UTTARAKHAND DISASTER RECOVERY PROJECT

International Symposium on Tackling the Challenges of Slope Stabilization and Landslide Prevention

Report

Government of Uttarakhand

Supported and co-sponsored by the World Bank and Japan International Cooperation Agency

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PREFACE

The State of Uttarakhand is often called "**Dev Bhoomi",** literally meaning abode of Gods. Uttarakhand is known for its scenic beauty, the lofty snow clad peaks of the Great Himalayas, glaciers, waterfalls, lush green meadows (Bugyals), valley of flowers, perennial streams, dense alpine forests and rare species of fauna and flora. Our State is blessed to be the source of the mighty Ganga and Yamuna that not only quench the thirst of millions of people but are also a symbol of spirituality and the Mother Goddess. We are also home to the shrines of Badrinath, Kedarnath, Gangotri, Yamunotri that draw thousands of pilgrims and tourists from across the world.

One of the youngest States in India, Uttarakhand is still struggling to find its way to thrive on its own resources. As mountains and forests cover a major part of the State, this poses some obvious challenges to the developers and planners. Pilgrimage to the four holy Shrines and nature tourism are one of the main sources of revenue generation for the State economy and better road connectivity is a prerequisite for harnessing the potential of the tourism sector. Moreover, improvement of the existing infrastructure facilities like roads, bridges and tunnels is needed for ushering and extending the benefits of basic amenities of health, education and development to the far flung areas. Construction of new roads and highways in Uttarakhand is also crucial from the perspective of security and safety of the border areas considering the strategic location of the State with respect to the international boundaries it shares with China (Tibet) and Nepal.

Fragile geological disposition, high level of seismic sensitivity and maintaining the rare and precious biological/ecological diversity are some cardinal issues that have to be borne in mind while pursuing any developmental activities in this State. Frequent occurrence of natural disasters like earthquakes, flash floods, GLOF and forest fires make the cutting of roads and maintaining them, a daunting task for the State machinery. The landslides caused by these disasters further aggravate our situation and make relief and rescue extremely challenging. Studies have shown that scientific studies about Himalayas show that there is an average of two landslides per square kilometre in this region. The National Highways, especially NH58, is damaged every year at several locations thus affecting transportation of people and basic goods and services. The loss of human lives and monetary losses have increased over the years, with increase in population and tourism activities in Uttarakhand. Several attempts have been made to contain the damage caused by these landslides but the results have not been as expected. This makes the government's job of ensuring the welfare of the people extremely challenging.

Post the June 2013 disaster, the State machinery has realized that we not only need to rebuild, but build better. This philosophy has formed the basis of the reconstruction efforts. We are not just rebuilding roads but innovating on the way this was done in the past. We are using better technology to build bridges that will be able to stand the impact of most disasters. Houses being constructed under the Uttarakhand Disaster Recovery Project not only include disaster resilient features but are also located at sites that are geologically safe; something that has never been done in this State before. In order to be prepared for future vagaries of nature, and predict disasters with more accuracy a separate Project Implementation Unit (PMU) for Capacity building, Disaster Risk Management and Early Warning System has been constituted. This unit is working to enhance the capability of government entities and others in risk mitigation and response.

Slope stabilization in particular remains to be an issue that needs to be widely discussed and technically understood. We also would like to understand how these landslides could be predicted in time to minimize loss of life and property. We have identified 43 chronic landslide zones that need to be treated. Varunavat landslide has already been successfully treated and stands as evidence to our efforts. But we want to understand the policies and best practices from around the world that will help us to formulate strategy and draft policies relevant to our State's fragile ecosystem. We need to have technologies available at hand for stabilization of chronic and recurring landslides such as Sirobagad, Sakni Dhar and Lambagad.

With this vision, "International Symposium on Slope Stabilization and Landslide Reduction" was organized by the Government of Uttarakhand led Uttarakhand Disaster Recovery Project. The event was co-sponsored and supported by Japan International Cooperation Agency (JICA) and the World Bank (WB). This symposium provided a forum for experts from around the world to share the existing knowledge and experience, get acquainted with the latest stabilization techniques being practiced in India, South-East Asia and in other parts of the world and brainstorm on the situation in Uttarakhand.

The esteemed panel of participants brought with them a wealth of knowledge and experience, which made the symposium extremely engaging. The discussions held after each session saw active participation from not just the technical experts but also the bureaucracy.

I would like to thank all participants for taking time to understand the unique problems posed by our geographical and topographical conditions and propose solutions that can guide our future policy towards slope stabilization. I also wish to thank the World Bank and Japan International

Cooperation Agency (JICA) for their commitment to the rebuilding of a more resilient Uttarakhand and facilitating sharing of knowledge through this conference.

This report presents a synopsis of the discussions held through the three-day symposium. The participants also proposed a number of technologically varied solutions that have been outlined in this report. Our vision is that this report will serve as a guiding tool for the slope stabilization initiatives that we undertake in Uttarakhand.

(Amit Singh Negi)
Secretary/ Program Director
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1.0 INTRODUCTION

The State of Uttarakhand has a vast area, almost 86 percent of which is mountainous, including the Himalayan region. The State shares its International boundaries with China (Tibet) and Nepal in north and east directions respectively and with States of Himachal Pradesh in the west, and Uttar Pradesh in the South. The newly formed State has constraints related to socio-economic development and strategic needs that have resulted in the launching of massive road network, infrastructure development and related activities in the hilly region. Since the inception of the State these activities have increased manifold.

The hilly regions of the State exhibit extremes of climatic conditions, difficult and hazardous terrain, topography and high altitude areas. Most of the area of Uttarakhand is sparsely populated and basic infrastructure facilities as compared to the more developed areas of other States of hinterland are generally absent. The roads in this State are generally affected by landslides and flashfloods consequent to torrential rainfall besides the snowfall and avalanche etc., compelling certain roads to be kept closed, especially in the monsoons and winter months. The highlands of the State are rich in natural resources, flora and fauna and are important for the launching of developmental projects, industries, tourism etc., for which road network is a basic need.

Recently the State has been badly affected by natural disasters, especially by the intense and prolonged rainfall followed by cloud bursts and Glacial Lake Outburst Flood (GLOF) in higher regions rendering in debris loaded flash floods resulting in toe erosion of hill slopes, erosion of river banks and landslides blocking road networks. Certain stretches of roads were washed out either due to toe erosion, riverbank erosion or due to sliding from the slopes. River bank erosion inflicted havoc on the human habitations in some of the flourishing townships like Uttarkashi, Sumari, Silli, Vijaynagar, Chandrapuri and Madkot. The damaged and blocked road network following the floods and landslides fettered the relief and rescue operations to a great extent.

In view of these diverse problems due to natural calamities in the area and the ever felt need of developing better infrastructural facilities for this nascent State, the necessity of preparing a long term scientific, holistic and sustainable programme for stabilization of the chronic landslides on various roads, the Government of Uttarakhand in association with The World Bank and Japan International Corporation Agency (JICA) organized an International Symposium “On Tackling the challenges of slope stabilization and landslide prevention” at Dehradun from 27-04-2015 to 29-04-2015.

The noted experts in the relevant fields from all over the world were invited to share their experiences and make the stakeholders aware of the modern techniques in slope stabilization. The following experts (Annexure-B) participated in this symposium and presented valuable, sustainable and economic solutions, which will be of much use in the field of slope stabilization.

2.0 OBJECTIVES

The International Symposium was organized with the following objectives:-

- Bring the experts of international repute on a single platform to debate on the challenges related to the landslides problems as they are being faced and tackled worldwide and then assess the scenario in Uttarakhand.
- Field visit to the two chronic landslide zones, i.e. Sirobagar and Sakhnidhar Landslides, which frequently disrupt the National Highway -58, and hold on site discussions followed by brain storming session with the view of coming up with cost effective sustainable stabilization measures or to suggest other viable alternatives.
- Make the Govt. Departments and stakeholders familiar with the modern landslide stabilization techniques through technical sessions.
- Capacity Building of the stake holders including the Government Departments like Public Works Department (PWD), Disaster Mitigation and Management Center (DMMC), Uttarakhand Space Application Center (USAC), Geology and Mining Department and local administration.
- To develop a precise framework of **planning, execution of plan and monitoring during the execution process as well as post execution** to tackle the challenges of landslide mitigation, prevention and stabilization.

3.0 PROCEEDINGS

3.1 Session-1: Discussion on the Field Visit and Observation

Chairman: Prof Yudhbir, Eminent Geotechnical Engineer, Dehradun

Moderator: Dr Yuka Makino, World Bank, Tokyo

Rapporteur: Dr. Kishore Kumar, CRRI, Delhi

Session report:

This session was dedicated to discussion on the field visit to Sirobagar and Saknidhar landslide zones. Three presentations dealing with landslide investigations and mitigation strategies were also made. Prof. Yudhbir, through his presentation has made very important points about predication of landslide hazard and on proper and detailed investigations of the landslide problems. He focused on lack of detailed geological, geomorphologic & topographic investigations. Prof. Yudhbir also emphasized on responsibility and accountability of the agencies/institutions/individuals has to be fixed in absence of which the dilution in seriousness of professional work is obvious. Mr. Rajendra Bhasin from Norwegian Geotechnical Institute (NGI) Norway talked on "Application of Ground Penetrating Radar (GPR)" and referred to non destructive technique of subsurface investigation which is very useful in areas, where destructive method may prove counterproductive. He also shared successful examples of application of GPR in India. Mr. Frode Sandersen from NGI Norway through this presentation on "Landslide Mitigation Strategies with examples" focused on risk from a landslide and explained details on the landslide process. He also described landslide mitigation strategies with some good examples.

In continuation of above, there was a discussion on Kaliasaur (Sirobagar) landslide. Prof. Yudhbir commented that no reports of the work done on Kaliasaur (Sirobagar) landslide are in public domain. As all participants had observations from the previous day, various opinions emerged in this discussion. Dr. Kishore Kumar from Central Road Research Institute (CRRI) gave participants an insight on the work carried out by CSIR-CRRI and CBRI on Kaliasaur. Dr. Garcia Lopez from National University of Colombia also put forward his views on how to prevent Kaliasaur landslide. He broadly agreed with the views of Dr. Kishore Kumar that the landslide gets activated from upper part during rains; thereby pointing to the need of effective drainage measures.

Mr. Amitabh Sharan suggested the following solution to the Kaliasaur (Sirobagar) landslide:

- Topographical Survey on 1: 500 scales with contour interval of 2 m covering area at least 100m above from crown portion and 100-100m both side from the side of the existing landslide.
- Surface Geological Mapping to be carried out on 1: 500 scales on same area, capturing also the cracks / creep in the zone above the crown; water condition if observed on the surface; rock type and its contact zones & the joint parameters, its opening, infilling etc.
- Installation of Multi Point Borehole Extensometer (MPBX) at different points at different levels to monitor the ground movement. Instead of MPBX, easy way to monitor the movement is installation of some target at different points at different levels and it should be monitored by "total station" regularly & religiously. The data collected to be analyzed.
- Procure a regional geological map (1:50000 / 1:25000) of the area from GSI to analyze the field geological conditions with reference to regional geological setups.

Below is the treatment suggested in general, to which further details will be added or modifications made after getting the above information.

- As the toe scouring is going on at river water level, the toe support is essentially required. However, it is practically difficult as the water level is maintained at certain point due to the reservoir of the lower dam. Still methodology can be explored to create a concrete RCC wall resting on the rock foundation and extended laterally beside the slide zone. If required it should be anchored with firm rock band on both sides and in between. The RCC wall slightly curved in shape with convexity towards hill side. The wall height may be up to 12 -15 m with a bench in between. There should be drainage holes provided at every 2 m centre to centre in the valley face of the wall. Back side of the wall will be filled with fine sand, pebbles & boulders. It should be properly compacted with rolling layer by layer. This will provide ample space for widening of highways and protection from subsidence.
- The loose material resting on the face and at the crown of the slide should be manually removed slowly with proper precautions under supervision. If any cracks at crown and face are observed, gout mix (Cement-Sand-water mix) to be pumped with very low pressure (pressure should decided after site inspection and investigation as above.). The grouting should be planned in such a way that all the loose mass hardens and become monolithic. If required, anchoring should also be planned.

- At road level, well designed circular shaped water catchment drainage will be required to capture the surface flow of water. These drainage systems will be connected by some underground canal system and will be connected to the drainage holes in the RCC wall below the road level.
- Two layers of flexible crate wall to be placed between road and the slide.
- The entire slide face will be covered by geo textile & bio turfs.

3.2 Session-2: Landslide Risk Assessment and Early Warning System

Chairman: Professor Satyendra Mittal, IIT, Roorkee

Moderator: Dr Yuka Makino, World Bank, Tokyo

Rapporteur: Dr. Ajay Kumar Naithani, NIRM, Bangalore

Session report:

The session on ’Landslide Risk Assessment and Early Warning System’ had six presentations dealing with early warning systems in landslide impact mitigation. The very first presentation by Ms. Reiko Abe was focused on “On Site Visualization (OSV) system”. She described about how an OSV System can be used at potential landslide site areas. The cost effectiveness of this system was also discussed. Dr. P.K. Champati Ray from IIRS Dehradun, in his presentation, talked about how remote sensing applications should be increased to identify potential landslide sites. For this, training and capacity building of personnel is required. He described that how IIRS Dehradun can play an important role on this aspect. Dr. Pankaj Jaiswal from Geological Survey of India (GSI) emphasized on the need for development of a model on the relationship between rainfall and probability of landslide. This model should be developed for different areas specifically. He suggested that to include catchment area parameter also in mathematical model. Mr. Jaiswal also emphasized that local people should be trained to read rain gauge, executing an evacuation plan and conveying critical information to the civil authorities. Dr. Vikram Gupta, Wadia Institute of Himalayan Geology (WIHG), Dehradun presented his work focusing on studying typical rain triggered landslides vis-à-vis long duration daily rainfall data of the area. The study is based on the assumptions that there is a direct correlation between the occurrence of landslides and the quantity of rainfall, intensity and duration of the rainstorm events. Prof C.C. Pant from Kumaon University, Nainital discussed the problems of instability in Nainital and suggested preventive / corrective measures. In his presentation he advised that extensive drainage should be provided at and around landslide prone areas. As far as possible, concrete channels should be made so that water does not infiltrate into the ground. The last presentation of this session was made by Mr. Ashish Gharpure from Maccaferri Environmental Solutions Pvt. Ltd. He shared some modern tools like wire mesh, gabion walls, soil nailing, debris/mud flow barriers utilized for landslide prevention. He also talked about bio-engineering methods are also effective in landslide mitigation.

3.3 Session-3: Slope Stabilization Methods/Technologies used in India

Chairman: Dr V.K.Sharma, Director, GSI

Moderator: Dr Yuka Makino, World Bank, Tokyo

Rapporteur: Dr. Vikram Gupta, WIHG

Session report:

The session on 'Slope Stabilization Methods/Technologies used in India' comprised of seven presentations dealing with contemporary techniques of landslide prevention. Prof. Chandan Ghosh of National Institute of Disaster Management (NIDM), in his presentation highlighted that simple solutions such as proper drainage measures cost hardly anything but are effective ways of prevention of landslides. Whereas hefty retaining walls or counterfeit retaining walls without proper engineering are neither practical nor effective solutions. He stressed on adopt a technique that reduces weight on the slope. The bioengineering methods especially the use of '*Vetiver grass*' was proposed to be applied on landslides. Shri. Harish Bahuguna from Uttarakhand Jal Vidyut Nigam (UJVNL) gave pan India glimpse of landslides and enumerated various techniques such as geo webs, geo-grids, geo-textiles etc. available in India to deal with landslides. He also shared case studies where geo-grids, soil nails, fence, timber piling were employed to contain slope failures. Prof. S.K. Sharma, IIT-BHU dealt with issues of acoustic fluidization and rapid reduction in' c' and 'phi' in presence of water due to sudden build up of stress coupled with newer "orogeny" that have unbalanced stresses, as reason for mass rock failures. He attributed slope failures to reasons such as adopting a steeper pit slope angle than appropriate, presence of water and effective measures not taken to deal with it, under-cutting of rock mass and presence of geological disturbances. He also advised application of '*Ram bans'* (a local plant species) to deal with slides and stressed research to assess the strength of the plant roots. Dr A.K.

Naithani, National Institute of Rock Mechanics (NIRM) highlighted that the stability of rock slopes is often significantly influenced by the structural geology of the rock in which the slope is excavated. Discontinuities may only indirectly influence stability where their length is much shorter than the slope dimensions, such as an open pit mine slope where no single discontinuity controls stability. A case study of a proposed dam site at Pulichintala village of Guntur District, Andhra Pradesh was discussed and determination of failure modes in rock slopes was done on the basis of the geological discontinuities. Shri. T.S. Rautela from Tehri Hydro Power Corporation (THDC) presented a case study of slope stabilization methods of Varunavrat landslide that occurred in 2003, on the upslope of Uttarkashi Township. The causes of the mega slide and the host of remedial measures such as designed benches and berms, anchors, rock bolts, shotcrete and geo-textiles etc. were discussed during the presentation. The communication tunnel designed to protect the overshooting of rock boulders is a unique phenomenon to prevent the consequences of the landslide hazard. An integrated approach for stabilization was adopted for ‘Varunavrat landslide’ to save the Uttarkashi Township. Mr Jitin Mukheja of Geobrugg India, gave a presentation on slope stabilization products such as rock fall and debris flow barriers, drapes, earthquake proof stabilization measures and green solutions for prevention of landslides. Sh. B.D. Patni, Chief (Geology), NHPC Ltd presented various case studies of hydro projects where landslide protection works were undertaken and slopes were tackled successfully.

3.4 Session-4: Slope Stabilization Methods/Technologies used in South and South-East Asia Region

Chairman: Prof. Chandan Ghosh, NIDM, New Delhi

Moderator: Dr Yuka Makino, World Bank, Tokyo

Rapporteur: Mr. Harish Bahuguna, UJVNL, Dehradun

Session report:

There were seven presentations in this session from the representatives of Govt. Departments, Institutes and Private agencies on topics ranging from the use of non frame methods, steel slit dams, soil nailing, bioengineering methods and using reinforced earth technology.

The first presentation was made by Takafumi Ishikawa, Nippon Steel, Japan, on ‘Solution Package for Landslides debris flow by utilizing “Non Frame Methods Steel Slit Dam” introduced in

South-East Asia'. Objective behind this presentation was to introduce the concept of Non Frame Methods for stabilizing the slopes. A typical non frame structure consists of three integral parts i.e. I) steel bars, ii) base plate and iii) wire rope. In this method the steel bars are driven into the strata and base plates are fixed on the threaded part and the bolts are connected to each other by means of wire ropes in a grid pattern. The advantage of this method is that it can be implemented without cutting the trees at the affected site and it can be applied to slopes varying in the inclination from 30^0 to 60^0.

Mr. Ishikawa then presented case studies from Bhutan, Taiwan and Japan where slope treatments are being done using this technique. The unstable slopes are being protected by providing a retaining structure at the bottom and putting the non frame structures for protecting the surface with or without using the synthetic membranes.

The case cited from Bhutan is being undertaken as a Cooperative Research Project with an objective of classifying the slope failures by form; analyze its collapse mechanism, trial and efficiency check of natural ground reinforcement, data collection on topography and fine-tuning the counter measure solutions suitable for Bhutan. The project also intends to monitor the data pertaining to soil moisture, ground water, vegetation change, rain fall and ground movement before and after the treatment.

In the last segment, the concept behind steel slit dam was presented quoting examples from Philippines. Steel Structures can be classified into open and closed type by their functions and features. They can be designed to arrest debris type flow or traction load. These structures can be A, B or T type in shape. Non frame methods can be installed rapidly without disturbing the forest or vegetal cover; however their use in India and SAARC region is yet to be attempted.

The second presentation in this session was made by Prof. Satyendra Mittal of IIT Roorkee on 'Successful Handling of Slope Stabilization and Landslide Prevention through Soil Nailing'. The objective of this presentation was mainly to elaborate on the success of soil nailing in stabilizing slopes. Prof. Mittal started the presentation by giving synoptic view of the problem of landslides and its effects followed by a glimpse of the conventional techniques like retaining structures and draping measures. Citing an example from Dagana, Bhutan, Prof Mittal spoke on the different design alternatives that included i)Design of Surface Drains, ii) Design of Underground geo-synthetic drain, iii) Design of Bored Cast-in-situ Pile, iv) Reinforced Earth Retaining Wall, v) Soil Nailing, vi) Dry Reinforced Wall (Pipe Gabions) and vii) Bio-Engineering.

The advantage with nailing is that it intends in-situ stabilization of the soil; it is possible in all types of soils and is very effective in the case of granular soils. These nails can be driven nails, grouted nails or pipe nails depending upon the site requirement. Case studies from different sites were presented. Soil nailing is a well established technique now days and is being practiced widely in India. The next presentation on ’Introduction of the Project for a Master Plan Study on Road Slope Management in Bhutan’ was given by Mr. Masanori Tozawa from JICA. The work carried out by JICA pertaining to a master plan study on road slopes in Bhutan was presented by Mr. Tozawa. The Royal Govt. of Bhutan gives very high importance to roads specially the feeder roads and hence for maintaining connectivity, it desired to develop a master plan. In their study, JICA studied a number of landslides along different highways. The key aspects discussed were the disciplinary management scheme prevalent in Japan which revolves around the cardinal notions of Risk inspection vis.-a-vis. proposed countermeasures and preparedness v/s response.

The master plan included four components viz. site inspection, inventory preparation, GIS database and rendering technical advice. The Japanese have four categories for study and management of landslides wherein the screening of the area is done through topographical maps followed by site inspection and field survey. Inventory on GIS is prepared and landslides are ranked as 1, 2 or 3 on the basis of severity. Regular checks and maintenance form integral part of the master plan. Dr. Shantanu Sarkar, Central Building Research Institute (CBRI), Roorkee gave a presentation on Landslide Hazard Mitigation: Issue and Challenges. This presentation primarily focused on four points i.e. landslide problems in Himalayas, Hazard and risk assessment, Landslide early warning and Control measures. It was emphasized that increasing intensity and frequency of rainfall in Himalayas have led to increased incidences of landslides and with more population growth more so in landslide prone areas the risk will be more pronounced. Examples of landslides from different parts of Uttarakhand Himalayas were cited.

The landslide disaster mitigation program should involve identification of possible disaster triggering scenarios, assessment of hazard & possible consequences for the different scenarios, early warning, recommendation & implementation of specific remedial measure, enforcement of building codes and good construction practice, proper land use plans and community preparedness and awareness building. A brief account of the concept and methodology of Hazard assessment was given and zonation maps for different areas were shown. The need for instrumentation and early warning was highlighted. The instruments for monitoring of surface, subsurface and structural deformations have also been listed. Case study of ongoing monitoring of Pakhi landslide in Chamoli district of Uttarakhand, with the help of GPS was cited.

Landslide control would encompass measures like relocating to safer places in order to avoid the slide affected area, grading of the slopes, surface and subsurface draining and reducing the load for reducing the driving forces, in-situ reinforcement, bioengineering methods and chemical treatments to increase the internal strength and provision of retaining structures for increasing the resisting forces. Example of Watwella slide from Sri Lanka was cited where drainage measures were effectively used for containing the movement. A variety of retaining structures like box wall, crib wall, geogrid wall, and gabion walls were given. For arresting the soil erosion various draping measures were illustrated and importance of soil nailing was emphasized. The use of timber piles, drum debris diaphragm wall and rock shelters was also exhibited. The author finally stressed the need for involvement and awareness of the communities which are living in or close to the slide affected areas.

The next presentation in this session was made by Mr. S. S. Shrimali, Indian Institute of Soil and Water Conservation, Dehradun on ‘Bio-Engineering Treatment of Mass Erosion affected Lands’. It highlighted the fact that the life of civil structures decreases with the passage of time whereas that of bioengineering structures increases which is vital for slope protection and soil erosion control measures. Bioengineering solutions use living plants for engineering purposes or plants in combination with engineering structures for protecting degraded slopes.

These measures are designed to catch the debris, armouring the surface, reinforce the soil, anchor the surface layer, support the slope and for drainage. These are useful for protecting the bare cut slopes (< 0.5 m deep), treatment of landslide/slip zones, gully stabilization, treatment of mined areas, prevent scour around soil conservation structures and for scour protection around river training structures. The important bioengineering techniques are planted grass lines, grass seeding, turfing, shrub and tree planting, shrub and tree seeding, live check dams, wattling, vegetated stone pitching and jute netting.

Case studies of different bioengineering solutions implemented at different sites such as lime stone mined area (Bharli Rudhana, Himachal Pradesh), landslide control Project at Nalotanala on Dehradun-Mussoorie road, minespoil rehabilitation project at Sahastradhara, and torrent reclamation project at Bainkhala near CSWCRTI Research Farm, Dehradun were cited. It was emphasized that mass erosion control calls for integrated watershed management plan starting from top to bottom. The use of different bioengineered structures like crib wall, gabion wall, gabion spurs, and draping such as geo-jute, mulches etc. were also discussed.

For the treatment of degraded slopes, landslides, torrents and river bank protection the future course of action should include appraisal and assessment of special erosion problems using modern tools and techniques (RS, GIS), people's participatory approaches for the treatment and management of degraded slopes need to be explored, cost effective bio-engineering measures including plant species for specific applications need to be identified/evolved, geo-morphological and hydrological aspects of special erosion problem areas need to be studied, economical utilization of drainage lines and profit sharing thereof should be explored and safe and economical designs for torrent control structures need to evolved along with vegetative measures.

Another presentation in this session was given by Mr. K. Navaneeth Kumar from Garware Wall Ropes Ltd on 'Intervention Technologies for Landslides, Rockfall Mitigation and Erosion Control'. This presentation mainly covered aspects on rock fall protection system, Gabion Gravity Retaining wall, Reinforced soil Wall and Slope system, Erosion control systems and River training works for roads along the River banks.

The basics of rock fall protection measures using galvanized steel wire rope netting along with its anchoring were demonstrated. Case studies of rock fall protection works from Konkan railways, Chattursinghi hills Pune, Sakleshpur from Mysore, Mumbai – Pune expressway and East coast rail ways Orissa were cited.

The examples of use of gabion wall from Pirangut Pune, Lanjigarh Orissa, and Lavasa Maharashtra were displayed. It was followed by giving examples of use of steel strip reinforced soil wall, geogrid reinforced soil wall along with slope facing techniques. Under the slope erosion control techniques the use of geo mat or mulch mat was discussed and examples from Chitradurga, Vizag, Talcher (Orissa), Udhampur (Jammu) and Kundli – Manesar (Haryana) were given.

The last segment of this presentation covered aspects on river training works for roads along the river banks through the use of geosynthetics. The advantage of geosynthetics over steel wires like high tensile strength, non corrosive nature and filtration characteristics were discussed. The use of stone Filled Polymer Rope Gabions, geotextile Bags filled Gabions, sand filled Geotextile Tubes and sand filled Geotextile Bags / Containers /Mattresses was cited from various sites like Teesta, Barimatha – Tapti river, Mula river, Pavana river (Pune) and Narmada river bank at Madhi (Gujarat).

The last presentation on this series was done by Mr. Atanu Adhikari from Reinforced Earth Pvt. Ltd. This presentation mainly dealt with Reinforced Earth and Precast and Pre-engineered solutions which, as claimed are eco friendly solutions and are useful in case of repair and rehabilitation works, river protection and bed protection, pre cast and pre engineering solutions and hill slope stabilization.

Pre cast cut ‘n’ cover Tunnel for traffic provides safety against land slide and mudflow and it will be advantageous for hilly areas. Various types of retaining structures viz. river front wall, approach wall and water front wall were shown in the slides.

The take away point from this presentation is the approach of adopting a balance in cut and fills section for designing and restoration of hill roads. Use of soil nailing and compacted fill layers was discussed and examples of hill road widening from different locations were cited.

3.5 Session-5: Slope Stabilization Methods/Technologies used globally

Chairman: Professor Yudhbir, Eminent Geotechnical Engineer, Dehradun

Moderator: Dr Yuka Makino, World Bank, Tokyo

Rapporteur: Dr. S. Sarkar, CBRI, Roorkee

Session report:

There were six presentations in this session from International and National participants. In this session apart from many good practices of landslide mitigation one study on geological and geomorphologic effect of Mandakini River and usefulness of forest conservation has been discussed.

The very first presentation by Dr Rolf Studer from Switzerland was on ’Slope stabilization and landslide prevention in Switzerland’. He stressed upon the effectiveness of bio-engineering for shallow landslide prevention. In his presentation, he showed landslide database and associated forest condition. He also mentioned about the book on “Bioengineering Hand Book” authored by him. The main point of his presentation was how good is bio-engineering measures for shallow landslides.

The second presentation in this session was made by Prof. Manuel Garcia Lopez of National University of Colombia on ’Landslide stabilization in the Colombian Andes’. He briefed about the tectonics of Colombia and landslide occurrences. He presented a few measures such as gabion wall, anchored wall, drainage measures etc.

Another presentation in this session was given by Dr. Kishore Kumar from CRRI on ’Control measures & mitigation – Some case records’. He talked about slope management system. He presented a list of landslide control measures and a few case studies in which CRRI has implemented a few measures.

Dr Takano from JICA presented on “Mitigation & management of destabilized slopes”. He mentioned about the traffic planning during the construction stage. He also commented on importance of cost estimation. A very important point emerged out from his presentation was the evaluation of surroundings during construction stage. He also stressed upon the soil balancing aspect through cut and fill and proper slope design. He presented a few measures such as soil nailing, rock fall protection, drainage well, surface drainage etc. He advised on understanding the problem and step by step solution.

The next presentation in this session was made by Dr. Hirotaka Ochiai from Forest Research Institute, Japan on ’Forest conservation and landslides in Japan’. He showed many examples of gully erosion and soil erosion from different counties. He mentioned about population and corresponding land use changes in Japan. He showed past distribution of landslides in Japan and referred to landslides in Hiroshima. He presented an excellent field experiment of debris flow. The main point in his presentation was the important role of forest conservation in landslide disaster mitigation.

The last presentation on this session was done by Prof. Y.P. Sundriyal from Garhwal University, Srinagar on “Challenges of slope stabilization in climatically & tectonically sensitive Himalaya – A case study of Mandakini valley in 2003”. He presented a detail study of the Kedarnath tragedy. He mentioned about the damage survey and presented the huge data of various locations which was affected by the 2013 disaster. He stressed upon the importance of understanding river discharge phenomena.

3.6 Session-6: Open Discussion/Brainstorming on the Uttarakhand Challenge

Chairman: Professor Yudhbir, Eminent Geotechnical Engineer, Dehradun

Moderator: Dr Yuka Makino, World Bank, Tokyo

Rapporteur: Dr. G.C.Joshi, UDRP, Government of Uttarakhand

Session report:

In this session a good debate on the landslides problem in Uttarakhand has been held. Speakers, Participant and others were deliberately participating in this session. Many suggestions have emerged out to mitigate the problem of landslide in the State. One important suggestion was t to develop a Standard Operating Procedures (SOP) or manuals to mitigate the landslides problem and if any Institutions / organizations have developed such SOPs or manuals they should share the same to public for the interest to the end users. Many of participants suggested that different case studies should be discussed in these manuals.

After that the discussion was held on what studies are to be conducted to understand the problem of landslide. By the detail deliberation all the participants agreed on the following studies that are to be carried out for the need assessment of landslide problem:

1. Mapping:
    - Topographical survey (Detail Topographical maps of 1:500 scale for 2 m contour interval)
    - Surface geological mapping –site and regional database
    - Quaternary geological and Geomorphic mapping
    - Hydrological mapping
2. Rainfall recording
    - Automatic rain gauge
    - Village-level rain gauge
3. Sub-surface exploration
    - Geotechnical
    - Field and laboratory testing
    - Hydrological monitoring
    - Geophysical investigation
    - Groundwater – hydro-geology
    - Tectonic activity
4. Monitoring of landslide movement – e.g. laser scanning and LiDAR (Light Detection and Ranging) survey

It was suggested that Geological Survey of India (GSI), Survey of India (SOI), Geology and Mining Unit (GMU) Uttarakhand, IITs and various private consultants conduct the above studies and make the reports available to Government of Uttarakhand.

The need for establishing more rain gauges in different parts of Uttarakhand was strongly felt by the participants and the same was recommended to the organizers.

Another most important aspect of discussion in this session was how to design and treat the unstable slopes. The design and Implementation procedures have been discussed. Following points have been suggested by the participants:

1. Steps for determining treatment
   - What was the form and shape of slope before failure
   - What soils and rocks are at the site and how did it get there
   - Define the failure mechanism – what was the mode of failure
   - Define the causes
   - The contributing factors and triggering factor
   - Shear stresses
   - First look at the standard design procedures
   - Look at other cases – and learn from other cases/countries/observations
   - Value engineer
2. Formation of advisory group
3. Quality assurance/supervision
   - Management of finance – who will bear the total cost
   - Design and supervision consultant is the same
   - Supervisor – third party construction supervisor independent from surveyor and contractor

To design and implement the various slopes, it was suggested that to achieve above objectives, different manuals/guidelines/standards/standard operating procedures already available in India or prepared by the different organizations like JICA, UNDP, and SWISS Bioengineering etc., should be studied and utilized. It was also suggested that, for designing and supervision of slope mitigation/stabilization works Design and Supervision consultant shall be hired and these works should be vetted by the task force that has already been constituted by the State government. Also at the execution stage quality check shall be confirmed.

The most important point of discussion was about the standard Schedule of Rates (SOR) for different items which could be used in the slope treatment works. It was suggested by the house that, some of the States have already given these rates like Delhi schedule of rates which can be used for making the slope protection estimates. The other good suggestion was that all agencies put their rates on the websites and make the process more competitive. It was also suggested that limited tender query could be done before execution of the work. One important point was discussed that because every site is different in nature and if we are going to adopt any new technology for treatment of slopes, item rates shall be invited from various agencies.

The discussion was held on what is the best construction mechanism for slope protection works. Following points emerged in this discussion:

1. Safety management – protection of worker
2. Clear criteria for selection
3. EPC (Engineering procurement construction consultant) or PMC (Project Management Contract) — clear accountability should be fixed
4. Clear technical specifications of the interventions written by the design consultant
5. International level Design Review Consultant (DRC)

The suggestion came that a Technical Task Force (TTF) should be created to develop the best construction mechanism, review during the execution and monitoring post construction and TTF should give the criteria on this regard. It was also suggested that a Project Management Team should be constituted for execution of slope protection works. A third party supervision of the work was also suggested by some of the participants.

A manual of similar types of case studies should be made compiling the following:

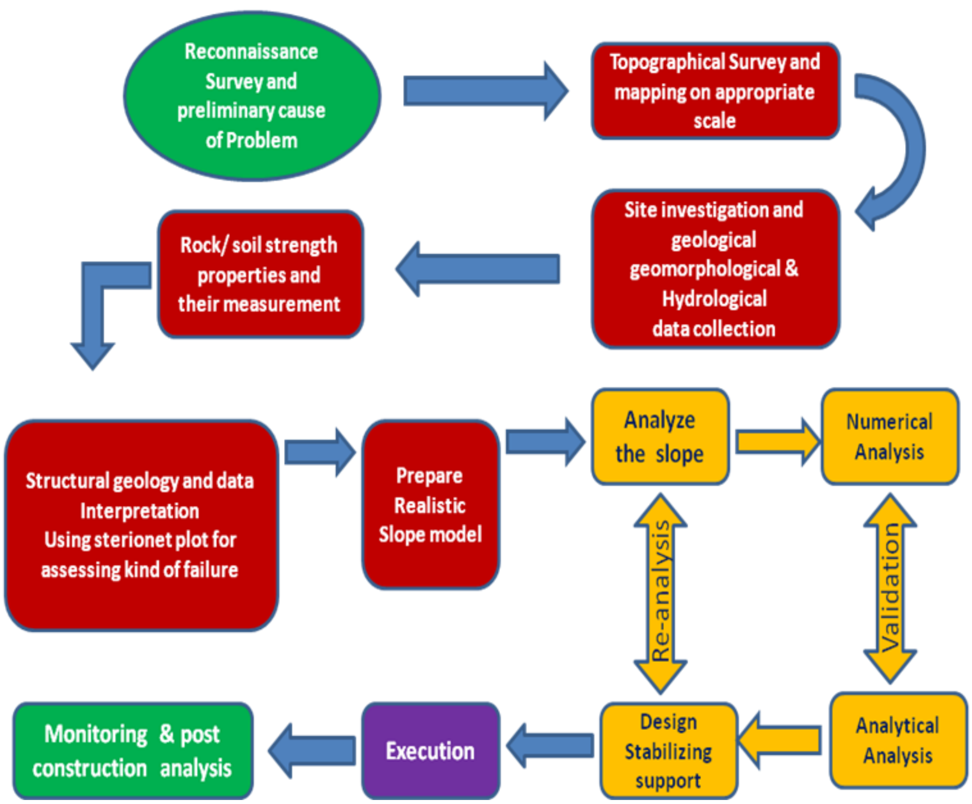
1- Best practices Examples of landslide problems and slope protection works
2- Documentation of landslide remediation works

These manuals should be available in public domain so that end users get help from these case studies and best practices could be used in future planning of landslide treatment.

It was suggested to standardize the training and capacity building programs in order to build the capacity of professionals and scientists on practical applications of landslide mitigation, for improved decision-making and better management of the problem. The objective should be achieved through lectures, practical demonstrations, laboratory exercises, plenary discussions, and field excursions. It was also agreed that a specific syllabus for landslides training should be developed.

4.0 OUTCOMES

The Symposium recommended the implementation of the following road map for Slope Stability Analysis and Stabilization of Chronic Slide Zones.



4.1 Topographical Survey and Mapping Investigations: - The area should be mapped in detail on appropriate scale preferably on 1:500 or 1:1000 scales with 2 m contour intervals giving the plan of affected area and typical cross sections which are required for stability analysis. Topography may be determined by Laser Scanning, LiDAR and Aerial survey, if possible, in order to provide overall geometrical features of the area. In general the topographical maps should include the information like the extent and nature of vegetation cover, surface run-off characteristics, presence of springs etc. Erosion may be observed in detail.

4.2 Site investigations Geological, Geomorphologic and Hydrogeological Data collection:- Geological map of the landslide area should be prepared by incorporating lithological, structural features like bedding/foliation planes, joint planes, faults, folds shear zones unconformity etc. in rock exposures and its contacts with the overburden, soils/debris material. Slope angle and slope direction should also be duly considered. These features should be studied in detail and should be properly marked on the map.

The rock type in the area should be identified and their quantity as well as quality should be precisely assessed. The minerals in the rocks and their alteration products should be taken into consideration. The investigation must be done to carefully observe the presence of any soft or incompetent products or beds or intercalated layers. Signatures of ground movement, limit of active scar, tension cracks, distress in the rock mass etc should also be marked on the geological map.

On several instances, geophysical studies may help in detecting such layers or pockets.

The influence of these structural features on the stability of the affected slope can be evaluated with the help of stereonet analysis/kinematic checks with the help of standard softwares.

In addition to it, geomorphological features like elevated and depressed zones, break in slope, erosion and depositional zones, mass movement vectors etc. should be marked either on the already prepared map or on a separate map.

The hydrological conditions like depth and seasonal fluctuations of water table should also form an important component of data required for landslide investigations. The information on the nature, extent and behavior of rainfall of a particular area, data from the nearest rain gauges or gauge and discharge sites of Central Water Commission, data on discharge in the major rivers and their catchment should be collected and made available to the agencies carrying out studies/investigation of landslides. The information on changes in the ground water table may be collected from local enquiries or by observation in the wells which are present in the locality or by noting the presence of springs etc. Sometimes, it may be desirable to drill a borehole or to install a piezometer, to observe the water level over a complete cycle of season.

4.3 Rock Soil Strength Properties and their measurement:-

The geotechnical Investigations shall be carried out with the objective of determining the nature and strength characteristics of the slope forming material. If it is soil or a mixture of soil and rock (composite soils), disturbed and undisturbed samples should be collected carefully from different locations of the affected area.

Disturbed samples may be made used for determining the index properties, gain size analysis etc. Undisturbed samples may be collected from the open pits or from boreholes, using prescribed sampling tubes. In the debris covered slopes, as it is very common in the case of Himalayan landslides, undisturbed samples of good quality can be collected only from open pits. These samples are basic requirements for evaluation of shear strength parameters, therefore must be collected very carefully.

4.3.1 Laboratory Investigations: - Following are some basic tests needs to be carried out on the soil and rock samples collected from the slide scar.

i. Determination of index parameters in case of soil samples.

ii. Shear characteristics of slope forming material. If the material is by and large fine grained, tri-axial shear test may be suitable. If sample contains relatively high content of gravel or rock fragments, direct shear test could be conducted more easily on such samples. All the tests should be carried out as per the prescribed standard procedures.

iii. Rock samples should be examined carefully to find out the nature of rock, extent of weathering, presence of any weak or incompetent inter layer etc. If suitable samples are obtained, strength of rock samples can also be determined.

4.3.2 Structural Geology and Data Interpretation:-In the rock slopes, orientation of discontinuity planes and deformational features like joints, folds, faults, along with other important structural features shall be carefully recorded. Preparation of cross-sections, longitudinal sections along with the stereonet projections of various discontinuity planes in order to define the type of probable slope failure (Planar type, Wedge type, Topple type or compound). In case of soil/debris establishment of slip circles. Cohesion (c) and Angle of Internal Friction (Φ) are to be calculated for both.

4.3.3 Prepare Realistic Slope Model: - In order to analyze the slope a realistic slope model shall be prepared on the basis of the data collected. Digital Elevation Model of the affected slope should also be prepared.

4.3.4 Analyses of Slope: - The slope stability analysis shall be carried out separately for the rock slopes and separately for the soil slopes and thereafter the protection measures must be analyzed for overall global stability. The rock slope stability can be analyzed by the slip circle analysis or by deformation (stress) analysis. The common methods of calculating factor of safety assuming circular failure surfaces are Fellenius methods and Bishop Method. The rock slope failure can be classified into one of four categories depending on the type of degree of structural control.

- Planar Failures - Governed by single discontinuity
- Wedge Failure - Failure mass defined by two discontinuities with a line of intersection that is inclined out of the slope face.
- Toppling Failure - It involves slabs or columns of rock defined by discontinuities that dip steeply into the slope face.
- Circular Failure - Occur in the rock mass that are either highly fractured or comprised of the material having low intact shear strength.

Interpretation of these data in order to allow three dimensional orientation data to be represented and analyzed into two dimensions can be done by the most commonly used by the equal area net and the polar net projections. Appropriate methods of analysis for a circular failure in rock depend upon the shear strength criteria used to characterize the rock mass material. Analytical techniques such as those presented by Janbu, Bishop, Morgensteru and price and Sharma can be chosen wisely considering the nature of the material whether it obey the Mohr- Coulomb criteria or not.

To analyze stability problems where conditions may preclusive the use of stability charts generally requires the utilization of computer program such as XSTABL, PC-STABL5, LISA and TALREN. Dynamic forces introduces in rock slope should be considered in slope design analysis as the area falls within the geodynamically active seismic zone. Design stabilizing support. A variety of remedial, corrective or control methods are practiced to protect hill slopes these shall be site specific, durable and effective.

4.3.5 Monitoring and post construction analysis: - Field instrumentation and monitoring is required for detecting signs of pending instability as well as post slide movements. The instrumentation program should be planned to provide the basic information of the following aspects.

a) Monitoring of built up and dissipating of pore water pressure

b) Measurement of different points in the movements, and

c) Measurement of surface movements.

4.3.6 Execution and post construction analysis:-The protection measures suggested as per design and above analysis by any specialized agency must be indemnified by them such that the risks associated with specialized works are being taken care of such construction. The designed life of suggested protecting measures shall be of minimum 100 years.

5.0 WAY FORWARD

Geological appraisal and geotechnical assessment should be made a prerequisite mandate for any infrastructure project in order to make proper and adequate plans for excavation and stabilization. The practice of getting a routine stereotype note/report from a geologist should be done away with and ample space and importance should be given for site specific detailed geological and geotechnical studies and investigations. A penny spent in such studies and investigations can save millions in future and also help in evolving lasting design solutions. Proper geological investigation will guide in selecting a tailor made excavation methodology for a particular road, bridge or a tunnel site which will help in minimizing the damage to the in-situ rocks and other natural materials occupying the slope at that site which in turn would mean optimizing the support measures.

Technical knowledge and expertise, institutional or freelancing, on the subject matter is available in the country and the State of Uttarakhand itself. The State is blessed to have premier departments of Government of India like Geological Survey of India and Survey of India in Dehradun. The former is the nodal agency of GOI for carrying out studies of landslides in India and has vast expertise in suggesting remedial measures for landslides. There are institutions such as IIT Roorkee; Central Building Research Institute, Roorkee; Indian Institute of Remote Sensing, Dehradun; Indian Institute of Soil and Water Conservation, Dehradun; and Wadia Institute of Himalayan Geology, Dehradun that have been carrying out studies of landslides and helping in evolving the treatment plans and stabilization measures. Basic geological mapping, data collection, analysis and numerical modelling and design can be done with Indian expertise.

Technology transfer in some of the cases is required from outside. The supply of some of the materials like geosynthetic textile, geocells, geogrid, steel fibre reinforced shotcrete, catch net fences and hydro seeding etc., may have to be imported. However, there are Indian franchises that have supply agreements with the original foreign suppliers.

Use of locally available material should be encouraged in the treatment of a particular sliding or subsidence zones. Locally available traditional knowledge pertaining to the historical behavior, modes of failure and immediate response from the natives to contain or treat slides should also be utilized.

Research & Development projects may be taken up with help from Department of Science and Technology (DST), for technological or material innovation, using locally available geological or natural material for stabilization of a particular slide zone.

Coordination and cooperation amongst departments like PWD, PMGSY and BRO is required so that concerted actions can be taken up in tackling the challenges put forth by the landslides/subsidence. Collaborative approach in this regard will also help in resource sharing amongst these departments which will immensely help in extending immediate relief to the people and also in tackling the challenges.

Early warning mechanisms at village/block level should be developed to avert loss to life and livestock. Community level interaction on the possible escape routes in the event of a landslide should be held and a general map of such escape routes should be available at the village panchayat level. It will help in evacuation process even before the arrival of the rescue teams from the government agencies.

Participatory learning workshops, disseminating basic knowledge on the phenomenon and threat perception about the landslide, should be made a part of school curriculum at least at junior high school, high school and intermediate level.

We will have to modernize our approach and aptitude towards the understanding of the subject matter pertaining to road cutting, blasting, for infrastructure development (bridge, tunnel etc.) and should have a tendency to adapt to state of the art technological innovations in this field. At the same time the appreciation for natural processes of landslide or ground subsidence or river bank erosion should be made in the right perspective so that the contribution/role of anthropogenic activities/interference in triggering a particular landslide can be evaluated correctly. The executing agencies like PWD and BRO should adopt modernized equipment for cutting roads or stabilizing hill slopes.

As stated above, there is no dearth of experience and expertise available on the subject matter. With the existing experience of stabilizing one of the mega slides such as Varunavat in Uttarkashi district, indigenous experts can tackle most of the challenges that the State of Uttarakhand is facing. However a strong will power and fast actions from the State machinery is required for that.

Annexure A: Abstracts

Application of Ground Penetrating Radar (GPR) for landslide investigations with examples from South and South East Asia

Rajinder Bhasin, NGI, Norway

Abstract

At the Norwegian Geotechnical Institute (NGI) in Oslo, Norway, there has been a continuous activity in development and testing of Ground Penetrating Radar (GPR) for different sub-surface mapping tasks. Three generations of GPR have been developed at NGI, the latest being the hand-held GPR system based on the "fieldfox" network analyzer. NGI's GPR has been successfully used for quick and cost effective mapping of landslides and for subsurface investigations throughout the world. GPR is a high resolution geophysical method, which is based on the propagation of high frequency electromagnetic waves. The GPR method images structures in the ground that are related to changes in dielectric properties and therefore it can be used for landslide investigations where the thickness of debris can often be estimated and slip surface identified. Being a non-destructive method, the GPR techniques being used extensively around the world for various applications including:

- Geological and hydro-geological investigations including mapping of bedrock topography, detecting slip surface pf landslides, water levels, glacial structures, soils and aggregates.
- Engineering investigations to evaluate dams, tunnels, pavements, roadbeds, railway embankments, piles, bridge decks, river scour, buildings and monuments.
- Location and evaluation of buried structures including utilities, foundations, reinforcing bars, cavities, tombs, archaeological artifacts
- Subsurface mapping for cables, pipes and other buried structures prior to trench-less operations.

This presentation will highlight the application of NGI's hand-held GPR for investigation of landslides. Examples will be shown of its use in South and South East Asia including India.

Landslide mitigation strategies with examples

Frode Sandersen, NGI, Norway

Abstract

Landslides and other mass movements are serious geo-environmental hazards in many parts of the world, especially in the Himalayas. In addition to the anthropogenic and seismic triggering factors for landslides, it is believed that the intense rainfall in the region not only contributes to rapid erosion and weathering of the rock mass, but also increases the groundwater level that leads to reduction in the stability of natural slopes. This presentation will highlight some of the structural and non-structural mitigation strategies for stabilization of landslides.

Structural measures include, but are not limited to drainage, erosion protection, channeling, vegetation, ground improvement, and barriers such as earth ramparts, walls, artificial elevated land, anchoring systems and retaining structures, buildings designed and/or placed in locations to withstand the impact forces of landslides and to provide safe dwellings for people, and escape routes. Physical protection barriers may be used to stop or delay the impact of debris flows, reduce the maximum reach of its impact, or dissipate the energy of the landslide. Such barriers may include “soft” structures in the form of dikes or embankments, or “hard” structures like vertical concrete or stone block wall. Any measures need to be part of a community’s master plan and subjected to analyses to assess and circumvent any negative environmental impact. It is important, when evaluating mitigation measures, to weigh benefits of the measures to be implemented and the possible negative effects these measures may have. Decision-making will rest in finding an optimal solution.

The non-structural or more generally "consequence reducing measures" include, but are not limited to: retreat from hazard, land-use planning, early warning and public preparedness (escape routes, etc) and emergency management.

Continuous technological progress and innovation make it virtually impossible to provide a detailed overview of mitigation strategies. This presentation will show some recent examples of landslide mitigation methods, which have been adopted in Norway and abroad.

Remote Sensing and GIS for Landslide Hazard Mitigation: Priorities for Uttarakhand

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Abstract

Uttarakhand was devastated by extreme climate event leading to unprecedented loss of human lives and property. Reconstruction and rehabilitation following the disaster provides opportunity for improving infrastructure and make society as well as infrastructure more resilient as the frequency of such extreme events is going to increase. In this regard emphasis is laid on Landslide hazard mitigation as this is the prime cause of maximum damage and destruction in Uttarakhand. Landslides can be mapped, monitored and modeled using Geoinformatics (GIT) tools and techniques. Particularly these techniques can be of immense value in large tracts of inaccessible regions like Himalaya. Traditional geotechnical analysis like factor of safety (FOS) calculation can be implemented in GIS and spatial patterns can be analyzed. Additionally, satellite remote sensing provides information on slope deformation using DInSAR and precipitation which is an important triggering factor of landslides in India. GNSS based observation can provide precise observation on slope deformation which is crucial to modeling and monitoring of active and potential slope failures. Satellite as well ground based information can be integrated using geoinformatics tool to develop an Early Warning System for landslides. Although opportunities are enormous, there exist gaps in appropriate policy framework to incorporate GI tools in slope stability assessment and monitoring related to disaster management and infrastructure development.

Challenges in landslide Early Warning for a catchment area and a way forward

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Abstract

Forecasting of a natural disaster has gained importance in many disciplines, including landslide studies. The first practical demonstration of landslide early-warning system was possibly in 1980s by United State Geological Survey in the San Francisco Bay area. Since then, several attempts have been made to forecast landslide events. In last few decades, with advancement in technology, research on site-specific monitoring of individual landslide for issuance of early warning has gained importance. However, the development of a real-time early-warning system for forecasting landslides, both in space and time, and communication of warning to individuals may appear a step too far, especially in large developing countries like India.

World over, many advances have been made in the methods for landslide forecasting; but the challenge remains in mapping individual landslide processes and the factor that results instability. The uniqueness of landslide phenomenon and the fact that each triggering event can result in one or many landslides in an area, make this geomorphic process difficult to predict in space and time. Although, it is possible to predict movement of a single landslide through detailed mapping and instrumentation; but, the challenge remains forecasting over a large area. Further, the high cost of instruments and their applicability over a limited area makes instrument-based landslide forecasting uneconomical. Challenges are also related to spatial prediction of a landslide. All the available models for landslide spatial mapping only provide a qualitative or probability-based quantitative susceptibility maps showing the probable initiation zones. Such maps do not point out 'precisely' where the landslide will actually initiate given the triggering condition and how it will behave down slope. Things get further complicated if it requires to associate temporal component with the landslide event and to communicate the warning i.e., how to inform the individual or community about the danger. Since, landslide distribution is localized and affects only a few individual or a certain segment of the society, communicating the warning, which are developed and issued from place located far away, to the concerned remains a challenge.

One way to overcome this is to use the locally developed rainfall threshold models for forecasting rainfall-induced landslides. The advantage is that the threshold models are economical and can be adapted for a catchment area. What it requires is establishing a relationship between trigger (rainfall) and landslide initiation. Forecasting of the trigger can provide information on ‘when’ landsliding would occur and this in conjunction with landslide susceptibility maps can delineate potentially hazardous areas and timely early warning.

Fig. 1 shows the operating procedure of threshold-based early warning system. The capabilities of this system rely on empirical models which are based on rainfall measurements. The warning system is composed of several components, including establishment of rainfall-landslide thresholds, rainfall forecasting methods, real-time rainfall monitoring and an automated computing system for evaluation of warning. The system is essentially based on a quantitative precipitation forecast either using remote sensing data or network of rain gauges. For Indian condition, with 0.42 million sq. km hill area being prone to landslide risk, such cost-effective landslide warning tool is the most viable solution. What is requires is establishing a threshold model for small river catchment or at Taluk level, establishing a tipping-bucket type rain gauges at village level, collection and dissemination of daily rainfall data and locally analyzing the threshold exceedance for monitoring. The process can be automated at district level and can be manually carried out at village level through village panchayat or school. In addition, threshold exceedance graph or chart along with the susceptibility map can be displayed at village level for facilitating community based response.

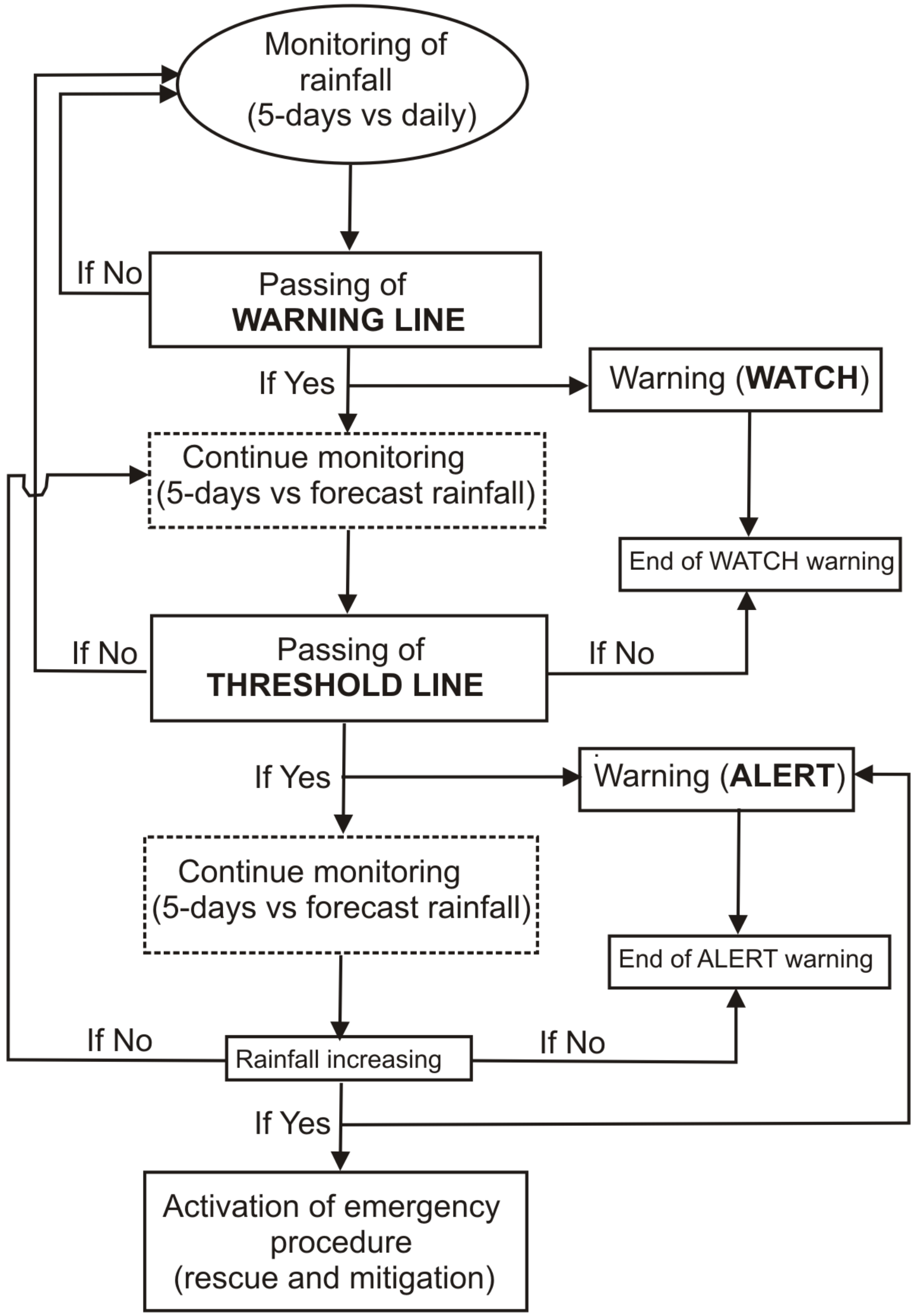

Figure 1 Operating procedure of warning system based on rainfall thresholds.

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Towards Establishing Rainfall Thresholds for triggering landslides for the Uttarakhand Himalaya

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Abstract

Landslide, in general, is mainly affected by the internal geological conditions like lithology, structure, tectonics, terrain morphology, hydrological conditions and external triggering factors like earthquake and rainfall. Rainfall induced landslides and related mass movement phenomena occur almost every year, particularly during the monsoon, which usually lasts from June/July to September, and accounts for the loss of hundreds of lives and damage to private and public property. According to an estimate an average loss of ~ 40-50 million USD incurs every year in India due to landslides and associated phenomena.

Uttarakhand Himalaya, having about 90% of its landmass under mountainous terrain, is plagued by landslides during or immediately after the monsoon, owing to its propensity towards unstable geological and structural setting, and steep slopes combined with severe weather conditions. It has been reported that two landslides occur in every square km of area per year in the Uttarakhand Himalaya. 1998 Surabhi Resort (near Mussoorie) landslides, 2003 Varunavat Parvat (near Uttarkashi) landslides, 2013 numerous landslides in the Yamuna, Alaknanda and Bhagirathi valleys, 2014 BaliaNala (Nainital township) landslide are some of the recently struck rainfall induced landslides that have caused great loss of life and property in the region.

With increasing number of rainfall induced landslides in recent years, particularly in the Uttarakhand Himalaya, an understanding of the relationship between rainfall and the incidence of landslides is of utmost importance. Though many studies related to the assessment of empirical rainfall thresholds for landslides initiation in order to predict landslide occurrence have been carried out all over the world, none of the established threshold value hold true for the Himalayan region, particularly for the Uttarakhand Himalaya.

The present study focuses on studying typical rain triggered landslides vis-à-vis long duration daily rainfall data of the area. The study is based on the assumptions that there is a direct correlation between the occurrence of landslides and the quantity of rainfall, intensity and duration of the rainstorm events. The studied landslides are 1998 Surabhi Resort landslide (located on the Mussoorie-Kempty road), 2003 Varunavat Parvat landslide (located in the Uttarkashi township), Wariya landslide in the Yamuna valley (located upstream of Barkot township), 2013 landslides in the Bhagirathi valley and 2014 Balia Nala landslide (located in the Nainital township). It has been observed that despite having different rainfall intensity in these different areas/valleys, there is large probability of landslides when the intensity of rainfall, in the monsoon season (total rainfall during rainy season /number of rainy days), in a particular area exceeds about 100% of the normal intensity of that area. However more landslide case-studies need to be investigated so as to establish the generalized rainfall threshold of the area.

Problems of Instability in Nainital: A case study

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Abstract

The Naini lake basin, located in the Krol belt of Lesser Himalaya, is approximately 21 km^2 in area. The rocks of the area highly deformed and criss-crossed by a number of faults which has rendered the slope forming material highly vulnerable to mass wasting. The mean slope value in the area varies from 20 degrees to more than 45 degrees. As a matter of fact, about 50% of the Naini lake basin is covered with debris generated by mass-movement. The fragile geological conditions, high rainfall coupled with anthropogenic factors have made the hill slopes highly unstable. Nainital has had a long history of landslides. The northwestern part of the township is covered by huge landslide lobes and fans produced by 1887 and 1880 slides. The 1867 slide produced the fan over which the Nainital club is located. The catastrophic debris flow of 1880 killed about 155 people and produced the almost gentle tract of the flats. The slopes of the Sher ka Danda are the dip slopes and the slates of the Lower Krol manifest 35-55^0 towards SW. The slopes of the Brook Hill and Shervani area are likewise covered by thick stabilized landslide deposits of unknown age. The cliff section of Naina peak continues to supply debris during rainy seasons. There are a large number of joints trending NW-SE in the slates which have widened due to percolation of rain water thus reducing the shearing strength of the rocks and soil forming material. The Middle Ayarpata slide of 1939 and Edwinstowe slide of 1942 were caused by heavy traffic in the area. This caused reactivation of shattered slope forming material comprised of slated overlain by carbonate rocks. The slips of the Purbeck lodge and Phansi gadhera in1942 and 1958 caused damage to the Raj Bhavan road .The chronic Balia ravine landslides is attributed to high shearing and shattering related to Nainital lake fault. The 17 August 1898 slide affected the Kailkhan spur and buried the brewery (Birbhatti). The right bank of Balia nala was affected by a slide of 1924. The stability of Nainital is directly related to the stability of the Balia ravine. The steep southern slopes of the Raj Bhawan-Lands End are presently highly unstable. The dolomites of the upper Krol and Tal are highly shattered and there are several vertical joints paralleling the Main boundary Thrust (MBT) has produced precipitous scarp into Nihal-Saulia causing rock falls and debris slides.

The slopes of the basin and the civil structures shows several signs and evidence of instability viz. tilting of the trees , cracks in the parapets, walls of the houses, tilting of electric poles etc. Actual cumulative measurements of pillars and pegs in different segments of the basin have` shown vertical displacements of the order of 22 - 60 cm during a period of 50-60 years. The stability of the township depends upon proper understanding of the geological, geohydrological and anthropogenic conditions prevailing a particular area and location. An attempt has been made by various organizations for understanding the problems of instability in the basin. A hazard zonation map of the township of Nainital has been prepared. An attempt will be made to discuss the problems of instability and suggest preventive / corrective measures.

Natural Hazard Mitigation Measures

Ashish Gharpure
Maccaferri Environmental Solutions Pvt. Ltd.

Abstract

As per World Meteorological Organization (WMO), Natural Hazards are defined as “severe and extreme weather and climate events that occur naturally in all parts of the world, although some regions are more vulnerable to certain hazards than others, and these become natural disaster when people’s lives and livelihoods are destroyed”. Natural hazards, majorly Landslides and Rockfall, commonly occurring in mountainous terrains, are receiving greater attention around the world primarily due to its increased frequency of occurrences and capability of causing catastrophic damages. With increasing developments of transportation network and infrastructure, the number of affected lives in the hilly areas is also increasing. Highway and railway construction in mountainous regions and hilly terrain presents a special challenge to geologists and geotechnical engineers because of these reasons. As far as India is concerned, Landslide events are distributed in all regions of the country differing from the scale of severity of disaster. There is now a sense of urgency and recognition of need to stabilize rock slopes and / or mitigate impacts of this increased exposure to Rockfall and Landslides. It is neither possible nor practical to detect all potential Landslide and Rockfall hazards by any of the techniques currently used in rock engineering. However, Landslide and Rockfall mitigations are areas which have experienced extensive technical developments in the past few years. It is extremely important to identify and categorize Landslide/ Rockfall Event by doing proper surveys and studies- Geophysical, hydro-geological, geotechnical, which in turn helps in assessing the risk involved. Beyond the basic theories, classification and causes of Rockfall and Landslides, this paper/presentation attempts to capture the recent developments, categorize and describe mitigation measures and deals with selection of different traditional and latest mitigation measures. Various Landslide Prevention and Remediation measures, like, modification of slope geometry, drainage measures, retaining systems, internal slope reinforcement, Bio-engineering and greening techniques are briefly explained in the paper/ presentation. Several mitigation measures for Rockfalls, which are classified as protection, retention and prevention measures, namely, modification of slope geometry, Drapery system, Rockfall ditches, Rock fall barriers, Rock sheds and Rockfall protection Embankments are also included briefly in the paper/ presentation.

Three case studies from India and abroad, are briefed in the paper/presentation explaining the problem and solution adopted.

Key words: Landslide Mitigation, Rockfall Mitigation, Natural Hazard Mitigation, Hazard Risk Assessment, Drapery, Rockfall Barrier, Rockfall Embankment, Drainage, Warning Measures, Protection Measures, Retention Measures, Prevention Measures

Landslide studies using space-based inputs

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Abstract

Satellite images have inherent advantage of extracting landslide information in highly inaccessible mountainous areas. Availability of high resolution data from Indian Remote Sensing (IRS) satellites such as Resourcesat-2 LISS-IV Mx, Cartosat-1&2 in conjunction with ISRO's geoportal i.e. *Bhuvan*, has culminated to a mechanism from timely data acquisition to dissemination, which is vital for assessment as well as management of landslide disaster. In the recent 2013 Uttarakhand disaster, a total of 6585 landslides covering approximately an area of 52 km^2 were mapped in the Bhagirathi and Alaknanda valleys using high resolution satellite data. Furthermore, a damage of two sq. km. of river terrace at 89 locations along the two river valleys was observed after the 2013 Uttarakhand disaster. Maximum loss of fluvial terrace was seen in the Alaknanda river valley in comparison to the Bhagirathi river valley. Digital elevation models (DEM) derived from stereoscopic Cartosat-1 data helped to estimate the volume of large landslides. Satellite data have also been used to map and monitor landslide induced lakes in the Himalayas. Landslide susceptibility maps (1:25,000 scale) prepared by NRSC in association with other knowledge centres for important tourist and pilgrim routes in the State of Uttarakhand is made available through *Bhuvan*. These maps are consumed with additional near real-time rainfall data from IMD and ISRO's weather data for landslide early warning in selective routes of Uttarakhand State.

Key words: satellite data, landslide inventory, landslide early warning, Bhuvan

Reconstruction Measures In Uttarakhand – Some Technical Solutions

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Abstract

In the third week of June 2013, the State of Uttarakhand was severely hit by heavy rains induced flash floods, moraine burst and landslides. Disruption of communication and adverse weather conditions complicated the situation for taking up timely rescue operation. This abnormally high amount of rainfall has been attributed to the fusion of Westerlies with the monsoonal cloud system of the East. Implication of "heavy rainfall" warning by India Meteorological Department (IMD) for the regions and absence of any modern science based geospatially validated "flash flood warning system" in place, caused systemic aberration in the interpretation of such "warning" by IMD. Thus meaning of such unusually usual "heavy rains" message reportedly given on 14th June 2013, carried luke warm response among the Disaster Managers of the State. So, dissemination of the same among the public through feasibly non-transparent "emergency operation protocol" met up with several incoherencies, that finally led to catastrophic situation.

Implication of heavy rainfall warning by IMD and nation's capability to know precondition before cloud burst in Uttarakhand have become issues of the national debate. An analysis of rainfall data for the past five years in the region, available with the India Meteorological Department, points to changes in rainfall trends, with a greater number of incidents of excess rainfall. The trends, however, did not indicate the kind of heavy rainfall that the State were going to receive in the month of June 2013, but such phenomena in the recent past point to the necessity for a robust early warning program based on weather monitoring devices.

While taking up the reconstruction of Uttarakhand flash flood-2013, it is recommended to regulate development to places where it can be safely carried out. A holistic approach is to be made including a check on the construction of roads, hydro-power and resettlement of pilgrim establishments.

The natural geological and geo-morphological along with ecological features make this task really challenging geo-professional. Taking all these factors into consideration, it is necessary that due precautions are taken while carrying out reconstruction work in the State. This presentation discusses various strategically important issues which need to be given due consideration while carrying out the reconstruction task for damaged buildings, infrastructure and other establishments in the disaster hit Uttarakhand. Some successful landslides and river training works, including Bio-engineering and Hydro seeding applications, using combination of Geosynthetics, Gabion wall, Geo-tube, soil nailing, etc. are explained in the paper.

Slope Stabilization Methods/Technologies In India

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Abstract

India is a vast country having myriad geographical, topographical and climatic regimes, each one of which is so distinct that a generalized understanding of the subject matter would lead to ambiguity. It would require an in-depth knowledge about the terrain and climatic conditions of a specific landslide zone or potentially unstable area before one decides to apply/implement a particular treatment/stabilization method to it.

Looking at the diverse geographical divisions viz. Peninsular region, Deccan plateau, Indo-Gangetic Plain, Thar desert and Extra Peninsular region, the slope instability problems are not equally distributed in space and time. Landslides and other types of slope instability have been reported occasionally from the Deccan trap region, However, the incidences are more in case of Sahyadri's and Nilgiri hills. The maximum instances of landslide and other instabilities occur in the Himalayan region. Mighty Himalaya extends for about 2500 Km in length from the North-west to the syntaxial band in the north-east and it exposes different kind of strata varying in lithology from the soft and friable sedimentary rocks of quaternary and Siwaliks to the massive hard and compact rocks of Central Crystallines. Different type of natural materials like glacial, fluvio-glacial deposits, terraces of river-borne-material, palaeoslide dumps and slope wash material adorn the slopes.

Topographic disposition, climatic conditions and regime of surface and underground water at a particular site guide the nature of movement of the slope forming material. The comparative high relief, steep gradient and abrupt discharge coupled with incidences of cloud burst results in the slumping, sliding, bank erosion and toe cutting. All these factors contribute towards inducing instability on the slopes.

Landslide zonation programmes, on different scales, viz. micro, meso and macro help in identifying/delineating potential zones for sliding/subsidence. Detailed geological mapping on 1:1000 to

1:10000 is carried out to bring out morphological and geological details of the slide zone. Subsurface explorations in the form of drilling and geophysical profiling are done to know the subsurface conditions. Geo-mechanical properties are determined by testing the undisturbed soil samples and bed rock samples in the lab.

After getting all the field geological detail and test results from the laboratories, kinematic checks for the slopes (in rock) and numerical modelling in discontinuous mode using 2D and 3D software's like Phase or UDEC/3DEC is carried out. Results of such analysis and modelling forms the basis for devising and designing the stabilization measures for a particular slope.

The choice of stabilization measure depends on the nature and extent of the movement and the site requirement. Availability of funds to a large extent, governs the scale of treatment/stabilization measure. Depending upon the site requirement a rigid or flexible type of measure is generally provided.

In India, both the above types of measures have been implemented in different terrain conditions and requirements and state of the art techniques are being utilized for devising the support measures. Soil nailing, bio-restoration techniques, geosynthetics, geomembranes, welded steel mesh, chain link membrane coupled with rock anchors and rock bolts are being used to stabiles the slopes. In case of deep seated instabilities cable anchors are also being used in combination with the chain link shotcrete or steel fibre reinforced shotcrete.

Slope Stabilization Issues In Large Scale Rock-Masses

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Abstract

Evolving capacity for predicting Landslides is a long-felt need and concern of the rock engineers. This capacity may enable us to protect people from the associated fatalities and losses. This in turn would reduce the impact of the future disasters. But even with all the efforts of the scientific community, we are right now not in a position to pinpoint occurrence of the landslides that continue to impact us throughout the world.

The recent Kedar ghaati disaster was technically a complex geo-technical issue encompassing reduction of “C” and angle of internal friction of the rock masses, coupled with large scale sudden floods. Hence, the rocks that were supposed to serve as basin for the water flow for its regulation- flew like sludge and slurry devastating every structure that came its way. This presentation would attempt to underline the magnitude of the problem, the possible approach for the right methodology, modelling possibilities and challenges, scale of operation of the activity, stabilization deliverables and tools and subsequent monitoring of the stabilized slopes.

The presentation would also inform about our core competencies and how IIT(BHU), Varanasi and our laboratories can involve in these rehabilitative efforts.

Engineering Geological Investigations and Mitigation Measures of Artificial Slopes – A Case Study

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Abstract

The stability of natural or artificial slopes generally depends upon the geometry, frequency and orientation of joint sets, dip of slope and its plane of weakness and condition of the slopes. Other parameters affecting the slope stability are climate, hydrology, tectonic movements, presence of breccia and human activities in immediate and/or adjacent area, underground openings. The blasting may bring about, years later, changes affecting the stability of slopes. When any slope (natural/artificial) shows the sign of instability, then it becomes essential to stabilize the slope by adopting the effective control measures depending upon the risk involved in it, in short term as well as in long term.

In order to evaluate the design basis parameters for the inclined/vertical walls of tail race pool and tail race channel of Pulichintala hydroelectric scheme (PCHES), engineering geological mapping (on 1:200 scale) was carried out. The Pulichintala hydroelectric scheme is being constructed, as a balancing reservoir to store about 45.77 TMC to facilitate supply of water in a regular manner to ensure timely nursery and transplantation operations during June and July in Krishna Delta and to install four units to produce 120 MW electricity by utilizing water from Pulichintala Reservoir. The proposed dam site is at Pulichintala village of Guntur District and Vazinepally village of Nalgonda District and located at 115 km downstream of Nagarjuna Sagar. The approximate latitude and longitude of the project site are: N16°46’14” and E80°03’33” respectively.

Grids were prepared for mapping of the TRP and TRC walls. The size of the grid is 2 m x 2 m, which was decided based on the mapping accuracy and resolution required for such investigations. All the lithological variance and structural discontinuities in rock mass were identified and mapped using

Total Station survey equipment. ISRM (1981) and IS: 11315-Part-5 (1987), classifications for weathered rock mass was used to characterize the rock mass into different grades. For the assessment of the stability of rock slopes, Slope Mass Rating (SMR) (IS 13365–Part-3, 1997; Romana, 1985) approach was adopted. The approach is based on modification of RMR system using adjustment factors related to discontinuity orientation with reference to slope as well as failure mode and slope excavation methods. The determination of failure modes in rock slopes was done on the basis of the geological discontinuities observed on the slope.

The rock types exposed after excavation on the wall sections are phyllites and phyllites with quartzite bands belonging to Cumbum Formation of Nallamalai Group. Phyllite is fine grained, hard and jointed in nature. Variation in the thickness of quartzite beds was observed. The foliation in phyllite and bedding in quartzite are parallel to each other. Foliation in phyllite has a general trend of N55^{o}E-S55^{o}W with dips towards southeast. Variation in the trend of foliation is due to minor folds present in the phyllite. The minor folds (tight isoclinal) plunge towards N70^{o}E-S70^{o}W. No evidence of faulting or shearing was observed along the inclined/vertical joints on the surface of inclined walls.

It was observed that the excavation of the TRP/TRC exposed the top 0.1 to 5 m thick reddish brown sandy/gravely soil, underlain by 5 to 7 m moderately weathered and disintegrated phyllite and then by fresh, hard and jointed phyllites with quartzite bands. The grade of rock mass based on the rock joint characteristics has the SMR values varying from 32 to 69, and falls under Bad to Good rock mass category. Based on engineering geological investigations, the geotechnical problems were identified, and remedial measures are suggested for the inclined/vertical walls.

Integrated Approach For Stabilization Of Varunavat Parvat Landslide – A Case Study

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Abstract

The State of Uttarakhand in North India has been witnessing a number of natural disasters such as earthquakes, landslides and flash floods etc. These disasters have greatly affected Uttarkashi Town and surrounding regions of 'Middle Himalayas' in the recent past. Uttarkashi Township, located on the right bank of the Bhagirathi River, is known for having a history of a number of natural disasters. One of such disaster was a major landslide on the slopes of the Varunavrat, a mountain which surrounds Uttarkashi Town from Eastern side. The disaster struck late in the night of 23rd September 2003, just towards the end of rainy season in the area. A number of commercial and residential buildings got buried during the process of massive fall of debris from the mountain. Fortunately, there was no human casualty as the movement of the mountain was very closely being watched and monitored.

The Varunavrat landslide has been classified as a classical example of debris slide (Debris slide in the crown portion, and rock fall and rockslide in the middle part). Both natural and human-induced factors are responsible for this disastrous slide; however, the main triggering factor has been identified as the surface and groundwater. State Govt. took immediate initiative to invite the attention of Central Govt. and sought requisite resources for tackling the disaster and save the Uttarkashi Town. Central Govt. by immediately appointing a high level Task Force to oversee the treatment works and also by designating the Tehri Hydro Development Corporation Ltd (THDCIL) as the technical consultant for providing the complete engineering solutions to the work, stressed the need to save the ancient and heritage Uttarkashi Town. The stability problem is unique because at the foothills of the mountain runs the National highway which leads to a great Hindu pilgrimage "Gangotri" and Uttarkashi a densely populated town is located.

An integrated approach of a stabilization measures with flattening of slopes by removing the overburden mass from the Crown area with suitable berms, effective drainage arrangement (surface & sub-surface), suitable erosion control measures for improving the stability of the slopes along with the multistage protection measures by providing catch pits, wide platforms, retaining walls and construction of tunnel on the national highway for mitigating the rock fall hazards were considered to be adopted to minimize the impact of disaster in future so that people of Uttarkashi Town can live safely without fear.

Successful Handling Of Slope Stabilization & Landslide Prevention Through Soil Nailing

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Abstract

The basic concept of soil nailing is to reinforce and strengthen the existing ground by installing closely spaced steel bars, called "nails," into a slope or excavation as construction proceeds from "top to down." This process creates a reinforced section that is itself stable and able to retain the ground behind it. The reinforcements are passive and develop their reinforcing action through nail ground interactions as the ground deforms both during and following construction.

Soil Nailing has been successfully used by the author at more than 35 locations in the country in various hostile situations. Authors experience incorporate landslide management in Shimla, Nainital and Dehradun and basement constructions, through stitching of soil by soil nailing techniques at various locations in Amritsar, Delhi, and Gurgaon etc. Full length paper shall discuss salient features of some of these sites.

Landslide Hazard Mitigation: Issues & Challenges

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Abstract

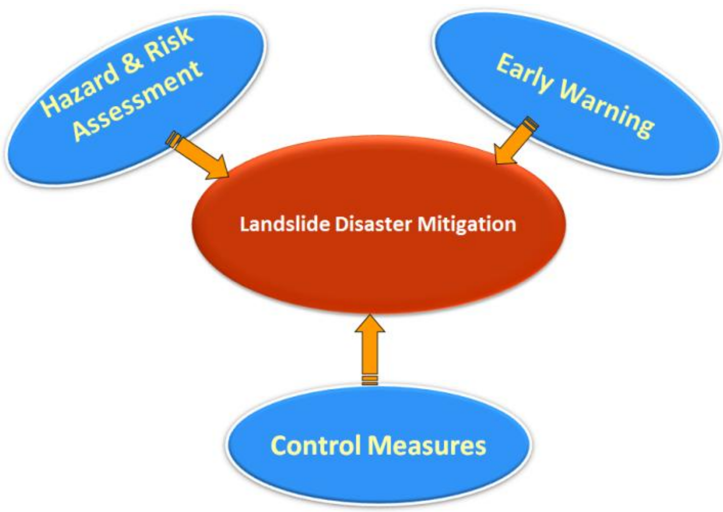
The natural disasters resulting from the major geological hazards such as earthquakes, floods, landslide, volcanic eruption and tsunami around the globe are increasing day by day. The lives and property loss resulting from landslides is enormous because of its frequent occurrences in hilly regions. In India, economic losses due to landslides are great and apparently are growing due to increasing rainfall intensities and frequencies, coupled with population growth in hills.

Landslide phenomena are recurrent problems in Himalayas and the hill roads are often blocked which sometimes also lead to casualties. In recent years there were several landslide disasters in the country and one of the worst affected States is the Uttarakhand. A large number of landslides have affected the main highways in Uttarakhand Himalaya. The traffics along these routes are always in danger as there is an every possibility of triggering landslides particularly during the monsoon period. For example, one such highway is the NH-58 from Rishikesh to Badrinath along the rivers Ganges and Alaknanda. The road stretch of 100 km from Chamoli to Badrinath in the upstream part of the Alaknanda valley is very prone to landslides.

A few problematic landslides along Chamoli-Badrinath sector of NH-58

The intensity and severity of landslide hazards can be minimized by efficient disaster mitigation and management. There are many issues and challenges which should be addressed for successful landslide mitigation. A few of the important issues that need scientific interventions are hazard and risk

assessment, landslide monitoring & early warning, landslide mitigation measures, education, training and public awareness. The prime components of landslide disaster mitigation are hazard & risk assessment, early warning and control measures. Landslide hazard and risk assessment is the first step towards mitigation & management plan. This can be accomplished by several approaches starting from creating database of existing landslides to the advanced techniques of landslide hazard/susceptibility mapping based on statistical modeling. Such landslide hazard/susceptibility maps of different regions of the country have been prepared by various researchers. Most commonly used techniques are qualitative map combination, information model, bi-variate and multivariate statistical methods, and soft computing techniques. The major concern regarding these maps are the small scale mapping due to which detailed information about the impending hazard are mostly missing.



Components of landslide disaster mitigation

Instrumentation and monitoring of landslide provides valuable data for temporal prediction of landslide which can be used as landslide early warning. A real time landslide monitoring system is an effective way to get a lead time for the necessary preparedness to face the hazard. As majority of the landslides are triggered by rainfall, it is essential to know the relationship between rainfall and incidence of landslides in a region for development of an early warning system. The landslide prediction model can be developed by modeling landslide events and rainfall to determine the critical rainfall threshold value for landslide occurrence. The commonly used landslide monitoring instruments are bore hole & wire extensometers, inclinometers, tilt meters, crack meters, piezometers along with rain gauzes. These days monitoring of ground movement by differential GPS is also being used for landslide monitoring.

Landslide frequency and consequences can be minimized by taking effective mitigation measures. To recommend a suitable remedial measure, a thorough knowledge of the landslide should be known which requires an in-depth scientific investigation. Effective landslide stabilization depends on investigation, selection of appropriate measure, precise design, construction methods and implementation cost. There are various landslide control measure techniques available today. In most of the cases water is the main culprit for triggering landslide and hence drainage measure is the most important remedial measure. Retaining structures are the second important remedial measures which are most commonly used. These include a variety of walls such as concrete masonry wall, gabion wall, crib wall, soil reinforced wall etc. Soil reinforcement by various techniques such as soil nailing, geogrid reinforcement etc and application of bio-engineering measures are now being widely used for unstable soil slopes. The impact of debris flow, which has the most disastrous effect, can be minimized by putting check dams made of various geo-materials. The other catastrophic events often resulted from rock slides and rock falls can be checked by rock bolts and anchors and installing rock catch fences. In case of multiple measures, it is recommended that all the prescribed measures should be implemented in an integrated way. Partial implementation of measures does not solve the problem.

The impact and socio-economic cost due to slope failures and landslides are much higher and difficult to estimate because of damages to houses and other civil engineering structures, frequent blockade of roads and lifelines, damage to communication facilities water supply, power supply etc. Disaster management associated with hill slope instability should address: proper land use plans, enforcement of building codes and good construction practice, early warning systems, construction of control measures, community preparedness and awareness building. A mitigation strategy would involve: identification of possible disaster triggering scenarios, and the associated hazard level; analysis of possible consequences for the different scenarios; assessment of possible measures to reduce and/or eliminate the potential consequences of the danger; recommendation of specific remedial measure.

Bio-Engineering Treatment Of Mass Erosion Affected Areas

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Abstract

Minespoils, landslides and torrents are mass wasting, causing heavy soil erosion and massive degradation of land and water resources. The soil erosion may be as high as 550 t/ha annum at such degraded sites compared to 3 t/ha/annum from a well forested watershed (Juyal et al., 1995). They cause considerable damage to the ecosystem and pose a constant threat to the life and property of the inhabitants. The present paper discusses the mass erosion problems prevalent in the north western Himalayan region including the mine spoils, landslides and torrents. It also suggest the rehabilitation measures which can be adopted in the region including Bio- engineering and engineering measures which have found effective in implementation in the field. These measures include slope stabilization measures, bank protection measures, channel stabilization and torrent control measures. Result of a case study of Sahastradhara rehabilitation project has also been discussed.

Slope Stabilization and Landslide mitigation using Reinforced Earth Technology

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Reinforced Earth Pvt. Ltd.

Abstract

Landslides are one of the natural disasters caused due to downward and outward movement of slope. Landslides mainly occur in the form of shallow or deep-seated slip circles due to high built-up water pressures and phreatic lines, erosion of hill slope, erosion of river embankment and sloughing from heavy down pour and flash flooding. Throughout history, landslides have had disastrous consequences causing enormous economic losses and heavy loss of life affecting the social fabric. This paper presents that Reinforced Earth® technique can help mitigate the consequences of such natural disasters by providing protection though its intrinsic, resilient characteristics. The paper also illustrates that Reinforced Earth® techniques are viable to improve the stability of vertical cuts and failed slopes substantiated with a case study.

Landslide Problems In The Colombian Andes, South America Evaluation, Prevention And Control

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Abstract

Colombia has been affected by natural disasters related to earthquakes, volcanic eruptions, flooding and mass movements, which have inflicted heavy human and material losses. Slope failures of varied types and sizes are common occurrence, most of them related to rainfall and weathering or earthquake-induced. Landslide dams and the subsequent debris avalanches and mudflows caused by the dam breakage are also frequent. Lahars associated with the 1985 El Ruiz Volcano eruption caused the worst natural catastrophe in Colombian history. A system of Disaster Prevention was implemented as an answer to the effects of this event. Several cities and rural communities are located in high risk zones, so that public awareness, hazard zoning and research have been increased in the last decades. In this paper a brief mention of the geographical, geological and climate conditions of the country, in relation to natural hazards, is made. Several cases of landslides, mudflows and avalanches, and the results of a national inventory of landslides in the highway network are described. Finally some comments on the methodology to evaluate mass movement risks and to study unstable zones are given.

Landslide Prevention, Control and Mitigation

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Abstract

A large number of landslides occur/ recur every year in some or other parts of the country, which cost us thousands of human lives and huge monetary losses by destruction of infrastructures and settlements. Highways which are primary surface communication means for catering all the needs of the inhabitants, tourists, pilgrims and armed forces in the border areas are among the most widely suffered infrastructure. CSIR-Central Road Research Institute (CRRI), being a premier road research laboratory in the country also deals with landslide hazards related to highways. CSIR-CRRI have been engaged in landslide hazard studies since its inception and worked on a number of unstable slopes along various highways all over the country including Uttarakhand. It is found that, depending upon the local conditions and triggering factors, landslide may differ from each other in their failure mechanism, type, shape, size, effect, importance etc. Hence, the remedial measures for their prevention and control or mitigation of their negative impact on various elements may also vary. However, there are measures which can be replicated in somewhat similar site conditions. In this presentation, author will discuss the efforts CSIR-CRRI has made towards landslide prevention, control and mitigation, through some of the recent case records of landslide studies on design of suitable remedial measures in different parts of the country.

Mitigation and Management of Destabilized Slopes in Road Planning and Construction

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JICA Road Expert in India

Abstract

The government of Japan and JICA (Japan International Cooperation Agency) will start Yen Loan Assistance on road construction in North East States in mountainous area. JICA will also start technical cooperation on guidelines for mountainous road construction (planning, tunnel, slope protection, high pier bridges, etc.). In this technical area, MLIT (Ministry of Land, Infrastructure, Transport and Tourism of Japan) has various knowledge and experience.

Therefore, the purpose of this presentation is to make provisions for mitigation and management of destabilized slopes in road planning and construction in India.

Challenges of slope stabilization in climatically and tectonically sensitive Himalaya: A case study of Mandakini River Valley after the heavy rainfall of June, 2013

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Abstract

During June 2013, Uttarakhand Himalaya witnessed heavy rainfall which caused large- scale slope destabilization and generation of huge amount of the sediments that clogged and changed courses of the rivers in Uttarakhand at various places. Changed river courses washed away infrastructure located on the landform along the river banks.

In Garhwal Himalaya main landforms are: Moraines, reworked moraines, Palaeo-landslides, debris flow, colluvial and fluvial terraces. On these landforms infrastructure are located and at very few places infrastructures are located on hard rocks. These all landforms are highly sensitive to water action either it is rainfall, toe cutting of rivers or impact of snow / glacial avalanche. Slopes of the Himalaya are very steep particularly in Garhwal Himalaya and these steep slopes gives high energy to even short lived streams which can damage any infrastructure which come across. During June 2013 major rivers of the Uttarakhand were clogged by huge amount of the sediments. The sediments were contributed from two major sources *viz*. the moraines and alluvial fans located in the Higher Himalaya and by the landslides in the Higher and Lesser Himalaya.

In Uttarakhand Himalaya flash floods are usually caused by high intensity focused rainfall in areas of orographic barrier, particularly in river valleys that are located in the south of the tectonically active Main Central Thrust where the hill slopes are precariously balanced. Slope instability caused due to increased pore water pressure in the south of MCT led to the obstruction of the stream course and finally breaching of such obstruction results in highly peaked flood hydrograph carrying voluminous of sediments downstream. This presentation is based on the studies carried out in Mandakini valley. Geomorphologically, Mandakini valley can be divided into three broad zones:

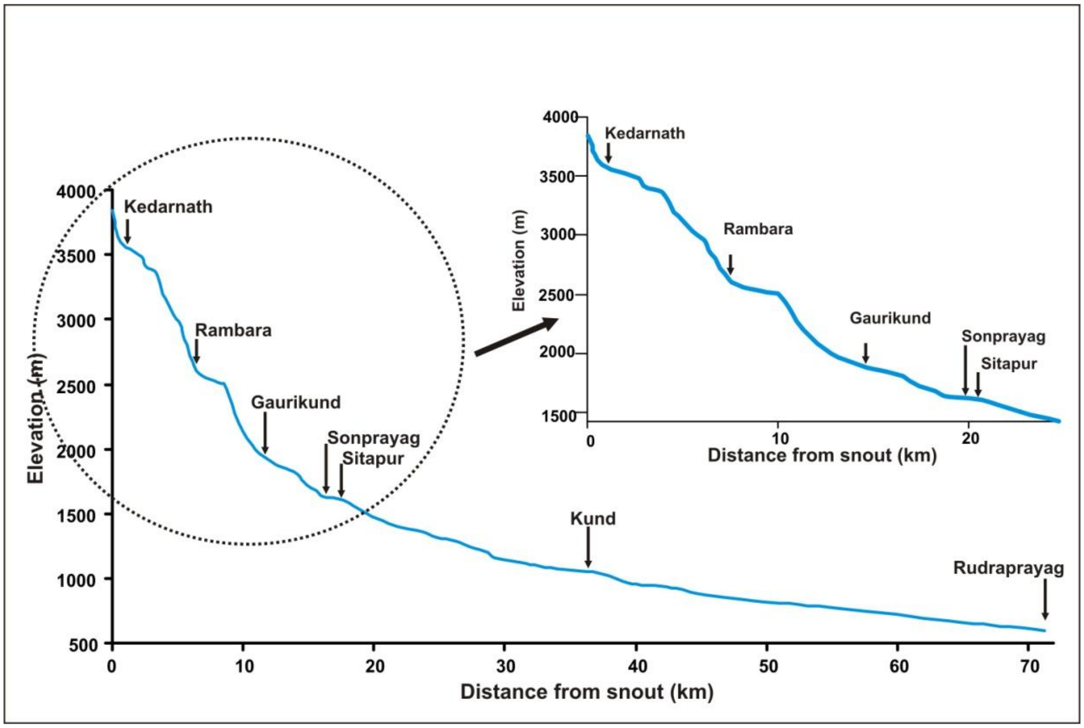
A. the Upper glaciated zone (>3500m) located above Kedarnath valley

B. The middle paraglacial zone located between Kedarnath and Gaurikund (<3500 - 2000m)

C. The lower fluvial zone (< 2000 m) below Sitapur

Our observations for unprecedented devastation around Kedarnath caused due to the water cascade effect of water flowing through steep gradient streams (270 meter per kilometer).

Further downstream between Kedarnath and Gaurikund although river gradient decreased to 138 meter per kilometer. Major volume of the sediments was trapped Sonprayag and Sitapur village where the stream gradient drops significantly 23 meter per kilometer. At these location river bed level was at 1611 m before the flood and rose to 1640 m after the flood implying of river bed ~29 meter due to sediment. Mandakini valley widens after crossing MCT at Kund village where the gradient drop down to the 6 meter per kilometer.



(Fig. 1. Longitudinal profile of Mandakini river showing distinct slope breaks around Kedarnath, Rambara and Sonprayag-Sitapur (inset: section enlarged between Kedarnath and Sitapur). These discontinuities acted as depocenters for the sediments transported down valley from Kedarnath).

The above river gradient reflects the slope conditions of the Mandakini valley. Geotechnically a particular landslide may be protected by using adequate technology but in the mountainous region particularly in Mandakini, Alaknanda, Bhagirathi and Yamuna valley it would-be a challenging task to stabilize hill slopes by using technology of slope stabilization beside the bioengineering technology. If we see rainfall pattern of the different valleys it varies valley to valley and place to place therefore it is also important to install good quality of the rain gauges to collect the rainfall data and on the basis of rainfall data rain shadow zones should be identified, which might be a comparatively good locations for rehabilitation purpose.

Beside the heavy and focused rainfall blasting (being used for road widening and construction of new roads, hydro power projects etc) should be prohibited which destabilize the slopes directly and facilitates destabilization of hill slopes indirectly). Further, the terrain north of the Main Central Thrust (Higher Himalaya) should be kept free from any major intrusion including the hydropower projects. The study necessitate immediate critical re-evaluation of the existing mountain development policy and approach towards harnessing the natural resources of Himalaya particularly enormous hydropower potential of the Himalayan region in general and Uttarakhand Himalaya in particular.

Annexure B: Participants

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Annexure C: Program Schedule

Day 1

Date: 27th April, 2015 Time: 7:00 am - 9:00 pm

Field Visit

S. No.	Activity	Time
1.	All participants assemble at hotel "Four Points by Sheraton"	6:45 am
2.	Departure for field visit to slide "Sirobagar" and "Sakni Dhar"	7:00 am
3.	Site visit of "Sirobagar" slide zone near Srinagar – slide inspection and on-site discussions	11:30 am
4.	Lunch	1: 30 pm
5.	Departure for "Sakni Dhar" slide zone	2:30 pm
6.	Site visit of "Sakni Dhar" slide zone near Devprayag - slide inspection and on-site discussions	5:00 pm
7.	Tea at Kodiyala	5:30 pm
8.	Departure for Dehradun	6: 00 pm
9.	Arrival at hotel Four Points by Sheraton	9: 00 pm

Day 2

Opening Ceremony

Date: 28th April, 2015 Time: 9:30 am - 11:00 am

S. No	Activity	Time
1	Registration	9 am
2	Opening Ceremony	9: 30 am
3	Arrival of Hon'ble Chief Minister	10 am
4	Welcome address by Additional Chief Secretary	10:10 am
5	Lighting of lamp by Hon'ble Chief Minister	10:20 am
6	Address by Chief Secretary	
7	Address by Deputy Country Director, the World Bank; and Chief Representative, Japan International Cooperation Agency	10:20 am
8	Address by Honb'le Chief Minister	10:40 am
9	Vote of thanks and setting of workshop goals by World Bank Operations Specialist for UDRP	10: 50 am
10	Tea	11:00 am

Session1: Discussion on the field visit and observation

Date: 28th April, 2015   Time: 11:30am-1:30 pm

Chairman & Moderator: **Prof Yudhbir**; Repertoire: **Mr Kishore Kumar**

S.No	Name of the Participants	Presentation Topic	Name of Organization	Time
1.	Prof.Yudhbir	Control and Remediation of Landslides		11:30 am to 11: 45 am
2.	Rajendra Bhasin	Application of Ground Penetrating Radar(GPR) for Landslides investigations with examples from South and South East Asia	NGI	11:45 am to 12:00 pm
3.	Frode Sandersen	Landslide mitigation strategies with examples	NGI	12:00 pm to 12:15 pm
4.	All present	Q & A on the presentations		12: 15 pm to 12:25 pm
5.	All present	Discussion on the field visit and observations		12:25 pm to 1:30 pm
6.	LUNCH			1:30 pm to 2:00 pm

Session 2: Landslide Risk Assessment and Early Warning System

Date: 28th April, 2015   Time: 2:00pm-5:00 pm

Chairman & Moderator: Prof Satyendra Mittal   Repertoire: Dr Ajay Kumar Naithani

S.No	Name of the Participant	Presentation Topic	Name of the Organization	Time
1.	Reiko Abe	Safety Management and combination Monitoring of Landslide using on site visualization, simple Weather Radar and Satellite Imagery	Oriental Consultant(JICA)	2:00 pm to 2:15 pm
2.	P.K. Champati Ray	Remote Sensing and GIS for Landslide Hazard Mitigation:Priorites for Uttarkhand	IIRS	2:15 pm to 2:30 pm
3.	Pankaj Jaiswal	Challenges in Landslide Early Warning for a catchment area and a way forward	GSI	2:30 pm to 2: 45 pm
4.	Vikram Gupta	Towards Establishing Rainfall threshold landslides for triggering landslides for the Uttarakhand Himalaya	Wadia	2:45 pm to 3:00 pm
5.	Y.P. Sundriyal	Geology and Geomorphology of Mandakini valley and terrain response of	HNB Garhwal University	3: 00 pm to 3:15 pm

		high rainfall event	Srinagar	
6.	Tapas R. Martha	Landslide studies using space-based inputs	National Remote Sensing Centre (NRSC (ISRO),	3: 15 pm to 3:30 pm
7.	Charu Chandra Pant	Problems of Instability in Nainital : A case study	Kumaoun University, Nainital	3:30 pm to 3:45 pm
8.	Ashish Gharpure	Natural Hazard Mitigation Measures	Maccaferri Environmental Solutions Pvt. Ltd	3:45 pm to 4:00 pm
9.	All present	Discussion/ Q & A		4:00 pm to 4: 40 pm
10.	Tea			4:40 pm to 5:10 pm

Session 3: Slope Stabilization Methods/Technologies used in India

Date: 28th April, 2015 Time: 05:15 pm-7:30 pm

Chairman & Moderator: Dr. V.K. Sharma Repertoire: Dr Vikram Gupta

S.No	Name of the Participant	Presentation Topic	Name of the Organization	Time
1.	Chandan Ghosh	Reconstruction Measures in Uttarkhand-Some Technical Solution	NIDM	5:15 pm to 5:30 pm
2.	Harish Bahuguna	Slope Stabilisation Methods/Technologies in India	UJVNL	5:30 pm to 5:45 pm
3.	S.K Sharma	Slope Stabilization issues in large scale Rock Masses	IIT(BHU)	5: 45 pm to 6 pm
4.	Ajay Kumar Naithani	Engineering Geological Investigation and Mitigation Measures of Artificial slopes-A case study	NIRM	6:00 pm to 6:15 pm
5.	Rajeev Visnoi	Integrated Approach for Stabilization of "Varunavat Parvat" landslide – a case study	THDC India Ltd.	6:15 pm to 6:30 pm
6.	Jitin Mukheja	Slope Stabilization products case studies from Indian Projects	Geoburgg India Pvt. Ltd.	6:30 pm to 6:45 pm
7.	All participants	Discussion/ Q & A		6:45 pm to 7: 30 pm

Day 3

Session 4: Slope Stabilization Methods/Technologies used in the South and South East-Asia Region

Date: 29th April, 2015   Time: 09:00 am - 11:30 am

Chairman & Moderator: Prof Chandan Ghosh Repertoire: Mr Harish Bahuguna

S.No	Name of the Participant	Presentation topic	Name of the Organization	Time
1.	Takafumi Ishikawa	Solution package for Landslides debris flow by Utilizing "Non Frame Methods "Steel Slit Dam" introduced in Southeast Area	Nippon Steel(IITA) (JICA)	9:00 am to 9:15 am
2.	Satyendra Mittal	Successful handling of Slope stabilization and Landslide prevention through soil nailing	IITR	9:15 am to 9:30 am
3.	Masanori Tozawa and Karma Dorji	Introduction of the project for a Master Plan Study on Road slope Management in Bhutan	Environmental Pollution Controller, P.E. Japan (JICA)	9:30 am to 9:45 am
	Shantanu Sarkar	Landslide Hazard Mitigation: Issue and Challenges	CBRI	9:45 pm to 10:00 pm
4.	S.S .Shrimali	Bio-Engineering treatment of Mass Erosion Affected areas	IISWC	10:00 am to 10:15 am
5.	K. Navaneeth Kumar	INTERVENTION TECHNOLOGIES FOR LANDSLIDES, ROCKFALL MITIGATION AND EROSION CONTROL	Garware-Wall Ropes Ltd.	10:15 am to 10:30 am
6.	Atanu Adhikari	Slope Stabilization and Landslide Mitigation using Reinforced Earth Technology	Reinforced Earth pvt. Ltd.	10:30 am to 10:45 am
7.	All participants	Discussion/ Q & A		10: 45 am to 11: 30 am
8.	TEA			11: 30 am to 12:00 pm

Session 5: Slope Stabilization Methods/Technologies used Globally

Date: 29th April, 2015   Time: 12:00 pm-1:30 pm

Chairman & Moderator: Dr.Fausto Guzzetti Repertoire: Ms Yuka Makino

S.No	Name of the Participant	Presentation Topic	Name Of the Organization	Time
1.	Rolf August Studer		Kirchenfeldstrasse, World Bank Consultant	12:00 pm to 12:15 pm
2.	Manuel GARCIA-LOPEZ	Landslide Stabilization in the Colombian Andes	National University of Colombia	12:15 pm to 12:30 pm
3.	Kishore Kumar	Landslide Prevention, Control and Mitigation	CRRI	12:30 pm to 12:45 pm
4.	Krishna Bahadur Pande	Countermeasure works to stabilize slopes and foot protection work in Sindhu	Ministry of Irrigation(Govt of Nepal)	12:45 pm to 1:00 pm
5.	Mr. Tatsuo Takano	Mitigation and Management of Destabilized Slopes in Road Planning and Construction	Advisor for Capacity Development on Highway/Expressway (JICA)	1:00 pm to 1:30 pm
6.	All participants	Discussion/ Q & A		1:30 pm to 1:45 pm
7.	LUNCH			1:45 pm to 2: 15 pm

Session 6: Open Discussion/ Brainstorming on the Uttarakhand Challenge

Date: 29th April, 2015   Time: 2:00 pm - 4:15 pm

Chairman & Moderator: Prof Yudhbir; Repertoire: Dr. Girish Chandra Joshi

Valedictory Session – 4: 15 to 5:00 pm

Annexure D: Field Visit Description

LANDSLIDE AT KALIASAUR (SIROBAGAR) ON NH – 58, DISTT. PAURI GARHWAL, UTTARAKHAND

Location

Kaliasaur landslide (Lat. 300 15': Long 780 53') also known as Sirobagar landslide, is located on Haridwar – Badrinath highway (NH-58), 18 km East of Srinagar town. The toe of the slide is on a sharp bend on the left bank of Alaknanda river.

Background Information

This monstrous slide is ominous for its menacing effects since 1920's. A number of slides have occurred at this location, in 1952, 1963, 1965 and 1969. The slide on 19th Sept. 1969 blocked 3/4th width of the river which is flowing about 100m below the road level. About 300m stretch of the road was badly damaged. The crown portion of the slide extended nearly 120m above the road. This slide movement continued to be active for over two weeks.

During 1970, 1971, and 1972 the land slide occurred again thereby disrupting the communication system and each time new bench had to be cut. Following heavy rainfall during August – Sept. 1984, a major landslide occurred which damaged the road considerably and retrogressively extended the scar. The slide in 1985 engulfed a total area of 86000m2 above and below road.

It was largely dormant till 2006 after which it got reactivated and is recurring since then.

Geology

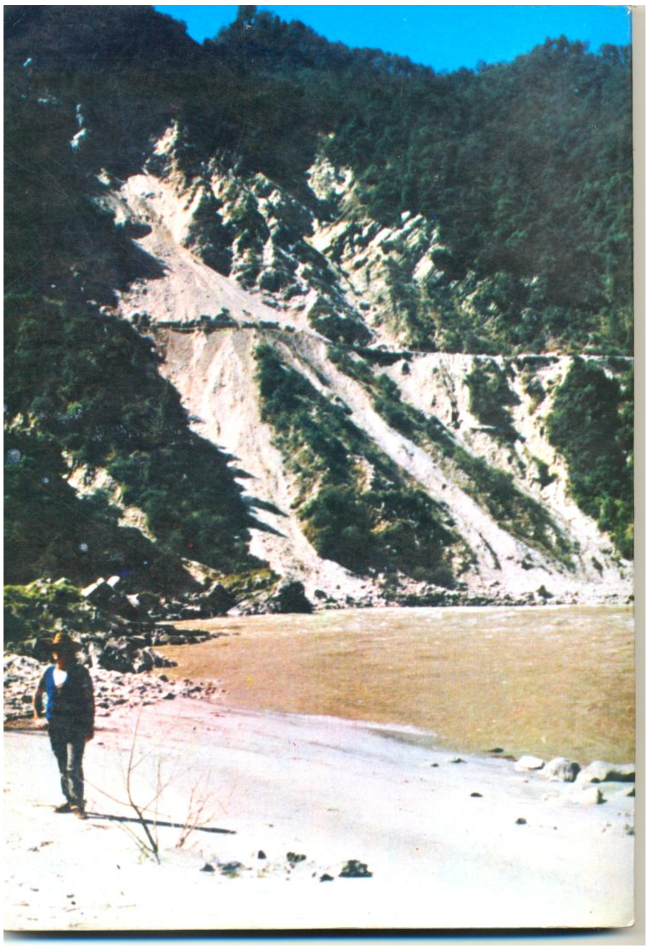
The slide area is located in the Lesser Himalayan block bounded in the North by MCT and in the South by MBT. Rocks belonging to Garhwal group are exposed in the area which consist of quartzite's , limestone's and dolomites which in turn have been intruded by the basic bodies. Section along the road and river reveals two type of quartzites i) light green quartzite with thin bands of maroon shale and ii) massive and well jointed yellowish quartzite. On the Western side of the slide zone the light green quartzite are exposed and they show southward dip with amounts ranging from 25dgrees – 60degree. These quartzites end abruptly along a scree zone beyond which massive yellowish quartzites dipping at 300 – 400 towards south-east are exposed. It is apprehended that the scree zone conceals a fault zone trending NE – SW and it extends across the river. The massive quartzites abut against the slide debris on the western most flank of the slide. On the eastern side the light green quartzites with maroon shales are exposed and they are dipping 30degree – 60degree towards south-east.

Mechanism

Sliding at the interface of the quartzite and maroon shales must presumably have been the starting point. Road construction and repeated back cutting required for restoring the road width. Poor drainage in the slide affected area. Recurring debris slides in the colluvium cover on the slopes. Removal of the vegetal cover because of many reasons. Toe cutting by the mighty Alaknanda river.

Remedial Measures

Following remedial measures were suggested adopted for the stabilization of the slide i) Grading of the slopes, ii) Provision of the surface and subsurface drainage system, iii) Timber piling for stitching the debris cover onto the slopes, iv) Construction of retaining and breast walls, check walls etc. and v) Afforestation measures.



View of Kaliasaur Landslide in 1980's

View of Kaliasaur Landslide in 2013

LANDSLIDE AT SAKNIDHAR ON NH-58, DISTT. TEHRI GARHWAL, UTTARAKHAND

Location:- Saknidhar (968.10 masl), is located about 50 km from Rishikesh town at CH. 277.800 km on Rishikesh-Joshimath-Mana Highway (NH-58).

Background Information:- Saknidhar landslide originated in the rainy season of 2010 and thereafter it has reoccurred on 10 different occasions, disrupting the traffic for an average 3.00 hour's duration. Originally the 25 m length of the road was affected by this slide which in due course enlarged by three times since then. Head ward retrogression of this slide is evident by the shifting of its crown level from its previous level i.e (±) 25 m from the road level to the present (±) 50 m level.

Geology:- Geologically this slide zone is located in the Lesser Himalayan Zone bounded between the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT) in its north and south direction respectively. The rocks belonging to Chakrata Formation are exposed in this stretch of the road which is represented by the massive, hard, purple and maroon colored quartzites with thin chlorite partings at this section. These rock masses are dipping towards the NW direction with the dip amounts ranging between 20^0 - 27^0. The rock mass has been dissected by four prominent joint sets and most of the joints, except bedding planes, are open and occasionally filled by the crushed and graded material. The rocks exposed adjacent to the slide zone are highly distressed in nature. The slide mass bears a very steep angle. The material involved in the sliding is of heterogeneous nature, it is debris at the toe and belly level while the soil containing rock chips at the crown part.

The ground reveals that the slope below the road is stable while the slide above the road is still active as evident by the now and then dry debris flow.

The hill side excavation in order to widen the road is the possible triggering mechanism of this slide.

All the protective measures i.e., construction of hill side retaining wall in order to stabilize this slide were failed.

Saknidhar Landslide

Annexure E: Symposium Photographs

<u>**Inaugural Session attended by the Hon'ble Chief Minister Shri. Harish Rawat Ji**</u>

Symposium Sessions

Field Visit to Kaliasaur and Saknidhar landslides

Group Photograph of All Participants