

**THEMATIC SESSION A2: LANDSLIDE, AVALANCHE AND
OTHER MASS MOVEMENTS**

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ABSTRACTS

**PHATA LANDSLIDE – GEOTECHNICAL AND GEOLOGICAL
STUDY**

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A detailed study was carried out on a slope which includes the Phata village (Guptkashi – Gaurikund road sector) where landslide of July 2001 caused heavy damage to life and property.

Topographic survey was carried out and contour map of the Phata landslide on 1:1000 scale with 1m contour interval were prepared.

On the slope two major drains are present, which are the main water sources in this area. Height of the crest from the road level is 135m. The middle portion of the slide is having mostly boulders, rock fragments and fine materials. Tension cracks developed due to sliding are present on the right flank and near the crown of the slide. The cracks are of 20-30cm width and 20-25m length.

Soil samples from different locations of the slide area were collected and analysed in the laboratory to evaluate the Geotechnical properties. Seismic

refraction survey was also carried out. The seismograms of the site show two distinct layers. Broadly it can be inferred that the overall thickness of the loose material in the middle of the slope ranges from 9 to 12m.

Slope stability analysis was carried out to ascertain the existing stability of the slope. The factor of safety under static condition without pore pressure turns out to be 1.43. Factor of safety was also computed for the local steep portions of the slope separately. The factor of safety for such steep slopes under static condition without pore pressure turns out to be around 1.2

With rise in pore pressure the factor of safety value turns out to be marginally more than unity (FS = 1.04) indicating the marginal stability of the slope. The seismic stability analysis was also carried out for the slope which shows that seismicity of the order of 0.15g may trigger slips on the slope.

The local topography of the slope is such that the drain flowing almost through the middle of the slope can carry considerable debris. However, the slope may not fail unless there is some major triggering factor. The human settlement in the form of school building, bank, post office, the local village level offices, shops and the residential houses located at foot hill slope may get affected in the eventuality of slide due to seismicity or rain.

The slope material has considerable silts and the permeability was found to be of the order of 10^{-6} cm/sec. As a result due to heavy rain continued for couple of days it is expected that pore pressure on the slope may rise and could trigger the local slip. Uttaranchal being on the high seismic zone the effect of seismicity plays a major role on the stability of the slope. Seismicity coupled with heavy rainfall can obviously trigger a major slide. However, the extent of the damage will depend on the magnitude of failure.

**SONAPUR LAND SLIDE: MASSIVE LAND SLIDE AT KM 141.740
ON ROAD SECTION JOWAI –BADARPUR OF NH-44**

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The road Shillong-Jowai-Badarpur-Churaibari-Agartala which has a total length of 482kms, and links Shillong, the capital of Meghalaya, with Agartala, the capital of Tripura state. It is the only line of communication for road transport for the state of Tripura, Mizoram, part of Manipur, Assam and Meghalaya.

An active and massive rock cum debris slide zone exist near to Sonapur village at km 141.740 ($92^{\circ}21'$, $25^{\circ}05'$, 83C/4) on the road sector Shillong-Jowai-Badarpur-Churaibari of NH-44. Probably due to severe earthquake in 1987 in the region, strata of this mountain developed further cracks and as a result a massive landslide got activated in 1988. Gully/ valley formation in this young mountain is causing massive flow of debris in every monsoon. Since then, lacs of cubic meter of debris has flow down. Though this slide zone did not cause much disturbance to road communication/ surface during 1988 to 1998, but during the monsoon of 1999, the slide area became suddenly very active and caused massive damages every year there after. At present, the landslide extends to a length of about 220 m and a height of approximately 370m above the road level while its breadth varies from 40m to 220m. The slide covers an area of 0.127sq km.

This massive, land slide which actually is a debris flow, has been causing severe disturbance to the road communication year after year. In Aug–Sep 2000 this road remained block for 22 days, in June 2001 and July 2004 for

a period of 10 days and again during the current year in June 2006, it remained block for one week continuously because of this landslide. However, any blockage to this vital link do not only impose major problem in management of landslide and traffic but also has major bearing on availability of essential commodities and their prices and also on National security.

This particular paper deals with the major problem of this land slide, its behavior, geology of the area, cause of the slide and the manner it gets activated and continues to flow. The paper also discuss about the measures taken in past to contain the slide, efficacy thereof and the alternative proposal that could provide relief to the road users.

**SLOPE STABILITY STUDY AROUND SERCHHIP HMARVENG,
DISTRICT SERCHHIP, MIZORAM**

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The entire state of Mizoram is highly susceptible to landslide due to its structurally controlled intensely dissected immature topography, fragile rock condition, high rainfall accompanied by frequent earth tremors. The hillslope stability has been further affected by extensive deforestation, unplanned development of road benches and human settlements and indiscriminate Jhum cultivation on steep hill slopes. The southern most three districts Lunglei, Lawngtlai and Shaiha of Mizoram experienced devastating landslides during wet season in 1993 and 1995. Serchhip town, the headquarters of Serchhip district, located about 150km south of the state capital Aizawl, is situated on a N-S trending water divide and dotted with numerous landslides, particularly along NH-54. A 900m long and 300 m wide NW-SE trending hillslope around Serchhip Hmarveng, Serchhip district of Mizoram has been severely affected by subsidence and as many as 13 no. of landslides of varying dimensions, endangering lives and properties of hundreds of people. This distressed hillslope lies over Middle Bhuban Formation of rocks represented by folded very soft shale and inter bedded soft sandstone and siltstone belonging to Bhuban subgroup of Surma Group of Tertiary age. The affected hillslope is predominantly made up of soil and slope wash debris with rare exposures. The stability analysis of this distressed hillslope in different saturation condition of the slope forming materials reveals drastic reduction of factor of safety from 0.88 in natural moisture content to 0.49 in completely saturated condition. This study clearly indicates that poor shear strength of slope forming material, severe scouring along nala courses, barren nature of slope, heavy loading of distressed hill slope and high hydrostatic

pressure on the slope are the main causative factors of slope instability. On the basis of detailed geotechnical studies the appropriate remedial measures in two phases have been suggested for stabilization of this distressed hillslope.

RAINFALL INDUCED LANDSLIDES OF KONKAN COAST – AN OVERVIEW

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Rainfall induced landslides are prevalent in the tropical monsoon regions of the globe. It is also reported that rainfall, in addition to the earthquake has enhanced the damage potential of the event, as they enhance the transportation / movement of debris. Hence, there is a need to understand the natural or cut-slope forming material behavior under saturated / over-saturated conditions and its susceptibility to slide / debris avalanche. Synergistic occurrence of flood and landslide has caused highest damage in India and elsewhere. This would help us in understanding the process mechanism and evolve disaster management preparedness. Landslide reported from the surface infrastructure (road and railway network) areas of West Coast of India is of great concern for the safety and security of people and goods, in addition to settlement and civil engineering projects.

As the slope forming material is often heterogeneous in nature, most of the reported debris of these landslides gets detached from the rock-soil contact or within the colluvium mass (depending on the boulder size). Degradation of surfaces covered by tree/shrubs aids the process of destabilization. Locations having near flat surface or concave morphometry enhance the hydrostatic pressure on the surface material and instability potential.

The rainfall intensity and duration varies with space, elevation/altitude and duration. A continuous monitoring of rainfall and water level in the colluvium having various cover factors would highlight the dynamic pore-

water relationship that is operating on the hill slope. Perforated stand-pipe arrangements are found to have performed well compared to rest of the instrumentation.

Agencies that are often troubled by the landslides require dependable guideline parameters that would indicate the probability of occurrence and vulnerable sections (intensity of damage & mode) for their preparedness operations. Their satisfaction of reported results increases, when the information is scaled down or referenced to their chainage. Further, hill slope hydrostatic measurement on the slope material would guide them in their selection of construction material and structure, when the zonation maps portray it.

An integrated data collection (inclusive of satellite data & Global positioning system based location information) and analysis helps in identifying the stretches of road sections (hilly areas) that are likely to be deposited by debris and or erosion and removal of stabilized pavement stretch. Anticipated rainfall intensity and duration at the higher slopes with reference to foot hill / base camp conditions would allow the agencies in positioning their road / debris clearing equipments and preparedness message. Three dimensional model and simulation of the debris movement would help in understanding the debris transportation process and debris arrestor devices.

Results of the studies on the Varundh ghat (parts of Sahydri mountain near Bombay) landslides are summarized above has lead to the formulation of procedures that could be followed in demarcating regions, parameters and preparedness instructions.

EXTREME RAINFALL EVENTS AND THEIR CONSEQUENCES IN INDIAN HIMALAYAN REGION: AN IN-DEPTH STUDY

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The Indian Himalayan Region (IHR) is inherently fragile and susceptible to natural hazard as result of its extreme weak geology, highly rugged topography and heavy monsoonal rainfall. The water-induced disasters are common in the IHR and are mostly triggered by extreme rainfall events, generally during monsoon months. Flash floods, floods, glacial lake outbursts and landslide dam and failure of such dams and other man-made structures are directly or indirectly triggered by extreme rainfall (cloud bursts). The river or stream in this region are generally of three types i.e. perennial river originates from snow clad peak of higher Himalaya, spring fed river/stream originates from middle mountain and third one is dry or seasonal stream also originates from middle mountains region. Due to deforestation, land use, soil, geology and other associated conditions the too much and too little water syndrome is common in both the type of streams. The river flows in the down stream are affected by above mentioned factors including extreme rainfall events, formation and subsequent failure of landslide dam. The formation of landslide dams and their breaching has been reported from east to west part of IHR. The longevity of landslide dams ranges from several hours to hundred of years, but most landslide dams lasts several days to a few months. Many IHR rivers like Alaknanda, Bhagirathi in Uttaranchal, Sutlej and Indus in J&K and Himachal Pradesh, Teesta in Sikkim and Brahmaputra in NE India region experienced formation of landslide dam by extreme rainfall events and subsequent breaching causing huge loss to life and property in down stream in the past. The Gohna lake (landslide dam formed lake) in Uttranachal became attraction of tourist in late nineteenth to middle of

twentieth Century. This lake was formed by river blockade in Alaknanda catchment and sustained for 76 years (1894-1970). The bursting of this lake was a result of extreme rainfall event (cloud burst) in the adjacent hill slope of the dam, the breaching created havoc in the downstream within a short period of time. The natural calamities have been taking place since time immemorial but as the population is increasing the impact of such incidents are much more perceptible. Due to increase in population and demand for livelihood the village people in Himalaya continue to develop their agricultural land as well dwelling in the banks of the vulnerable rivers, which sometimes swept away in flash floods or always sensitive for such events specially during monsoon season. The snow avalanches and glacial lake outburst floods predominate at very high elevations, debris flow and flash floods in middle elevations and floods in the plains. Hundred of lives and million of rupees worth of infrastructure and property are lost every year as a result of water-induced disasters in the IHR. Experience from other parts of the world indicate that landslides, debris flows and associated disasters could be accurately predicted based on rainfall characteristics and known thresholds for slope instabilities and floods which could eventually help in reducing damage to life and property. However, the hydrometeorological systems of mountain areas are very complex and poorly understood. The paucity of rainfall data, threshold values for location specific landslides and other related parameters are required to be understood the phenomenon of triggering of mass movements in IHR. Intensification of rainfall recording network, intensity of rainfall and return period of extreme rainfall events in sensitive areas of IHR needs much more attention for formulation of future strategy of management and mitigation to cope up from loss of life and property by such events. Some of the rivers in Himalayan region are flowing in more than one country and the upstream downstream linkages for early warning

system would also play a vital role in reducing the damage occurred by flash flood particularly in down stream country.

GEOTECHNICAL CONSIDERATIONS OF HILL SLOPE STABILITY AND LANDSLIDES

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Landslides occur as natural phenomena in hilly terrains and also due to disturbances caused by construction activities, e.g., housing and transportation. Natural slopes which have established a balance with the geological and geotechnical features of the area get disturbed by human actions like mining, deforestation and road construction which perforce are required to fulfill the development needs of the area.

Landslides fail to attract as widespread attention as earthquake or cyclone because landslides usually occur in “remote” areas on the hills, often far away from the urban growth centres. Yet instances are plenty where landslides have killed thousands of people and the resulting economic loss to the region has been no less than that from a major earthquake or cyclone.

While it is true that a number of factors, such as hill movement, rainfall, river flow and local and regional geology have important bearing on the landslide, at the time of actual movement it is basically the interplay of the forces of instability with the resistance offered by the soil or rock that controls the ultimate slide. Geotechnical investigation, therefore, forms an integral part of a landslide management programme.

Investigation of landslides requires considerable judgement because natural slopes are seldom homogeneous and the shear strength of the soil is difficult to determine. While the mathematical calculations for stability can be done with the help of numerous softwares it is often difficult to establish the shear strength of the soil or rock mass and the boundary conditions.

The paper describes the geotechnical aspects of hill slope stability and landslides and methods of landslide investigation. The major considerations required for evaluation of the engineering properties of soil relevant for landslide investigation are discussed. The effect of earthquake is discussed in detail. An investigation of Chandmari landslide, Sikkim is presented as a case study. The slide occurred on June 8-10, 1999 killing eight people and severely injuring more than fifty. The slide has been monitored for six years in which time it appears to have reached a certain degree of stability. The analysis shows a predominantly debris failure but the lower hills appear to have become stable by now. The study shows that monitoring and instrumentation are essential to understand the behaviour of unstable hill slopes and to work out short term and long term management strategy. Some guidelines for monitoring landslides are suggested.

**EXPERTISE, INFRASTRUCTURE AND HIGHLIGHTS OF R&D
WORKS AT CRRI IN THE AREA OF LANDSLIDES**

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The Central Road Research Institute has been working in the area of landslide investigations, slope stabilization techniques, erosion control measures and landslide hazard zonation studies since early 1960s. Institute has since developed expertise in the area of landslides and built a strong infrastructure for investigation, mapping, analysis of landslides and design of remedial measures. Infrastructural facilities for field exploration, laboratory testing, monitoring instruments and analytical tools have been developed and are being used in R&D studies on landslides. The nature of work carried out by the institute includes sponsored R&D, consultancy for stabilization of landslides and slope stabilization, and training of professionals. Some of the important R&D works of the Institute include the following studies;

- Development of Asphalt mulch techniques for slope erosion in 1968
- Assessment of re-alignment in Sikkim Area based on hazard zonation technique in 1969
- Development of rock fall protection techniques and field application for stabilization of rock fall in J&K Area in 1976
- Deep drainage techniques for slope stabilization – installation of horizontal drains in Nilgiri Hills area in 1983
- Development of landslide hazard zonation techniques and preparation of landslide hazard zonation maps for road stretches in Sikkim area, 1984
- Application of coir geogrids for slope erosion control measures, 1985

- Development of software for slope stability analysis, 1989
- Landslide hazard zonation mapping of Nainital – Kathgodam road, 1989
- Development of trench drainage techniques using geotextiles, 1998
- Soil nailing techniques for slope stabilization, 2000

Development of engineering database on landslides and instrumented monitoring of landslides, geotechnical engineering mapping of Delhi for earthquake hazards in GIS platform, landslide studies in Bhutan, studies on rockfall problems on Mumbai-Pune expressway are among the large number of studies carried out by the Institute. Number of documents, standards, guidelines for Indian Roads Congress and the Ministry of Surface transport, Government of India has been contributed by the Institute.

Presently, among other activities on landslides, the project ‘development of instrumentation on early warning of landslide’ is being pursued as one of the inter laboratory, network project. As part of the activity, institute has been conducting model studies simulating field conditions in the live model in the laboratory. Experiments are being conducted on different soil types and rainfall conditions. The percolation of water, development of pore pressure, surface runoff, slope movements, failure mechanism etc are being monitored by actual measurements through instrumentation and controlled soil conditions in the model studies. Conventional as well as fiber optic instruments are being used in the project. The present paper is intended to include among other activities, the salient findings of the study.

RETREAT OF HIMALAYAN GLACIERS: SOME EXAMPLES FROM GARHWAL HIMALAYA

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Glaciers are the result of Ice ages. The Himalayan glaciers are the consequences of Ice Ages related to Quaternary-Pleistocene period. In India, the glaciers are restricted to the Extrapeninsular region i.e., the Himalaya (Latitude 27°N to 36°N and Longitude 72°E to 96°E). There are about 15,000 glaciers in Himalaya that form a unique freshwater reservoir of 12,000km³ (Valdiya, 1998), which support Indus, Ganges and Brahmaputra river systems.

Himalayan glaciers are receding faster than glacier in any other part of world. The Himalaya is ecologically fragile, as on global warming and increased anthropogenic activities, the glaciers are retreating with ascending snow line and descending timberline. In the last 100 year alone, the global mean temperature has increased by 0.5-1.0°F (WMO/UNEP, 1990). Therefore, recession glacier is an upward migration of the environmental stress in response to global warming on mountain environments. Incidents of landslides, changes in river regimes, floods etc. in downstream areas are the major consequences of glacier retreat.

In the present paper, the recession of some of Himalayan glacier was identified by monitoring of snout fluctuation and area vacated by the glaciers. Since last phase of glacial advance (200 to 300 years ago), the Himalayan glaciers show a progressive glacial retreat and down wasting. Presently the frontal retreat is dominant. Over the last 25 years, the

Gangotri glacier has retreated 850 m (approximately), compared to 2km over the last 200 years (Sharma & Owen, 1996). Data for 61 years (1936-1996) show that total recession of Gangotri glacier is 1147m, with an average rate of 19m/year. The present data (1996-2002) reveals that the snout is receding at the rate of 25m/year. The general geomorphic evidences also suggest that majority of the glaciers are in process of recession.

Therefore, there is an urgent need to study the causes and effects of glacier retreat in detail with a focus on different issues like possible influences of climate changes on glacier retreat, impact of anthropogenic activities, neotectonism etc.

LARGE SCALE MAPPING AND MONITORING OF PATALGANGA LANDSLIDE

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Most of the topographic maps of hilly terrain of our country which are used as base maps for carrying out various studies including landslide investigation and mapping are available in small scale of 1:50,000 and a very few in 1:25,000. Small scale maps typically represent extensive areas, but they offer only a gross perspective on details. The potential for accuracy drops as the area mapped grows larger and the scale grows smaller. Such scaled maps are not suitable for in-depth and accurate landslide investigations and instrumented monitoring. A large scale map which shows a limited amount of space and provides a considerable amount of detailed information about that space can only be used for detailed landslide investigations, mapping and monitoring. Patalganga landslide which was considered for large scale mapping and monitoring, is a moderate Landslide, covering an area of 0.91sq km, situated adjacent to National Highway 58, at km 256 in Garhwal Himalya. The landslide was developed during a flashflood of July 1970 in the Alaknanda valley, which brought in loss to the life and property of an unprecedented magnitude and was named as Alaknanda Tragedy. Patalganga landslide developed at a place where a small hamlet was situated during the 1970 tragedy. Since then the landslide is repeatedly occurring during every monsoon. The recurrence reminds the public about the 1970 tragedy when Patalganga was blocked at a narrow constriction which became the cause of the fateful event of 1970. Similar narrow constriction exists at the toe of the Patalganga landslide, which is flared to become even more dangerous, if the same amount of rain falls with in 24 hours as fell during 20th August of

1970. The above facts brought forth the need to give a fresh look, not only to Patalganga landslide but also on Patalganga basin. The large scale base maps in 1:500 and 1:12500 scales for Patalganga landslide and Patalganga basin respectively were prepared using high precision total station and GPS survey as well as remote sensing data. A reference datum (of known coordinates and height) was setup in the area using Differential GPS of sub-mm accuracy. The base map thus prepared was intended to be used not only for the current mapping but also for the continuous monitoring of the Patalganga landslide after every monsoon season. 1:500 scale provided opportunity to precisely monitor the slope movement vectors in millimeter scale. The reference points installed at different locations in the area ensure the repetition of the contouring without any distortion. The base maps were utilized for preparation of other maps such as geology, landuse, landcover, geomorphology, geotechnical, drainage, drainage basins, landslide and many others using extensive field survey. GIS as well as Image Processing software provided excellent prospects to overlay, clip, join various thematic layers and draw out new groupings of the layers and their relationships to understand various factors, their interrelationships and the mechanism of the slope processes. Repeated monitoring of Patalganga landslide carried out through monitoring of the steel peg markers installed on the slope has helped in determining the type and magnitude of failure. This paper highlights, in brief, the work carried out in the Patalganga basin and on Patalganga landslide.

LANDSLIDES HAZARD ZONATION ALONG NATIONAL HIGHWAY (NH-1A) FROM ‘MOUR’ TO ‘NASHRI BATOTE’ IN JAMMU AND KASHMIR, INDIA

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The pressing needs to reduce the expected loss caused due to Landslides require focused research programme. In the present study, similar attempt has been made for the zonation of areas in a part of J&K which are prone to severe landslides. The study area is located along the National Highway NH1A from Mour Village (district Udhampur) to Nashri batote (district Doda). In the present Landslide Hazard Zonation Study, various zones have been marked as most hazardous that may cause severe disasters in future and may affect the local inhabitants in and around the area extending from Udhampur to Nashri on one hand and may cause serious disruption of traffic on strategic Jammu Srinagar Highway. This zone is known among the most landslides sensitive zones in the world. In the present landslide zonation study, two factor have been considered. First are geological & topographic factors that include lithology, geological structure / lineaments, geomorphology, drainage etc. Second is the triggering factor which includes rainfall, earthquakes and anthropogeny. Although the factors listed under geological / topographic parameters have been considered as basic inputs for landslides zonation study, three triggering factors namely rainfall, earthquakes and anthropogeny may be considered as external factors which may trigger the occurrence of landslides.

LANDSLIDE HAZARDS ALONG NH-39 IN MANIPUR, INDIA

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The present study deals with the factors associated with the occurrences of landslides along National Highway (NH-39), connecting Assam-Nagaland-Manipur-Myanmar. The study area falls under high seismic zone (Zone-V) along a Churachandpur-Mao-Thrust (CMT) trending N-S is situated west of the Indo-Myanmar subduction zone. Based on the study of micro-seismicity, deformation rate and creeping, it is inferred that the CMT is an active creeping fault. The NH-39 runs almost parallel to CMT for a distance of 150kms and severely effected by the frequent landslides and mudflow hazards. The kinematics and slope stability analyses are used to understand the causes of slope failure despite of the material of the terrain comprises of high factor of safety.

ROLE OF REMOTE SENSING & GIS IN LANDSLIDE SUSCEPTIBILITY STUDIES

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The losses due to earthquakes and floods in India are much more than landslides, however, landslide occurrence being more frequent is considered to be a major geological hazard. Recently few landslide disasters in Himalaya have made tremendous impact on the society. As a result of increase urbanization, hill slopes are being disturbed due to various construction activities particularly the road construction. It is therefore necessary to know the landslide potential zones before any construction activity begins so that adequate control measures can be applied well in time. Landslide susceptibility mapping, which delineates the potential landslide zones, is useful for such purpose. The paper presents the use of remote sensing and GIS in landslide mapping and preparation of input data layers and their integration for landslide susceptibility studies.

Remote sensing and GIS techniques play a significant role in landslide susceptibility mapping. Landslide identification, which is a crucial parameter for any landslide susceptibility study, can be very well done particularly with multispectral and high spatial resolution satellite data. Application of GIS is extremely useful for thematic data layer generation and for their spatial data analysis, which involved complex operations. Hence efficient landslide susceptibility mapping can be carried out by combining GIS with image processing capabilities.

With the recent advancement in remote sensing and GIS technology, landslides can be well identified, mapped and transferred to the real world to produce a landslide inventory map. Remote sensing techniques are well

suited for landslide studies as landslides directly affect the ground surface. Landslide information extracted from satellite images are mainly related to the morphology, vegetation and drainage conditions of the slope.

The interpretation of landslides from remote sensing data requires knowledge of the distinctive features associated with slope movements and of the image characteristics associated with these features. The spatial and spectral resolutions of the remote sensing data provides the primary control on the interpretability of slope instability phenomena and thus decides the applicability of type of remote sensing data for landslide studies. The IRS LISS-III, though good for differentiating the barren land from vegetated land, does not serve the purpose fully to identify the landslide slopes due to its poor spatial resolution while the IRS PAN data with 5m spatial resolution, provides better interpretation for landslide mapping. Different factor maps such as landuse/land cover, lineament, geomorphology and drainage maps needed for landslide susceptibility mapping can be very well prepared from the remote sensing data.

Landslide occurrence depends on complex interactions among a large number of partially interrelated factors. Hence analysis of landslide susceptibility studies requires evaluation of the relationship between various terrain factors and landslide occurrence. Over the past few years, there has been a significant contribution of GIS for spatial data analysis. An ideal GIS combines conventional GIS procedures with image processing capabilities and a relational database. The thematic data layers can be prepared in GIS platform and the data can be stored as attributes for any further analysis. With the GIS a much larger variety of techniques become attainable and it is very easy to modify the resultant map any time. Hence a number of maps can be prepared by modifying the input

parameters and their weightings till it matches with the actual ground condition.

LANDSLIDE HAZARD ZONATION FOR DISASTER MITIGATION IN HIMALAYA

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There is an unprecedented demand for energy for the development of Indian economy. The Himalaya is the source of huge potential for hydropower. However this development is beset with natural disasters as the Himalaya is the youngest mountain system in the world which are very active. The geodynamics of Himalaya is of a certain nature that encompasses plate motion and triggering of a large pile of exposed and unexposed crustal material to stress accumulation. There is a possibility that the landslides have been occurring in the regions of large stress accumulations. Since this leaves us with indirect methods of using geological knowledge related to these processes and the measurement systems are costly. Therefore, geological and geomorphological parameters have been used in landslide Hazard zonation. The paper describes this with examples from Himalaya.

Landslide risk reduction in Himalaya is being attempted through the program on Landslide Hazard zonation. The author has prepared a methodology for Landslide Hazard Zonation based on category of slopes that are called facets. Facets are elements of landscape which have similar geological and geomorphological characteristics. Weightage is given to selected parameters based on their affinity to landslide occurrence. This weightage is added to get a score for each facet. This figure gives an estimate of the hazard in that facet. The mapping at progressively larger scales can built up an inventory of hazard risk in the area. Himalaya are fragile and very active mountain system. The newly carved out state of

Uttaranchal needs progress also which means more communication network and more disturbance to the terrain. The paper discusses the risk perception and the utility of landslide hazard mapping in risk reduction in Himalaya.

LANDSLIDE HAZARD ZONATION OF INDIA USING GIS TECHNIQUES

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A Landslide Hazard Zonation (LHZ) map is useful for selecting suitable locations to implement development schemes in the mountainous terrains as well as for adopting appropriate mitigation measures in the unstable hazard prone areas. A landslide hazard zonation mapping was done covering the areas in India involving the hill ranges namely Himalaya, North-eastern hill ranges, Vindhyas, Western Ghats, Eastern Ghats, etc., and the results are discussed in the paper.

The available thematic or factor maps, viz. slope, land use, rainfall, geology and vegetation in the scale of 1:6 million pertaining to the study area were used for the analysis. The landslide zonation analysis involved grid data sets (the discrete data sets from different themes were converted to grids) to compute the final land use susceptibility grid through integration and weightage analysis of the source themes. The entire hazard mapping was landslide inventory centered on a GIS Platform. The rank and weightage values were also modified from region to region to achieve the best match between the reported landslide inventory of the region and the corresponding inferred landslide hazard zonation map.

The study area has the landslide hazard zones distribution of severe to very high, high, medium to low and unlikely respectively. The zonal management significance with respect to various hazard zones were discussed. The landslide Hazard Map, so developed needs to be popularized among the Architects, Engineers and Development Planners and also to public so that it becomes tool not only for regulating

construction or development activities but also as a means of managing or mitigating landslide disaster.

EARTHQUAKE INDUCED LANDSLIDE MANAGEMENT ON URI-KAMAN POST ROAD IN KASHMIR VALLEY-IMMEDIATE CHALLENGES

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On October 8, 2005, Jammu & Kashmir was struck by an earthquake of 7.8 magnitude on the Richter scale. The earthquake affected hundreds of villages in five districts of Kashmir Valley. There have been 100 after shocks of magnitude 5 or more, following the main earthquake. The earthquake damaged about one lakh houses and affected about five lakh population. Uri and Tangdhar regions bore the brunt of the killer quake. Communication network in these two regions was the worst affected as the earthquake caused severe damage to roads, bridges and other public utilities. The pattern of intensive and extensive devastation to road network ranged from deep cracks in road formation, sinking of formation, formation breaches, damages to protective structures extensive damage to road surface and damages to culverts and bridges. A total length of 370 km of the road network in Uri and Tangdhar sectors was the worst affected. 17.25km long Uri-Salamabad-Kaman Post LoC road on the Srinagar-Muzaffarabad road was subjected to the worst ever destruction due to heavy movement of rocks and boulders from as high as 100 meters on to the road surface. Project Beacon of the Border Roads Organisation lost 66 personnel in the earthquake-induced rockslides.

The Project was fully conscious of the fact that immediate movement of relief columns OC Civil Administration, Army and NGOs to the affected areas required early opening of the lines of communications. Coupled with this is the search for the dead bodies, missing personnel, calming down the charged up emotions of the Next of Kin of the construction workers who

were not aware of the fate of their bread winners and to top it all, maintaining the morale of the Project personnel to open the road at the earliest.

The paper gives an account of how the immediate challenges were met head on by the personnel of the Project Beacon so swiftly that none ever imagined that the lines of communication upto Uri and Tangdhar were ever closed by the earthquake-induced landslides. The paper described the typical problem of assignment of the damages on a road stretch which was not fully approachable, committing a likely time frame of opening to the State Administration, nonavailability of multiple attack points for slide clearance, immediate requirement of reaching, medical relief to the victims and organization of other relief material. It describes the risky, challenging, tiring and trouble some situation into which it was forced.

It describes the Himalayan task of clearing about one lakh cubic meters of rockslide debris by unconventional thinking and dynamic planning, fully ensuring that at each stage, earliest, uninterrupted and unhindered connectivity to the villages cut off by the earthquake is established. It deals with the psychological strain on part of all those involved in losing 66 of their comrades but still being bold/courageous enough to execute the task of early opening of the road to LoC against the backdrop of never ending after shocks of the earthquake, thereby helping the Air Force authorities to save on the limited available air effort and the Army to reduce logistic burden. The early reopening of the road helped in establishment of a relief point and also the families on both sides of the LoC to reunite with each other.

At the end, the papers brings out certain shortcomings noticed in the synchronous disaster planning and preparedness and offers recommendations which deserve to be considered while evolving a holistic planning for a foolproof disaster preparedness to successfully message such earthquake-induced landslides as experienced by the Chief Engineer of the Project who lived through the disaster and rose to the expectations of all stake holders.

IMPORTANCE OF EARTHQUAKE INDUCED LANDSLIDES IN LANDSLIDE HAZARD MAPPING

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The time has come to take an unconventional view and perhaps even a highly controversial, provocative position and conclude that the landslide hazard mapping, the way it is done, is not really on the path to progress. The whole attempt to hazard mapping is pseudo-scientific, and as it surfaces time and again, all we have done so far is to rush in the enormous power of remote sensing and GIS to produce factor maps and then monotonically weave them in to hazard maps sidetracking several vital concerns. We seem to ignore hazards due to (a) past landslides, not obvious on the surface, (b) earthquake-induced and earthquake-triggered landslides, (c) runout effects of avalanches and earth flows (d) consequential landslides upon formation and bursting of landslide dams, where such possibilities can be foreseen, (e) delayed, progressive failures, especially on unprotected deep cuttings and (f) visible part of unchecked urbanization and anthropogenic factors. What is more, by ignoring the essentiality of validation of inferred hazard maps against hard and soft ground truths, and by downplaying the user-friendly angle, we make matters much worse!

Most of the current landslide hazards mapping approaches are either blind or lame, or dumb, or at best on crutches. We have produced maps by limited ground surveys without an iota of appreciation for macro-geomorphology and remote sensing. Such maps are blind. We have produced maps by remote sensing with very little or no ground verification

of truth. Such maps are lame. We have produced maps that will be hard to certify reliable because they have bit of both, but not enough. Such maps are on crutches. The user unfriendliness of the maps is reflected in their muteness to a development planner or a disaster manager. Further more; usually the scales of maps are not large enough to help either meaningful risk analysis, or imaginative development planning. The small-scale maps are usually over sung, as the non-scientists among us seem get lured and begin to question the need for further mapping when some such maps are already available. Wrapped with uncertainties, use of such maps may do more harm than good, and the mammoth effort built in the production of such maps may at best reduce to a mere academic exercise.

Since landslide hazard is strongly dependent on the degree, extent and rate of human intervention, and those are the hardest things to comprehend, judge and evaluate, the maps admittedly cannot be free from the ensuing limitations. Therefore, when it comes to slope failures, it would be wrong to replace the subjectivity and value judgment of the wise with all appealing sophistry of stochastic methods, and popular vote called consensus.

The paper spotlights the importance of earthquake-induced landslides in landslide hazard mapping and rakes up some of the hitherto neglected issues solely with the view to stimulate a debate to arrive at the way forward.

NUMERICAL MODELLING OF EARTHQUAKE TRIGGERED LANDSLIDE IN JOINTED ROCK SLOPE

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Deformation mechanism in rocky slope causes sliding and rotation of blocks leading to slide failure. Rock discontinuities in a massive rock mass play a very important role under static and dynamic conditions. To study the stability of jointed rock slope, a case study has been done. Static and dynamic analysis of a 750m high rock slope in western Norway has been performed using a discontinuum modelling technique UDEC. For predicting the behavior of rock slope, parametric study including the effect of insitu stresses, reduced friction angle at joints, dynamic loading under strong earthquake records has been done. This model has helped in understanding the effect of geo-mechanical properties of rock mass affecting the stability of rock blocks and dynamics of rockslide.

METHODS FOR EVALUATION AND MITIGATION OF EARTHQUAKE-INDUCED LANDSLIDES

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Failures of slopes commonly occur during major earthquakes and, apart from liquefaction, often constitute the most visible and damaging landslides. Recent incidents like 1989 Loma Prieta, 1994 Northridge, 1995 Kobe, 2005 Kashmir earthquakes provided several examples of earthquake-induced landslides. In this paper, the various aspects of static and seismic slope stability analyses have been discussed including the different classical and recent methods devised for these analyses. Among the techniques to evaluate the seismic slope stability, Newmark's sliding block method has been the source of plenty of research work in this field which has led to several improved slope stability analyses procedures under seismic conditions in the recent years. A recent study on the analysis of stability of slopes under seismic conditions by using the method of vertical slices with due consideration of the interslice forces is mentioned. The sliding soil mass is divided into a number of vertical slices by considering interfacial forces between two consecutive slices, and the limit equilibrium analysis for these slices under the influence of static forces along with pseudo-static seismic forces are carried out. The effects of variation of different parameters like slope inclination, soil friction angle and seismic acceleration coefficients both in horizontal and vertical directions on the dynamic factor of safety are depicted. Comparison of the present results with the existing solution is also reported. Finally, a review of the performance of reinforced soil slopes under earthquake condition, compared to an un-reinforced slope shows that the earthquake-induced landslides decreases significantly by use of reinforcement in slopes.

**FORMATION AND BREACHING OF LANDSLIDE DAMS AND
RELATED ASPECTS: DOCUMENTED EXAMPLES FROM THE
HIMALAYA**

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Landslides and related mass movements are common in the Himalayan terrain. Owing to the inherent geomorphic setting in the form of steep slopes and narrow valleys, these landslides often temporarily block the major rivers or their tributaries, thus creating lakes. The landslide dams are formed in a wide range of geomorphic setting. Most common type of these dams are due to rock and debris avalanches, rock and soil slumps and debris flow. These dams breach either shortly or may take couple of years' time after their formation, depending upon the characteristics of the material involved and the quantum of water flowing through the channel. The formation and breaching of these dams cause submergence of the terrain in the upstream regions and flash flood in the downstream region.

The present article discusses and analyzes the formation and breaching of historical and recent landslide dams in the Himalaya. The creation and the breaching of landslide dam in Birehiganga River during 1893 and 1970, Dhauliganga River during 1956, Rishiganga River during 1967, Patalganga River during 1970 in the Alaknanda basin, Madhmaheshwar River during 1998 (Garhwal Himalaya), Kali River during 1998 (Kumaon Himalaya) and Satluj River during 1998 and 2000 and Spiti River during 2005 (Himachal Himalaya) are some of the well documented, large-scale landslide dams. The causes and the consequences of the landslide dams in the Satluj and Spiti Rivers have been analyzed in great detail by the authors. The preliminary analysis of the data set indicates that the

frequency of the creation of the dams in the Himalayan terrain has increased in the recent past possibly due to shift in climatic patterns.

The outcome of this study will have two major implications for the disaster management. Firstly, with the establishment of magnitude-frequency relationship of landslide / landslide dams in the past and present will help in understanding global climate change and secondly, with the preparation of inventory of landslide dams, the risk posed by it must be evaluated so that proper landuse planning may be formulated for the development of the Himalayan region.

EARLY WARNING SYSTEMS AGAINST LANDSLIDES

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Forecasting the occurrence of a landslide or a mass movement event is a highly complex matter dependent on interplay of a great variety of factors, not always easy to assess or estimate with reliability. Most attempts to predict occurrences of slides are based either on measurements of rainfall and time dependent surface and spatial variation of piezometric pressures within potentially sliding masses or on the visible changes in the surface features of a landslide including preslide deformation. Acoustic Emission Monitoring aids in forecasting and therefore can be a very powerful tool in obtaining premonition of impending failures. In fact, in most cases, slope collapse is preceded by subtle warning phenomena of various kinds. Pre or post failure rates of movement of a slope are certainly important but to define failure by pinpointing the acceptable levels of total displacement in a given situation is equally important. For a slope supporting human settlements or other important buildings, a few centimeter of displacement leading to cracking of buildings or tilting of walls may be construed as the slope failure. On the other hand, in some cases several metre of movement could be tolerated provided it does not lead to a catastrophic failure.

Incipient instability of slopes and early warning ensuing landslides is possible through systematic mapping, slope instrumentation, monitoring and real time data analyses. Modern technology offers a number of high resolution instruments that can capture, monitor and transmit data for real time analyses and forecasting.

A lot more research is necessary to be able to have fair appreciation of severe limitations and uncertainties in forecasting and early warning. There is a huge and often unjustified criticism of the Government that it failed to predict a landslide disaster. Consider a forecast with 50-60 percent probability of a major landslide at some location in Assam where earthquake is expected to provide a triggering force. If such a disaster were indeed to occur, hundreds could perish and thousands will be affected in one way or the other. How should then the government handle such a forecast? If they neglect it and the landslide indeed occurs as predicted, government will almost certainly be accused of inaction. If the government acts fast and spends public funds on preventives and slide does not occur, it would be accused of wasteful expenditure when more important projects lie in abeyance for want of funds. Every failed forecast will be blamed for ensuing fear psychosis, panic reaction of public and media, diverted attention from real issues, disruption of normal life, speculations on land prices, and rise in insurance premium, high economic and social costs, mass exodus, and mob violence. Public education is the only way to ensure that it understands the difficulties and learn to believe the government, if decides to suppress a forecast based on its own value judgment..

Public response to a forecast is another difficult area. If the people are not educated, they will interpret the same forecast differently. If not fully aware of the lethal consequences, they will generally take warnings light.

Besides providing a critique on the present state-of-the-art, the paper will reflect on the composite dimension of early warning against landslides in India.

LANDSLIDES – IT’S TIME THEY ARE PREVENTED

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With advancements in technology, hilly terrains are being ‘conquered’ to make way for roads, railways, lifelines and resort townships. And today, there are many more man-made landslides than ever before. The need for infrastructure development cannot be debated in today’s context; but, the feasibility of landslide prevention certainly should be. Major infrastructure links have witnessed time and again multiple landslides during monsoons and consequent losses including human. Recurring losses have evoked recurring ad-hoc remedial measures on an annual basis to keep the links operational. It is about time the problem is looked at from a different perspective and concerted efforts are made to understand and prevent them. Based on experience in the Western Ghats, a few generic situations are highlighted and a few suggestions are made for possible prevention.

A common situation observed along major motorways and railway links is the construction of the formation on a sloping natural ground. Where width for right-of-way is insufficient adjacent to deep valleys, the road is laid partly on fill and partly on natural sloping ground. This produces in its wake serious problems of subsidence, therefore of drainage and, consequently, a preventable landslide during heavy downpour. Such sites are easily identifiable at reconnaissance stage itself and alternatives can be thought of at planning stage. Another situation (perhaps, the most common) is one of debris flows from hills along hidden sheet rock surfaces. There have been instances of several such slides taking place simultaneously in a single day during a typically heavy downpour. With technologies such as remote sensing, GPR and reliability and risk analysis, there is a reasonable

chance of identifying these hidden rock surfaces and these potential trouble spots. There are other situations as well. This paper highlights some possibilities for hazard mitigation in such situations.

**SYNCHRONOUS DISASTER PLANNING FOR IMMEDIATE
REOPENING OF SNOW AVALANCHE RAVAGED JUMMU -
SRINAGAR HIGHWAY : CHALLENGES**

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During Feb 2005, the 294km long Jammu-Srinagar Highway experienced one of the most severe winters in 37 years. It experienced unprecedented snow tsunami on 18 and 19 Feb 2005, which triggered massive avalanches along the National Highway. The area of Jawahar Tunnel along experienced 10 avalanches of various magnitudes. Of the 294km long highway, about 200km from Kud (near Patni Top) to Srinagar was covered with snow heights ranging from 4ft to 50ft.

Jammu-Srinagar Highway is the only link to the Kashmir Valley with the rest of the country and is aptly called the life line of J&K. The snow tsunami not only closed the road completely, but also closed the Srinagar Airport, threw the telecommunication links out of gear, stranded hundreds of vehicles on either side of the funnel, rendered hundreds homeless and fell hundreds of tree alongwith electric and telephone poles on the highway. The road experienced sever damages to formation, surfacing and permanent works. The road maintenance teams deployed all along the highway as per pre-disaster planning were trapped between land / snow slides and avalanches. The clearance equipment too was covered under high snow. At the Jawahar Tunnel, about 360 personnel of various agencies got trapped inside as portals of the tunnel on all four sides were covered with snow. Fuel, Oil and Lubricant stores, ration stores and the entire snow clearance equipment was buried under the snow. Also, 11 personnel of the Project Beacon were buried under the high snow, out which only five managed to escape. In all, the life line to the Valley was

cut off. The Kashmir Valley was too unmanageable to be maintained by air. Lakhs of people prayed for early opening of the highway.

Project Beacon, responsible for the maintenance of the highway swung into action. The situation was alarming, expectations of stake holders on the early opening of the road were high and the urgency, importance and sensitively of the situation demanded that the bull be caught by the horn.

The paper describes the immediate challenges before the Project-Incremental and continuous connectivity to all villages and towns connected by the snow clad highway, non-availability of snow covered, snow clearance equipment, non-availability of labourers, inability to carryout reconnaissance of the area to plan the mammoth engineering task, lack of tele communication, constantly increasing pressure of Central and State Governments, Army, Public, traders and the press to open the highway and the non-feasibility of multiple attack points to deploy the equipment.

The paper describes as to how these challenges have been met by the Project by dynamic planning, unconventional thinking and fully ensuring that at each stage, connectivity to the population cut off by the snow tsunami is incrementally established. It describes the conflict between prioritization of resources of converting singly lane to two lane or to extend the singly lane connectivity further and the conflict between delayed cum safe road versus hurried cum unsafe road.

At the end, the paper describes certain lessons that were thrown up due to this unusual and once in a life-time opportunity which have a bearing on an integrated and comprehensive disaster preparedness for any such future

eventuality. The paper also suggests various initiatives required to be taken by various stake holders – State Administration, Traffic Police, Border Roads Organisation, Media and the public in the short term and long term so as to be more prepared and ready to face any such eventuality – all these as experienced by the Chief Engineer of the Project, who lived through the disaster and rose to the expectations of all stake holders.

ASSESSMENT AND MITIGATION OF LANDSLIDES IN THE HIMALAYA

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Landslide is the most natural of geologic processes. A thorough investigation produces information that forms the basis for design decisions. The engineering approach to landslide studies has focused attention on analysis of individual slope failure and their remedial measures. The analysis and solution of landslide problems as well as prevention of landslides requires an understanding of geology, hydrology, seismology, geotechnical exploration and engineering, computerized analytical methods, and practical and constructible engineering solutions.

India has about 25% of its geographical area under mountainous terrain and Himalaya being the youngest mountain chain is geologically/tectonically very unstable and seismically active. These weak terrains have experienced several landslides which have claimed numerous human lives. Proper planning and developmental schemes in these terrains only can take care of the instabilities of the slopes and the safety of the human lives which can keep the resultant geo-environmental hazards to a minimum. Landslides need to be properly studied and adequate measures are to be taken at the appropriate time. If not, landslides gradually increase in size and attain large dimensions causing innumerable problems recurrently.

Central Soil and Materials Research Station has been involved in the investigation of numerous landslides in the North eastern region of India and the neighboring country Bhutan. The Chandmari landslide located in the North Eastern state of Sikkim with a loss of 38 lives in 1997. Similarly,

Kohima the capital township of Nagaland experienced heavy landslide claiming loss of many human lives during the rainy season of the year 1999 at several places. A series of landslides occurred in the Tala Hydroelectric project, Bhutan area due to the unprecedented rainfall in the year 2000. CSMRS has been actively involved in the assessment and mitigation of these landslides. The paper focuses about the landslide phenomenon, its mitigation and the experiences of CSMRS in the North eastern region of India and the neighboring country Bhutan.

OPTIMIZATION OF SOIL NAILS FOR SLOPE STABILIZATION USING DIFFERENT SOFTWARES

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Stabilization of slopes is a common problem faced by geotechnical engineers. Several techniques are used to get over this problem. Soil Nailing Technique is one of them, which is promising and applicable in a wide range of conditions. The design of the soil nailing system can either be done manually or with the help of softwares. Since several solutions are possible to stabilise a given slope, it is desirable to look at the optimisation of the solution. The paper presents a case study of a slope in the Himalayan region. It describes the geometry of the problem, the geotechnical investigations carried out and the design of the soil nailing system. The design was carried out and optimised using more than a software and their results compared. It describes the details of execution of the works and the instrumentation provided.

NAILED SOIL WALL FOR LANDSLIDE PROTECTION AT NAINITAL

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Landslides, one of the natural catastrophes always cause a major problem in the Himalaya by killing hundreds of people every year, besides damaging the properties and blocking the communication links. Mass movements in the mountainous terrains are natural degradation processes, and one of the most important landscape building factors. Most of the terrains in mountainous areas have been subjected to slope failure at least fragility, extreme rainfall, deforestation, instability of slopes, tectonic activities. To reduce the landslide probabilities at critical locations, scientific slope stabilization techniques like soil nailing, soil stitching, rock anchoring etc. are commonly used. The present paper discusses the solution for the stabilization of the slope that was exposed to landslide by using soil nailing method.

**FRAMEWORK OF COMPREHENSIVE GUIDELINES FOR
SITING OF HUMAN SETTLEMENTS IN LANDSLIDE PRONE
HILLY TERRAINS OF INDIA**

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Human settlements in the hilly terrains of India have often faced disastrous situations due to inappropriate siting on susceptible hillslopes, e.g. landslide tragedies of Mumbai (2005), Varunawat (2004), Amboori (2001), Malpa (1998), Kullu (1995), Nilgiri (1993). The amount of losses incurred by these disasters in terms of economy, life and environment are colossal. Therefore, appropriate siting of structures is a serious concern to the researchers, professionals, administrators and the public. Since the country has a wide variety of geo-environments, no single approach is feasible to be followed for all kinds of situations. Although some specific guidelines for particular situations have been proposed and Indian Standards Code (IS 14804:2000) on residential buildings in hilly terrains also exist, yet further improvements are needed and comprehensive guidelines with case examples from actual field studies are still lacking. The present paper attempts to discuss about the framework of comprehensive guidelines that would deal with most possible situations of siting in the country.

Siting basically involves systematic selection, planning, designing and development of a part of the terrain for any particular landuse to stimulate safer and sustainable growth. This paper focuses only on siting of human settlements in landslide prone hilly terrains of India. It attempts to present those factors or conditions that can aggravate or reduce the risks to the human habitats due to ground failures like landsliding, liquefaction and subsidence.

The important factors in the siting process include the hazard history of the area, topography, geology, geomorphology, meteorology, hydrogeology, neotectonics, seismicity, landuse and landcover conditions besides the existing infra-structure, amenities and essential services available at site. The guidelines also emphasize on the need of preliminary and detailed geological / geotechnical investigations for assessing, averting or reducing the impacts of any terrain failure. Development of comprehensive guidelines based on the proposed framework would be quite helpful in dealing with real-time problems of human settlements in landslide prone hilly terrains of the country.

**TECHNO-LEGAL AND TECHNO-FINANCING REGIME FOR
DISASTER RISK MITIGATION**

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Human settlements are frequently affected by natural disasters - earthquakes, floods, tsunamis, hurricanes, cyclones, landslides, droughts, wild fires and sea erosion - which take a heavy toll on human lives, destroy buildings and infrastructure and have far reaching economic and social consequences for communities. Every disaster brings with it, in addition to the extensive damage to property and infrastructure, also a heavy toll on human life and livestock. Consequently it results in heavy financial losses, disruption of activities and loss of labour productivity unleashing a chain of compounding economic losses at the national level.

The vulnerability of human settlements to disasters is continuously rising due to the concentration of population and economic activities in large urban and rural agglomerations in addition to the precarious location of settlements of the poor in both urban and rural areas. These populations are highly vulnerable to natural disasters on account of very high densities and locations on flood plains, hill slopes, coastal areas, seismic belts etc.

Substantial efforts are being made throughout the world to overcome the impact after the natural hazards. Even the well-developed countries like USA, Japan have suffered from severe disasters in the past. But with an integrated approach to Regional Development Planning with community participation and integrated approach to disaster mitigation, these countries have been able to reduce the impact of disaster to a great extent over a period of time. Further, these countries are continuously engaged in collecting the data base, information, undertaking research on risk

assessment, vulnerability prediction, development of disaster prevention and mitigation techniques and creation of an awareness among the masses through series of actions for training, education and capacity building. Most of the developed countries are still continuously engaged in strengthening their disaster management capabilities in the form of short term and long-term strategies.

However, developing countries battle disasters after they have happened and are hampered by the lack of organized databases as well as lack of Action Plans. All efforts are concentrated on post-disaster relief and rehabilitation efforts with rescue, recovery, relief, reconstruction, repairs, renewal and retrofitting and economic rehabilitation. It would have been more prudent to provide for pre-disaster mitigation efforts.

RESEARCH STUDIES IN LANDSLIDES — RE-SETTING PRIORITIES

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Landslides in India are particularly severe in the Himalayas. The young active geologic set up, high rainfall and increasing cultural activities have contributed to the severity of the problem. Eastern Ghats, Western Ghats and Nilgiri Hills are also affected but with reduced intensity. Ecological damage, economic disruption and human losses are on the increase due to the pervasive nature of the landslide phenomena, accentuated by the fast pace of development that the country is witnessing.

Scientific investigations are conducted by many agencies, research and academic, supported by DST, CSIR, MoEF, Ministry of Mines, Ministry

of Water Resources and other funding agencies. Most of these efforts continue to be concentrated on preparing landslide hazard zonation maps on macro and meso scales with the help of remote sensing data. Work on modeling mass movements, developing control measures and demonstrating their efficacy is limited. It requires painstaking efforts in the field for generating data on the shear characteristics of the slope forming materials and geo-mechanical behaviour of the discontinuity surfaces. This then leads to understanding the processes operating at the surface(s) of failure-an essential pre-requisite for adopting suitable control measures. Wherever such basic data have been collected, we have seen success of control measures like drainage of surface and subsurface water, slope modification by cutting and filling, use of geo-synthetics and jute-derived material for arresting soil erosion and soil slips. There is an urgent need to enlarge this experience by further evolving these initial success stories in varied geologic settings, in-building the cost/economic dimensions. Research priorities thus need to be re-set to invest greater proportion of resources on projects devoted to:

- Instrumentation of representative landslides in different geologic settings and monitoring their behaviour over extended period of time
- Geotechnical characterization of discontinuity surfaces
- Developing cost-effective control measures and validating their efficacy
- Developing integrated database at different spatial resolutions
- Training of manpower and technology transfer
- Management of slopes with proper land use regulation.

It is hoped that with the constitution of the National Disaster Management Authority at the apex level, studies on landslides will receive a fresh

impetus and acquire greater focus to give them an application bias and result orientation. Funding agencies can make a definite positive contribution towards this task, thereby putting landslide research in the country on a sustainable footing.

Research Studies in Landslides — Re-Setting Priorities

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