of India, the Indian Space Research Organization, the Defence Research and Development Organization, the India Meteorological Department and the Council of Scientific and Industrial Research and other related agencies in order to promote research and development work, systematic field

investigations and large scale mapping, as a matter of urgency. Such initiatives will help pave way for reliable landslide hazard, vulnerability, risk and damage assessments and ensure cost effective design of protection works.

3. NDMA, NIDM and DST should consider setting up of dedicated National Groups on Landslide Studies (NGLS) in different parts of the country. It would be essential to network these Groups to facilitate free exchange of information and expertise, and establishment of databases on all aspects of landslides. These Groups should be charged with the responsibility to carry out programmes and projects including scientific documentation of best practices, besides supporting landslide remedial services, disaster education and training. NGLS should be tasked to evolve through interactive dialogue harmonized landslide terminology, unified landslide classification systems, purpose based hazard mapping scales, and promote scientific approaches to landslide studies and remediation. Each one of the NGLS must necessarily be parked in a knowledge based institution with proven expertise on landslides and deep commitment to the programme implementation as it develops.

4. Individual professionals, study groups and organizations must exercise utmost restraint in publishing landslide hazard maps, without adequate test of field validation. Government funded organizations should not allow inclusion of uncertified maps in any of the government reports and publications. Uncertified hazard maps represent no more than work in a preliminary stage of progress.

5. Greater levels of investments are necessary by NDMA and DST for studies and projects leading to forecasting and prediction of Landslides. Unlike earthquakes, individual landslides, if scientifically investigated, instrumented and monitored, studied and analyzed, could be predicted, and landslide disasters that would have otherwise occurred, could be averted. Higher order of attention and greater levels of investments than at present, are also essential to create good examples of functional and reliable early warning systems against landslides.

6. Ministry of Human Resources, NDMA, DST, CSIR, UGC, AICTE, the State Disaster Management Authorities, and the Corporate Sector should promote landslide education at all levels through innovative programmes fashioned to meet the diverse needs of different target groups such as communities, professionals, landslide disaster managers, decision makers, press and media and others. We emphasize the need of developing audio-visual and other teaching aids and knowledge based products to improve the quality of teaching. There should be quality improvement programmes for in-service teachers.

Recommended Ten Point Agenda for Adoption

1. As of today, the country is grossly deficient in good, pace setter examples of Science based and technology supported Stabilization of landslides. Our first priority should be to demonstrate conclusively by example the power of modern science and technology to fix some of the chronic Landslide Hotspots, in high landslide risk areas. This will have to be ensured by a truly multi-disciplinary expert team, charged with the responsibility, either at the state or at the national level. Once such examples are visible, the practice of the profession will dramatically improve to yield cost and speed effective control of landslides.
2. As of today, the country is without a single good example of early warning against landslides even though such a warning is possible for many types of landslides. Since early warning can save lives and support stitch in time, early warning systems systems

should be tailor-made to fit specific high danger landslides. It is necessary to give a fillip to landslide early warning research and create pace setter replicable examples of Site Specific Early Warning Systems; and link such systems intimately with public awareness and landslide disaster management practices

3. As of today, the country lack capacity, especially in multi-disciplinary expertise and state-of-the-art infrastructure and technology. We need to create and nurture dedicated and committed network of teams to introduce and sustaining fundamentally sound landslide investigation and cost-effective slope remediation & prevention practices.

4. The education on landslides is currently part of standard courses in engineering geology, geomorphology, earth sciences etc., not effectively related to the beauty and complexities of native problems. Promotion of landslide education as a part of overall Disaster Awareness, Education and Training is essential, at all levels. Crash programmes and self education and e-learning programmes hold a great potential, if fashioned to meet the needs of different target groups. Education should be fully supported by state-of-the-art kits and knowledge based multi-media products.

5. Multi-hazard districts of the country have been identified without reference to landslide hazards. It is important that landslide concerns get woven into multi-hazard mapping and in the practice of overall hazard, vulnerability and risk assessments. Investments are necessary to establish approaches facilitating estimation of risks due to landslides inclusive of co-seismic as well as post-seismic landslide events, as well as tsunami –triggered events.

6. The Vulnerability Atlas of India does not report on Landslides. Currently it is being updated to include landslide hazards as reflected in the Landslides Atlas of India. This too will not serve the purpose as the information refers to a small scale, not suitable for development planning or risk management. We need to create good pace-setter and user-friendly examples of large scale landslide hazard mapping in selected high risk areas, recognizing urbanization effects and demonstrate their practical use to different target groups.

7. A number of our heritage and archaeological buildings are under threat, being supported by unstable mountain slopes. It is a national obligation to protect pre-identified Heritage and life line buildings and strategic roads from landslide disasters by pro-active remediation.

8. As of today, we have not all Standardized landslide definitions, classification system, hazard mapping scales and procedures. The landslide related BIS codes are also dated. Sound professional practices will continue to elude us until a common language base is established.

9. Information in useable form is the key to successful landslide investigation and management. It is necessary to take the dust of (revive) the decade old dormant project on establishment of a Landslide Knowledge Network, and couple it with the National Disaster Knowledge Network.

10. Invest in Research and Development in peer-identified high priority areas, outlined in the paper.

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