DISASTER RESILIENT INFRASTRUCTURE IN THE HIMALAYAS: OPPORTUNITIES & CHALLENGES

ABSTRACT VOLUME

Uttarakhand State Disaster Management Authority, Government of Uttarakhand

Index

Background Note

Number of disaster events as well as losses arising from these are increasing across the world. It is now widely accepted that climate change would further exacerbate the intensity and frequency of climate and weather-related hazards. Intensifying hazard pattern combined with greater concentration of people, capital assets and economic activity in the hazard prone areas would lead to even higher economic losses unless systematic steps are taken to stop the creation of new risks and reduce existing risks.

With this recognition, 187 nations of the world came together at the Third World Conference on Disaster Risk Reduction in Sendai, Japan in March 2015 and adopted the Sendai Framework for Disaster Risk Reduction (SFDRR). After the adoption of the Sendai Framework, India hosted the first Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) in New Delhi in November 2016 to develop the Asia Regional Plan to implement the SFDRR. While inaugurating the AMCDRR, Hon'ble Prime Minister of India Shri Narendra Modi outlined a ten-point agenda to provide added impetus to the implementation of the SFDRR. The first point on PM's ten-point agenda calls for mainstreaming disaster risk reduction in all development sectors. It places special emphasis on ensuring that all new investment in infrastructure development takes into account disaster risk considerations.

The Himalayan region, due to its unique geo-climatic conditions, is exposed to a range of natural hazards. Environmental degradation, unplanned development, vulnerable built environment and increasing population pressure are leading to high level of disaster risk, which manifests itself in major disaster losses every few years.

The region faces major threat of a devastating earthquake. Despite having experienced major earthquakes in the recent past in Kashmir and Nepal, several segments of the Himalayan belt are identified as possible sources of a much larger earthquake. A major Himalayan earthquake would threaten lives and livelihoods as well as the economy not only in the Himalayas but also in the densely populated surrounding plains. With the existing state of scientific knowledge, earthquakes cannot be predicted in space, time and magnitude. This uncertainty attached with earthquakes is often cited as being a major hindrance in minimizing seismic losses. Long quiescence between major earthquakes also leads people and policymakers to underplay the threat; voluntary compliance and implementation of techno-legal regime are therefore ignored.

While the Himalayan region faces a plethora of natural hazards described above, the region also has its own developmental challenges. Improvement in the socio-economic status of the people of the Himalayan region would require creation of jobs, improvement in market linkages for the products emanating from the region, better access to energy systems and better access to health and education services. This would inevitably require investment in new infrastructure. If developed properly, this new infrastructure has the potential to reduce disaster risk and bring forth sustainability in the socio-economic systems of the region. On the other hand if risks *to* this infrastructure (e.g. earthquake risk for bridges and dams) as well as potential risks *from* this infrastructure (e.g. landslides triggered by road building projects) are not properly understood and taken into account while developing the new infrastructure, it could set off a chain of cascading disaster risks which would be hard to manage and might lead to disproportionately high losses in future.

It is in this context that the present workshop is being organized by the Uttarakhand State Disaster Management Authority. Though focusing on all hazards, the main emphasis would be on seismic hazard. Accordingly, the workshop is divided into three sessions that are dedicated to:

(i) understanding the seriousness of the hazard risk particularly seismic risk,
(ii) state of infrastructure in the region and seismic safety measures therein, and
(iii) way forward for minimizing the threat.

Over the course of two days, the workshop would attempt to address following sets of issues:

Assessment of risk:

- Disaster risk assessment as it relates to the identification and development of large infrastructure.
- Impact assessment of frequent seismic tremors in the region on infrastructure and livelihoods.
- Risk analysis based on hazard and vulnerability based on multiple events (earthquakes, floods and the like).
- Challenges and issues in assessing fragility of terrain and instability of slope due to seismic tremors.
- Risk from infrastructure:
    a. Assessing changes in risk profile due to hazards created by infrastructure (damages, disruptions).
    b. Regional disaster risk considerations in planning and design of new infrastructure.

Laws, rules and standards: Development, adoption, implementation and enforcement of standards for disaster resilient infrastructure:

- Disaster resilient measures in development projects such as roads, railways and dams in this region.
- Building regulation, land use policies and bye laws for disaster safety.
- Systems for developing and updating standards and policies.
- Challenges in enforcement and implementation of codes and standards.
- Roles and responsibilities of government departments / agencies in Disaster Risk Reduction (DRR).
- Improving interdepartmental coordination for DRR.

The role of finance in risk reduction in infrastructure:

- Strategies for risk financing.
- Incentivising resilient infrastructure.
- Cost-benefit analysis.
- Role of insurance for risk management.

Recovery, rehabilitation and reconstruction:

- Trends in management and financing of recovery and rehabilitation in Uttarakhand.
- Systematic approaches for assessing losses, estimating needs, and channeling adequate funds to the affected areas in a timely manner.
- Developing reliable mechanisms for financing key infrastructure recovery.
- Build Back Better, 'safe to fail' infrastructure.

Research, building and sharing knowledge on disaster resilient infrastructure:

- Long term perspective on hazards and need for further research for infrastructure in the region.
- Knowledge sharing on research and development relating to monitoring plate motion, impact of tremors and implications.
- Integrated perspective on risk assessment and management.

Capacity building for disaster resilient infrastructure:

- Better understanding of earthquake risk in the region, DRR and role of different stakeholders.
- Development of capacity to predict and mitigate risk of disaster to infrastructure.
- Sensitization of local officers so as to ensure required disaster safety measures in departmental plans and policies and enacting appropriate legislative measures where required.

Vinod K. Gaur

Vinod K. Gaur initiated academic programmes in Geophysics at the University of Roorkee in the early 1960 and the first research initiatives in the Himalaya, bringing to light the existence of concentrated seismic activity fringing the MCT, now recognized as the southern limit of the locked zone identified from GPS studies also initiated by him in the 1990s. He now mentors young researchers in the design of their research endeavours in various fields of science and engineering involving inverse modelling.

Matching the state of practice with the state of knowledge for hazard mitigation in the Himalaya

Himalaya is a spectacular place in the solar system. It has been built metre by metre over the past 50 million years ever since powerful mantle convection in the earth arranged its stolid Indian lithosphere to push Eurasia northward by penetrating its southern shore. This persistent process, still continuing apace @ 4.5 cm/yr, created and sustains the Himalaya and its supporting Tibetan buttress, even as the Indian continent suffers partial attrition beneath Tibet. In the resulting Indo-Tibetan convergence @ about 2 metres a century, India's leading upper crust is periodically ruptured and thrust southward onto itself in catastrophic slips, to sustain the Himalaya. Weather and climate too collaborate with the three phases of water to fashion a unique landscape, a maze of wondrous ecologies, and a garland of human cultures. However, the periodic crustal slips that produce damaging earthquakes, also pose a grave hazard to our increasingly designed world, even as they sustain these precious endowments. But, the stock of knowledge and technology available today has the potential to substantially minimize the attendant risks.

The key to reducing risk lies in reducing our vulnerability to these natural paroxysms of the earth system, by arming ourselves with reliable knowledge to estimate the highest intensity of ground shaking (accelerations) that a site is likely to experience over a desired future time window. Wide availability of such quantitative hazard maps complemented by widely disseminated designs and construction practices, have the potential to so enhance societal resilience that future earthquakes do not only spare life but even more importantly, the infrastructure support system to ensure undisrupted business in their aftermath.

The lecture will show how our understanding of the space – time evolution of catastrophic slips along the Himalaya, has progressively refined with knowledge of inter-seismic deformation rates coupled with tomographic images of the underlying crust and incisive post event analyses of recent damaging earthquakes, notably the April 2015 Gorkha Earthquake. For example, the first GPS measurements from Bangalore in 1994, allowed one to conceptualize the generalized process whereby great Himalayan earthquakes nucleate, mediated by an inter-seismic strain accumulation zone. This zone decouples a seismic creep on the northern dipping decollement from the locked portion of the southern Himalaya, and its width is a measure of the capacity of the strain reservoir and thereby of potential slip along its various segments to drive future earthquakes. Concurrently, imaging of the deeper Himalayan crust, has revealed how and how far has the Indian crust driven beneath Tibet. This simplified model, however, has been shown to be grossly inadequate, perhaps, misleading, by the incomplete rupture of the recent Gorkha earthquake, that gives new meaning to several such events in the past. An important lesson learnt, in particular, is the role of the laterally varying geometry of the descending Indian plate and the imperatives of incorporating its consequences to refine our models for calculating earthquake hazard.

Thus, we stand on the threshold of another significant improvement in our ability to provide earthquake engineers with more credible values of earthquake hazard as a basis for resilient design. This will require well argued experimental investigations to be mounted and a systematic and sustained programme to generate necessary earth data and analytical abilities, as has been done in the better studied Nepal Himalaya. It is fondly hoped that discussions during the workshop would generate productive strategies to deliver quantitative hazard maps as well as analytical approaches to landuse planning coupled with sound engineering designs and regulatory measures.

Earthquake vulnerability assessment of public buildings in Uttarakhand

- Public buildings serve many important functions on the aftermath of any disaster.
- Damage to public buildings add to the misery and trauma of the disaster affected community.
- Seismic vulnerability of 11239 public buildings of different state government departments comprising of 18835 units was assessed using rapid visual screening (RVS) technique.
- 80 percent of the surveyed units are masonry structures mostly built in the period 2002-16 (55 percent) and 1984-2001 (32 percent).
- 75 and 23 percent of the surveyed units have stripped and isolated column foundation.
- 38 and 27 percent of the surveyed RCC and masonry building units respectively have asymmetric plan.
- Construction quality of 47 percent of surveyed masonry buildings and 16 percent RCC buildings is observed to be low.
- Most surveyed buildings are deduced fall in Grade 4 damage class signifying very heavy damage (heavy structural damage and very heavy non-structural damage). This includes 58 percent of Education Department, 49 percent of Health Department, 56 percent of Administration, 48 percent of Fire and 57 percent of Police Department.
- 5-16 percent buildings of various departments fall in Grade 5 damage class signifying total destruction (very heavy structural damage). This includes 06 percent of Education Department, 04 percent of Health Department, 16 percent of Administration, 14 percent of Fire and 5 percent of Police Department.

This calls for undertaking detailed vulnerability assessment of buildings falling in Grade 4 and 5 damage class and thereby undertaking planned retrofitting / reconstruction of weak structures. SDMA has already initiated this process and retrofitting plans for Health Department infrastructure are being prepared.

Harsh K. Gupta

Presently Member, Atomic Energy Regulatory Board, Government of India and President, Geological Society of India, Immediate Past-President, International Union of Geodesy & Geophysics (IUGG) and formerly having served as Member, National Disaster Management Authority (2011-14), Secretary, Government of India, Department of Ocean Development (2001-05) and Director, National Geophysical Research Institute, Hyderabad (1992-2001) Prof. Harsh K. Gupta is a geoscientist of international eminence and has contributed immensely to the understanding of reservoir triggered seismicity. He planned and edited Encyclopedia of Solid Earth Geophysics; a 1500 + pages two volume treatise published by Springer. Fellow of Indian National Academies; TWAS and American Geophysical Union Prof. Gupta was the Leader of the Third Indian Scientific Expedition to Antarctica which succeeded in constructing the first Indian permanent station, Dakshin Gangotri, in a record time of one Antarctic summer (1983-84). He spearheaded setting up of Indian Tsunami Early Warning System for the Indian Ocean which is now rated among the best in the world.

Developing an earthquake resilient society

Earthquakes are one of the worst natural calamities. In the recorded history, millions of human lives have been lost and economic losses amount to 100s of billions dollars. We are in the 17th year of the 21st century. However, human lives lost due to earthquakes and the resultant tsunamis in these 17 years have far exceeded the total such loss in the entire 20th century.

The state of Uttarakhand is quite prone to earthquakes. Way back in 1905, the Kangra Earthquake had created an isolated area of high intensity in Dehradun and nearby foot-hills. The 1999 Chamoli Earthquake of M 6.8 had claimed over 100 human lives in Uttarakhand.

As short- term earthquake forecast is not feasible and at the same time earthquakes shall continue to occur, the best solution is to develop earthquake resilient society. To meet this goal, the National Disaster Management Authority (NDMA), had undertaken development of earthquake scenarios, as to what would happen if one of the earlier earthquakes occurs today. This was done for the repeat of the 1905 Kangra and the 1897 Shillong earthquakes. The Kangra Earthquake had claimed ~ 20,000 human lives. It is estimated that if a similar earthquake repeats today in the middle of the night, up to 900 thousand human lives could be lost. A mega mock drill was conducted on 13th February 2013 involving the states of Punjab, Haryana, Himachal Pradesh and the Union Territory of Chandigarh. This was preceded by year -long preparations and training, particularly to school children, safety of life line buildings, public awareness and the like. Several shortcomings were identified. The best part was the development of public awareness. It is important to carry out a similar exercise for Uttarakhand.

Kamal Kishore

Kamal Kishore is a member of the National Disaster Management Authority, India. He is an architect and urban planner who has worked on disaster risk management issues for over two decades. Among other policy initiatives, he leads NDMA's work on disaster resilient infrastructure. He has also led the development of national guidelines for disaster risk management in museums and cultural heritage sites and precincts. Prior to NDMA, he worked with the United Nations, the Asian Disaster Preparedness Centre and TARU. Kamal has advised national governments in more than ten countries on disaster risk management issues. He has supported post-disaster recovery after major disasters in Bangladesh, India, Indonesia, Iran, Myanmar, Pakistan, the Philippines and Sri Lanka. His early work includes support to post-disaster reconstruction after the Uttarkashi (1991) and Latur (1993) earthquakes.

Towards disaster resilient community

Over the coming decades, a large proportion of the world's infrastructure will be built in India. For example, over the next ten years, India will double its energy output, increase the length of national highways by 50%, and increase the length of metro lines by six times. A large part of this infrastructure development will take place in the Himalayan states, where investment in infrastructure is a pre-requisite for sustainable development. Inevitably, all of this infrastructure will be exposed to a range of geophysical as well as hydro-meteorological hazards. Infrastructure projects if planned, designed and executed to adequate standards can enhance the overall resilience of the communities they seek to serve. On the other hand, if they are planned, designed and executed poorly, in the fragile environment of the Himalayas they can set off a chain of processes and exacerbate disaster risks. In such a context, planning of all new infrastructure must adopt a comprehensive disaster risk management approach. Such a comprehensive approach would include: systematic evaluation of risks to and from infrastructure; develop standards and regulations that focus on not just the present risks but also future risks; financing mechanisms that encourage investment in resilience; and robust institutional mechanisms to support post-disaster recovery of infrastructure.

Vineet Kumar Gahalaut

Dr. Vineet Kumar Gahalaut is the Director of National Centre for Seismology, Ministry of Earth Sciences, New Delhi. He is on lien from CSIR-NGRI, since June 2015. Dr. Gahalaut completed his masters degree from University of Roorkee (now IIT) in 1989 and then Ph.D. from the same institute in 1995 on the topic "Himalayan earthquakes and their occurrence processes". Since then he is involved in research related to earthquakes and their seismogenesis in India using crustal deformation data from GPS measurements. He has established more than 100 permanent GPS stations in various tectonic domains of India, out of which 23 are established in the Kumaun - Garhwal Himalaya. He is the recipient of several awards; prominent of these being the PRL award in Earth and Planetary Sciences 2011, CSIR Young Scientist Award 2001, INSA Medal for Young Scientist Award 1997. He has to his credit more than 100 papers in the peer reviewed international and national journals and a book on Three Great Tsunamis published by Springer.

Locked fault zones along the Kumaun Garhwal Himalaya: Implications for earthquake hazard♣

Earthquakes in the Himalayan region occur due to the ongoing convergence between the Indian and Eurasian plates. This convergence is accommodated on the underlying Main Himalayan Thrust (or detachment) through stick and slip manner and can be measured through GPS observations. Here we analyse GPS measurements from ~30 permanent GPS sites from the Kumaun- Garhwal Himalaya, which include 22 new GPS sites installed during the period 2012-15. Analysis of GPS measurements suggest that about the shallow part of the MHT (up to 100 km from the MFT) under the Kumaun - Garhwal Himalaya is locked and is accumulating strain at the rate of 18 mm/year. The inversion of site velocity estimates for plate coupling suggests a high (>0.7) plate coupling up to a width of ~90 km from the Main Frontal Thrust which approaches to zero towards north in the a seismically creeping MHT region. The estimated coupling ratio suggests large amount of slip deficit or strain accumulation in the Kumaun - Garhwal Himalaya. Considering that no great earthquake has occurred in past 500 years or more, this region has high potential for the occurrence of a great earthquake. Based on the information on locking, subsurface structures, and lessons learnt from the 2015 Gorkha earthquake, it is important to develop scenarios for earthquake slip and damage, and identify regions which can suffer high damage in the future earthquake.

♣*This paper is co-authored by Rajeev Kumar Yadav, Amit Kumar, S.P. Sati, J.K. Catherine, Param Gautam and Kireet Kumar*

Yogendra Singh

Dr. Yogendra Singh is Professor and Head of Earthquake Engineering at Indian Institute of Technology Roorkee. He obtained his B.E. in Civil Engineering from IIT Roorkee (then University of Roorkee) in 1989 in First Division with Honours and M.Tech. and Ph.D. in Structural Engineering from IIT Delhi in 1990 and 1994 respectively. His research interests include performance based design of buildings and bridges, seismic vulnerability and risk evaluation, non-linear modelling and analysis and seismic evaluation and retrofitting of structures. He has 23 years of research and teaching experience, guided 11 Ph.Ds., published 54 research articles in refereed journals and presented 97 papers in national and international conferences. He has been member of several expert teams for post-earthquake damage surveys and is convener of the BIS expert group on performance based seismic design of structures. He has collaborated with NORSAR, Norway, NGI, Norway, NTU, Singapore, Stanford University, USA, University of Edinburgh, UK, and University of Windsor, Canada.

Seismic challenges for construction in Indian Himalayas: Current standards and practices[♣]

Indian Himalayas are one of the most seismically active mountain ranges in the world, which cover far north to north-east India. The geological formations of Indian Himalayan mountains are relatively young and have therefore witnessed several devastating earthquakes in the past. Majority of the Indian states in this region are categorized under the most severe to severe seismic zone (*i.e.*, seismic zones IV and V) as per IS 1893: Part 1 (2016). Rapid urbanization, infrastructure development and scarcity of flat land in Indian Himalayas are driving the people for heavy constructions on hill slopes for residential and commercial purposes. Many a times, buildings, bridges, tunnels and others are forced to be placed on slopes despite of unfavourable conditions for construction. Multi-storeyed RC buildings, with foundations constructed at different vertical levels are quite popular and coming up in increasing numbers on slopes in the India Himalayan region.

During the present decade, Sikkim Earthquake (2011), Nepal Earthquake (2015) and Manipur Earthquake (2016) have highlighted issues related to topographic amplification, slope instability, seismic bearing capacity of foundations on slope and seismic slope-building interaction. These issues are still a huge challenge for construction in Indian Himalayas.

During a seismic event the ground motion characteristics are significantly altered by topography of the site and influenced by factors that include shape, size, and slope of the hill, and predominant frequency of the ground motion. Seismic stability of slopes under building loads and slope-building interaction are the most crucial problems being faced by the structural and geotechnical engineers, and one of the frequently faced questions from the development control agencies in these areas related to the density of buildings and their permitted height.

[♣] *This paper is co-authored by Dhiraj Raj, and Mitesh Surana*

Compared to foundations on flat land, the foundations in hilly regions are more prone to failure due to slope instability. In case of an earthquake event, a synergistic effect of sloping ground and seismic loading may cause severe stability related problems for earth retaining structures and foundations due to reduction of bearing capacity. The post-earthquake reconnaissance studies by several researchers highlight the influence of seismic actions on bearing capacity.

It is to be noted that the structural configuration of the buildings on hill slopes is significantly different from those located on flat land, due to the constraints posed by the hill topography. The hill buildings with their foundations located at different levels, have large irregularity in plan as well as in elevation. In addition, the short columns present on the uphill side are prone to brittle shear failure. The experience on multi-storeyed buildings during Sikkim Earthquake (2011) has shown that the hill buildings are subject to extreme torsion at the level of uppermost foundation, which results in failure of hill buildings at this level (Singh *et al*. 2012).

Only a few standards (EN1998-5 2004; AFPS 1990) include topographic amplification (based on the height and ridge angle of the 2D slope configurations) in a simplified manner, where frequency-independent amplification factors not larger than 1.4 are prescribed. Most of the current codes of practice on stability of slope recommend use of pseudo-static methods and satisfaction of a minimum factor of safety against stability of slope consisting of soils without high pore-water pressure or significant strength degradation under cyclic loading and sites without abrupt changes in geometry and stratigraphy (EN1997-1 2004; NCHRP 2008; USACE 2003). Some other codes (EN1998-5 2004; NCHRP 2008), in addition, recommend use of displacement-based methods for safety assessment of slopes.

Current standards and codes of practice are limited only to the estimation of bearing capacity of shallow foundations on flat ground (IS 6403 2002; IS 1904 2006; IS 1080 2002; EN1997-1 2004; NCHRP 2010) subject to purely vertical loading and several correction factors are provided for shape, size, base inclination of the foundation, eccentricity and inclination of the applied load, and horizontal seismic coefficient (EN1998-5 2004). EN1998-5 (2004) and NCHRP (2010) recommend using empirical formulations of failure envelope or load interaction diagram for assessing the stability of foundation. Guidelines for estimating bearing capacity of foundation on slopes, particularly under the effect of seismic actions, are mostly lacking. The current seismic design codes in India (IS 1893:(Part 1) 2016; IS 13920 2016), as well as other major international codes (ASCE 7-16; ASCE 41-13; EN1998-1 2004), do not cater to the specific needs of the hilly regions for seismic design of structures.

Several initiatives are underway at the Department of Earthquake Engineering, Indian Institute of Technology Roorkee in the direction of seismic safety of hill construction. These include study of topographic amplification (Singh et al. 2015; Narasimha 2015; Shadab 2017), stability and bearing capacity of foundations on slopes (Raj and Singh 2016a; Raj et al. 2017a), slope-building interaction (Raj and Singh 2016b; Raj et al. 2017b), seismic fragility analysis of hill-side buildings (Surana et al. 2015a; Surana et al. 2015b; Surana et al. 2017). A simple Ms-Excel based tool has been developed to estimate the seismic bearing capacity of foundations located on slopes (Raj et al. 2017a).

Prabhas Pande

Dr. Prabhas Pande did his M.Sc. in Geology in the year 1971 and was awarded the degree of Doctor of Philosophy in 2008 by the University of Lucknow. In his service career in the Geological Survey of India (GSI) spanning 37 years, he carried out geotechnical investigations of several river valleys and communication projects and studied over 15 damaging earthquakes that occurred in the Indian subcontinent since 1991. He supervised seismic hazard assessment of urban agglomerations at micro level, active fault mapping and palaeoseismic studies apart from providing policy and planning support. He superannuated as Additional Director General, GSI in 2011. He has served as a Member of the Scientific Board of IGCP, UNESCO from 2002 to 2005. He was sent on deputation to France in 1995 and to Bhutan in 2001 to conduct seismotectonic evaluation studies. Dr. Pande was part of the Indian delegation to Chile, Peru and Canada in 2010 and 2011 and served as a Geotechnical Consultant for Chindwin Valley projects in Myanmar. He was Technical Consultant for Kalpasar Project, Government of Gujarat and represented GSI in several national and international committees including the Global Earthquake Model (GEM). He was a Member of the Peer Group constituted for the first revision of the Vulnerability Atlas of India and that of the BIS Committee entrusted with the task of bringing out the fifth version of the Indian Seismic Code.

Since his superannuation Dr. Pande is actively associated with various programmes associated with earthquake research, seismic hazard assessment, landslide studies and disaster management. He has investigated the 2015 Gorkha Earthquake along with a team of Scientists from IIT Kanpur. Presently, he serves as the Chairman of the Expert Committee on active fault studies under the aegis of the Ministry of Earth Sciences and is a Member of various national committees constituted by the DST, MoES, Nuclear Power Corporation of India and GSI. As a Consultant, he has carried out seismotectonic evaluation of a number of river valley projects in the Eastern Himalaya and in the Middle East.

Dr. Pande has written over 50 technical papers and authored/edited several major publications of the GSI, including the Seismotectonic Atlas of India and 2001 Kutch Earthquake.

Seismic hazard of Uttarakhand: Lessons learnt from the study of damaging earthquakes of the state

Uttarakhand, the youngest of the Himalayan States, has its geographical limits defined by Tons-Yamuna rivers in the west and Kali river in the east. Endowed with generous natural resources, its 65 percent area of 53,483 sq km is covered with forests. Bounded by snow clad mountains in the north and gentle alluvial plains in the south, Uttarakhand shows an altitude variation of over 6500 m. The other drainages of prominence are Bhagirathi, Alaknanda, Ganga, Mandakini, Dhauliganga, Nandakini, Pindar, Nayar, Goriganga, Ramganga, and Kosi. Some of the high mountain peaks remaining under the perennial snow cover are Vasuki Parbat, Satopanth, Chaukhamba, Bithartoli, Himal, Dunagiri, Nanda Devi, Nanda Kot, Trishul and Mangtoli. The 290 km long snow range nestles within its folds a total of 968 glaciers that feed the mighty river system belonging to the Ganga basin. Its plentiful water resources descending relentlessly through its snow-fed rivers hold a cumulative power potential of 30,000 MW, of which only 12 percent has been harnessed so far.

However, on the other side, the state is plagued with a number of natural hazards that include earthquake, landslide, snow avalanche, cloud burst, flash flood, glacial lake outburst, and hailstorm and forest fire. Though landslides are the most frequently occurring geohazard, earthquakes remain a cause of maximum concern to the society because of their unpredictable nature and great destructive power affecting large areas.

Uttarakhand constituting a 12 percent segment of the 2400 km long mobile belt encompasses a wide assemblage of rock units ranging in age from Proterozoic to Cenozoic. Flanked by the Tibetan tectogen in the north, the mountain chain has two broad divisions; main Himalayan belt and frontal fold belt. The former includes the high and low grade metamorphic complexes overprinted by fold-thrust movements and poorly/unmetamorphosed litho-assemblages folded during the Himalayan orogeny. The latter comprises the cover rocks of the foredeep affected by tectonic disturbances during the terminal phase of the Himalayan orogeny. A number of granitoid and basic volcanic bodies have been emplaced within the rocks of the Proterozoic age. The Bhabar and Terai plains of Haridwar, Nainital and Udhamsingh Nagar districts are composed of alluvial fill in the Indo-Gangetic foredeep.

The main structural discontinuities dissecting the Uttarakhand Himalaya are the Main Central Thrust (MCT), North Almora Thrust (NAT), the western continuity of which is referred to as Srinagar Thrust, South Almora Thrust (SAT), Ramgarh Thrust, Martoli Fault, Alaknanda Fault, Main Boundary Thrust (MBT-I, II & III), Himalayan Frontal Thrust (HFT) and the wrench faults of Yamuna, Ganga and Kali (GSI, 2000). The MCT, formed some 45 million years ago due to the collision, has brought the Central Crystallines in juxtaposition with rocks of the low grade complexes and, in a sense, marks the southern boundary of High Himalaya. The surface trace of this north dipping plane is sinuous and at places offset by transverse faults. The NAT, a southerly to sub-vertically dipping discontinuity, separates the Garhwal Group from Morar-Chakrata-Tehri formations in Garhwal region and Almora Crystallines in Kumaon region (Kumar et al., 1989). The most distinct structural plane is the MBT that separates the Tertiary from Pre-Tertiary and is present throughout the length of the Himalaya. The Lesser Himalaya is confined between the MCT and MBT.

The Uttarakhand region, like rest of the Himalaya, is in a state of tectonic flux as demonstrated by the imprints of tectonic episodes in the Quaternary sediments. Though the surfaces like the MCT and NAT appear to have hardened, the discontinuities of the Outer Himalaya are considered still mobile.

The observed Bouguer gravity anomaly gradient beneath the Lesser Himalaya and the Gangetic foredeep is of the order of 1 mgal/km, which increases to 2mgal/km beneath the High Himalaya. This increase in gravity gradient has been explained on account of steepening of Moho from 2°-3° beneath the Lesser Himalaya to 10°-15° beneath the High Himalaya. Cean and Molnar (1985) have interpreted this steepening due to a weakness of the Indian plate and, therefore, its consequent bending. The upper surface of this flexure is a favourable locale for strain locking, particularly where intersected by deep seated transverse structures.

Earthquake catalogue of India Meteorological Department (IMD) indicates that in the period from 1803 to 2010, a total of 230 seismic events of $M \geq 4$ have occurred in Uttarakhand. Of these, 31 events contained energy of damaging proportions (M>5.5). Fault plane solutions of eight of the seismic events indicate a predominantly thrust type mechanism of rupture with the nodal planes paralleling the Himalayan trend. The decades of 1910-20, 1940-50 and 1990-2000 were periods of high seismic outbursts in the Uttarakhand Himalaya.

The records of destructive earthquakes of the region are available in different reports and publications of the Geological Survey of India (GSI) and IMD. Oldham (1883) mentions the occurrence of a strong earthquake on 1 September, 1803 at 1:35 hrs of M6.5 in the upper Ganga valley. The tremor killed 200-300 people in Barabal and inflicted severe damage in Badrinath. Oldham's catalogue mentions of another earthquake of 25 May, 1816 of M6.5 near Gangotri that induced numerous landslides. On 28 August, 1916 an earthquake of M7.5 having its epicentre in west Nepal had a considerable influence in Kumaon region and caused heavy damage in Dharchula. In the Kapkot Earthquake of 28 December, 1958 of M6.0, over a dozen houses collapsed. On 29 July, 1980 the Dharchula-Bajang Earthquake of M6.1 and epicentral intensity VIII caused extensive damage to buildings and induced numerous landslides. 25 April, 2015 Gorkha Earthquake of M7.6 had minimal effect in Uttarakhand with the seismic intensity barely reaching IV on MSK-64 scale.

The most destructive earthquake documented so far in Uttarakhand was that of Uttarkashi of 20 October, 1991 of M6.6 (Mw 6.3) and epicentral intensity IX in the Bhagirathi valley. The earthquake caused damage to 94,898 buildings, took toll of 768 human lives, injured 5066 others and induced over 115 major landslides. The main shock was followed by 2000 aftershocks within a period of two months. A host of villages, mostly of Uttarkashi district, faced lingering problem of slope instabilities in the following months.

On 29 March, 1999, another earthquake of M 6.8 (Mw 6.6), referred to as Chamoli Earthquake, occurred in the Alakhnanda valley that inflicted damage to over 1,87,000 buildings, caused 106 human fatalities, 453 injuries and induced numerous landslides. A total of 700 aftershocks were picked up during a 5-month monitoring following the main shock.

The seismicity in the Garhwal Himalaya is mostly confined within the Lesser Himalaya, lying between the MCT and MBT, more so towards its northern margin. The most accepted seismotectonic model of the Himalaya identify a low, northerly dipping detachment surface along which the Indian continental crust underthrusts below the Himalayan blocks (Seeber and Armbruster, 1981; Ni and Barazangi, 1984). Ni and Barazangi (1984), on the basis of seismicity database pertaining to the period 1961-1980, suggested that most of the events located just south of the MCT trace along the detachment, the upper surface of the Indian plate, at depths of 10 to 20 km. A 50 km segment of the detachment in the Garhwal-Kumaon-Nepal Himalaya, that happens to be lying 15-20 km below the Lesser-High Himalaya boundary, is in a state of maximum inflammation. The larger sized seismic events nucleate along this segment of flexure of the detachment where the tectonic environment of deformation is mostly thrust type. The various available fault plane solutions indicate that the moderate/large magnitude events, e.g. 1991 Uttarkashi, 1999 Chamoli and 2015 Gorkha, have all a predominantly thrust-type rupture mechanism along a very low, northerly dipping plane having strike paralleling the Himalayan trend.

The role of deep seated transverse features is important in two ways. First, these form locales of major asperities where intersected by thrusts and faults oriented parallel to the Himalayan trend and, thus, of major strain locking. Secondly, the transverse features constrain the boundaries of a seismogenic block and so define its generating capability and hazard level. In a thrust-type environment as that prevailing in the Garhwal main seismic source zone, the transverse structures serve as facilitators but rarely act as the principal seismogenic sources. It is interesting to note that the drainages of Yamuna, Bhagirathi, Ganga, Alakhnanda and Kali in the Uttarakhand Himalaya have been carved out along the traces of deep seated transverse structures and majority of the destructive seismic events of the region have occurred along these major valleys.

Earthquake activity in Uttarakhand has been quite prolific as a result of which 1000 human lives have been lost and property worth crores of Rupees destroyed or impaired in the last 200 years. The State’s 31.1 percent area comes under Seismic Zone V and 68.9 percent in Seismic Zone IV of the Seismic Zonation Map of India corresponding to Zone Factors of 0.36 and 0.24 respectively. The entire districts of Chamoli and Bageshwar and more than 94 percent area of Rudraprayag and

Pithoragarh districts fall in Seismic Zone V. As per the 2011 Census data, the population of Uttarakhand and the number of housing units stand at 10,086,292 and 3,383,410 respectively, showing a rise of over 15 percent per decade. This growth has certainly increased the vulnerability factor, particularly of the urban centres, where the construction activity is going on at a rapid pace violating many of the safe construction norms. It is a matter of great concern that any major earthquake of future could prove to be much more disastrous for Uttarakhand.

GSI has done landslide susceptibility mapping along the major river valleys of Uttarakhand. In the Yamuna valley, an area of 1800 sq km has been mapped where 568 incidences of slope failures have been recorded. In the Bhagirathi valley, an area of 6900 sq km has been covered where a total of 526 landslide incidences have been identified. The study shows that 17 percent of slope failures have occurred in the High Himalaya, 81 percent in the Lesser Himalaya and 2 percent in the overburden mass.

The Mandakini valley, which faced the terrible deluge of June 2013, records 614 landslide incidences in a 400 sq km area. It is a fact that, so far, casualties on account of earthquake triggered landslides in Uttarakhand are rare. But, in the present times, when there is rampant growth of all sorts of constructions taking place at unfavourable locations, the safety aspect seems to have been compromised to a large extent.

The geohazard scenario of the state merits comprehensive understanding of the tectonic and geomorphic processes operative within and outside a fragile crust on the one hand, and adoption of safer ways to live in an environment that is seismotectonically and geotechnically unpredictable and rather critical, on the other.

Earthquake risk mitigation efforts of USDMA

- Seismic hazard, vulnerability and risk assessment of the entire State.
- 500 engineers trained in earthquake safe construction at IIT – Roorkee and GBPUAT – Pantnagar.
- 1484 masons trained in earthquake safe construction and 52 demonstration units constructed.
- Model seismic retrofitting of 8 schools and 80 masons trained.
- Non-structural retrofitting of 400 schools.
- Seismic vulnerability assessment of the built environment of major urban areas using rapid visual screening (RVS) technique.
- Seismic vulnerability assessment of 11239 lifeline public buildings.
- Earthquake early warning generation and dissemination.
- Preparation of detailed retrofitting plan of the hospital infrastructure of the State.
- Strengthening building bye laws.
- Earthquake response plans of the districts.
- Mock exercises for prompt response and smooth interdepartmental coordination.
- State Disaster Response Force (SDRF) raised.
- 14550 volunteers imparted search, rescue and first aid through 582 training programs of 10 days duration.
- Incident Response System (IRS) institutionalized for all disaster response operations and concerned officials trained from State to Tehsil level.
- Audio-visual and print IEC material prepared for mass awareness so as to ensure voluntary compliance and disaster resilience.

Rajendra Kumar Pandey

Dr. Rajendra Kumar Pandey, Professor, Department of Electrical Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi has assumed the charge of Director General, National Power Training Institute (NPTI) on 11th July, 2016 on deputation to Ministry of Power, Government of India.

Prof. Pandey received PhD in Electrical Engineering from IIT Kanpur in 1992. He is professionally active Senior Member of IEEE having Membership of Power and Energy Society (PES), Smart Grid Community (SGC), Communication Society and has contributed in power and energy systems globally in various capacities as Member of Editorial Board of reputed Transactions/Reviewer/Advisor in advance areas of power systems. He has a long working experience in the field of High Voltage Direct Current (HVDC) Transmission Technology and Flexible AC Transmission Systems (FACTS) Devices Control, Intelligent Power Control along with the Operation of Power System in Open Access since last 34 years. He is a Member of India Smart Grid Forum (ISGF) and associated with WG1, WG2 and WG6 which are Advanced Transmission, Advanced Distribution and Policy & Regulations respectively. He has visited various countries including USA, UK, China, Canada and Hong Kong in connection with different projects/conferences/invited talks. He has published more than 140 peer reviewed papers in both national, international journals and conferences of repute.

In addition to the DG-NPTI, he is also the Chairman of High Power Committee of BHU and Coordinator of Green Energy Centre BHU constituted for executing the Solar Energy Project (Grid connected mode) with a cost of 450 cores, both for BHU main campus & Rajiv Gandhi South Campus (RGSC) in Barkaccha, Mirzapur in association with SECI, MNRE, Govt. of India. He is also Principal Investigator of Smart Grid Project (involving multi-stake holders- BESCOM and IIT (BHU), Varanasi) namely “Design and Development of a Smart Energy Grid Architecture with Energy Storage” funded by Department of Science & Technology, Govt. of India, which is being implemented under his leadership at Chandapura Division, Bengaluru and partially commissioned in March 2017. The full commissioning is expected to be completed by the end of January 2018 followed by R&D.

Strategic technology integration for alert signalling and avoidance mechanism: Earthquake safety

Himalaya Region is very important from various angles for India, especially large hydro projects and related safety issues. The impact of natural imbalances are primarily affecting the underground activities which have been observed in recent unnoticed cloud bursting phenomenon in hilly regions and also in earthquake in Nepal. The dynamics of earth has been changing due to massive uncontrolled under water dynamics which sometimes unnoticeably perturbs the earth behaviour especially in Himalayan belt. With advancement of technology, it has become relatively easier to analyse the underground changing dynamics of earth, which may be, due to many parameters such as weakening the earth by huge impact of unequal forces responsible of deteriorating equilibrium point at respective location. The technology integration may involve satellite imaging in a specific region of interest with real time signalling of images which may be an indicator for assessing deviation of equilibrium with ongoing perturbation inside the earth from the equilibrium point in normal mode (reference point). The deviation factor may be mapped as a parameter for assessment as it becomes larger in the normalized scale. The normalized scale may be in 0 to 1 scale point. The acceptable range may be 0.1-0.2 depending on the vicinity of hydro projects or population nearby Himalayan belt. With advance technology of GIS mapping and data analytics, a thumb rule may be evolved which may then be generalized based on the factor of regional safety. Since the technology being proposed is based on the imaging, a high capacity communication corridor is required to transmit the data and also very fast algorithm is to be developed for giving the result of equilibrium deviation with straightforward prediction of zone likely to be affected with degree of risk. With upcoming IoT, the real time processing may be done at centralized control location which may have high performance computing facilities.

The innovative concept being presented needs to be tested with multi-group experts involving geology expert, satellite data analytics, algorithm developer and meteorological analyst. The basic approach of alert signalling and avoidance mechanism of earthquake is based on equilibrium shift being monitored in real time and the associated error becomes a criterion of prediction and remedial measures initiation.

The biggest challenge as on date has been precise prediction and location detection apriori. Since the proposed approach may not have been used in earthquake prediction, this may be a new methodology not only for the prediction but also for Himalayan belt coming under danger zone due to changing earth dynamics due to many other unidentified factors. The approach being discussed may prove to be a tool to evaluate the changing patterns over a period of time in any region on earth, and after carefully examination a formulation may be evolved based on the geographical location as one of the parameters and other underground changing patterns may also be noticed.

Since the entire region can be grouped in multi-zones while going for data analytics, the inter-zonal impact may also be examined with proposed concept and specific comments on the process of initiation of earthquake can be established.

M. L. Sharma

Prof. M. L. Sharma has more than 32 years of experience in teaching, research and consultancy in the area of earthquake engineering and engineering seismology.He joined Department of Earthquake Engineering, IIT Roorkee as faculty in 1985 and has published more than 200 research papers in journals and conferences and authored more than 450 technical reports. He has guided 15 PhDs and 52 Master’s degree students. 10 PhDs and 9 Master’s student are presently working with him.

Prof. Sharma has rendered expert advice to more than 400 major engineering sites in India and abroad for seismic hazard and risk assessment. He has successfully attempted to analyze and quantify the uncertainties in final hazard estimates and the same has been used for seismic microzonation of NCR, Dehradun city, Srinagar city (J&K), and Phuentsholing city in Bhutan.

His long association with the strong ground motion program of DST has resulted in development of ground motion prediction equations which are extensively used to estimate seismic hazard in India and worldwide. Prof. Sharma has played key role in the deployment of the first digital telemetered seismological sample array in Garhwal-Kumaun Himalaya in 1985-86 with the aim to study present seismic status and RIS around Tehri dam. High quality digital data produced first results on characteristics of source parameters for the Garhwal Himalaya. Based on the data collected by these arrays, including Kol, Lakhwar and Tehri dam a 3-dimensional velocity structure has been proposed for Garhwal Himalaya. Prof. Sharma played key role in MOUs for Kalpasar multipurpose scheme of Gujarat state, DRIP program of CWC with Madhya Pradesh and Uttarakhand Government.

Prof. Sharma introduced the studies based on SAR interferometry for deformation estimations and the convergence rates between Ganga and Yamuna Tear near the Himalayan Frontal Fault have been estimated using this methodology. He is the one who initialized earthquake early warning system in India. He has been actively associated with many international programs especially with Norway, Mexico and Taiwan for disaster mitigation. The lessons learnt through many damage surveys of moderate earthquakes carried out by him have resulted in advice for future in form of many of his international publications. Prof. Sharma is associated with Uttarakhand Government for many seismic hazard and risk assessment programs and is one of the members of the Technical Task Force.

Based on the contributions by Prof. Sharma in disaster mitigation he was awarded the A.S. Arya-IITR Disaster Prevention Award in 2012. He is Fellow of Indian Society of Earthquake Technology, Indian Geotechnical Society and Indian Geophysical Union. He is life member of American Geological Union and annual Member of SSA and EERI. Prof. Sharma has played important role in ISET and is the present President of the ISET.

Earthquake early warning system in North India

Almost all the results of seismic hazard exercises in Himalayas converge to conclude the urgent and utmost need to employ disaster mitigation and management strategies. The spurt in damaging earthquakes and silence in the gaps in Himalayas has beefed up the research work to predict the next big earthquake for its size and time. Due to fast pace of development and that too without proper planning and our inability to predict earthquakes and to reduce seismic hazard, a different mitigation approach is required to reduce massive loss of lives and economy.

The emergence of real time seismology, advanced signal processing and faster communication facilities lead to the development of an eminent tool for disaster mitigation called earthquake early warning (EEW) system. The designing and implementation of an EEW system requires dense network of sensors and an effective EEW algorithm for detection, location and estimation of magnitude of an event in real time to issue an alarm. The EEW systems make use of two approaches; (i) regional warning approach based on processing the data from a network of seismic instruments to estimate size of earthquake and ground motion at other sites and (ii) onsite warning approach in which the ground motion identified at a site is used to provide warning of coming ground shaking at the same site. Many countries have succeeded in designing and implementing EEW systems. However, India in spite of having one of the world's most seismically active belts like Himalayas and having important cities in its vicinity has not yet made enough in-roads in this disaster mitigation and management attempt.

IIT Roorkee initialized EEW in India with the deployment of 84 sensors in seismic gap region of Garhwal Himalaya with the help of Ministry of Earth Sciences in 2015. These sensors stream data in real time to a computer server at Roorkee using VPNoBB of BSNL (58 sensors) and SWAN network of Government of Uttarakhand (28 sensors). This data is processed for issuing warning for Magnitude 6 and above earthquakes. Presently, sirens connected to the server for taking the command have been fitted within the campus of IIT Roorkee. This project was successfully completed in March 2017 but without any measures undertaken to issue the warning to public.

Subsequently, in May 2017 Government of Uttarakhand sanctioned a project to IIT Roorkee for maintenance of present EEW system in Garhwal Himalaya, installation of 100 additional sensors covering Kumaun region, installation of sirens in SEOC at Dehradun and all district HQs of Uttarakhand and installation of 100 sirens in cities of Dehradun and Haldwani.

It is the first instant where EEW is to go public in India. Many examples of recent earthquakes in Mexico and Japan have proven the success of EEW in reducing the loss of lives. The EEW system is in developmental stage and may include some of the components like non-availability of size of earthquake at the time of warning, false alarms and intensity at the point of observation in near future. The team at IIT Roorkee is not only engaged in development of software but also the hardware for EEW including the sensors and others.

Prashant Kumar Champatiray

With a post graduate and doctoral degree from IIT Bombay and MS and PDF from the University of Twente, The Netherlands Dr. Champatiray is actively involved in research, education and training in the field of applications of remote sensing, GNSS and GIS in geosciences, geohazards and planetary geology.

He is presently Group Head, Geosciences and Disaster Management Studies (GDMS) Group and Head, Geosciences and Geohazards Department of the Indian Institute of Remote Sensing, Dehradun. His research interests include monitoring and modelling of landslides, active fault mapping, seismic hazard assessment, geodynamics, crustal deformation, earthquake precursor studies, mineral exploration and planetary geology.

His professional career spans over 30 years during which he has implemented 14 projects, guided more than 100 students including 11 PhD students and published around 200 papers including 54 papers in peer-reviewed national and international journals, and most importantly delivered more than 100 invited presentations at national and international forums.

Space based TEC observation and modelling for Earthquake Precursor studies- Recent success stories and way forward

Electron content in the ionosphere is very sensitive to temporary disturbances of the Earth's magnetosphere (geomagnetic storm), solar flare and seismic activities. The Global Navigation Satellite System (GNSS) based total electron content (TEC) measurement has emerged as an important technique for computations of earthquake precursor signals. In this study, we have examined the pre-earthquake signatures for 8 strong magnitude (Mw>6: 6.1 to 7.8) earthquakes with the aid of GNSS based TEC measurement in the tectonically active Himalayan region using International GNSS Service (IGS) stations as well as local GNSS based continuously operating reference stations (CORS), set up by IIRS, WIHG and many others. The results indicate very significant ionospheric anomalies in the vertical total electron content (vTEC) few days before the main shock for all the events. Geomagnetic activities were also studied during the TEC observation window to ascertain their role in ionospheric perturbations. It was also inferred that TEC variation due to low magnitude event could also be monitored if the epicentre lies closer to the GNSS or IGS station. Additionally, in order to assess the methodology in other geological regions, various earthquakes from South America, Sumatra, Indonesia and other regions of world have been analysed with a prime focus on precursor and epicenter detection. These also have proved very encouraging results. For Nepal Earthquake of 2015, near and far station data have been analysed showing vary clearly the variation of TEC with respect to strain built up region. Data from non-earthquake region (higher northern latitude) have also been studied to correlate with seismic events. Many aspects of TEC observation are under further studies. Additionally, other atmospheric observation like VLF propagation and ozone monitoring will also be mentioned as potential precursor parameters. Overall, the study has confirmed TEC anomalies before major Himalayan earthquakes, thereby, making it imperative to set up a much denser network of IGS/CORS for real time data analysis and forewarning. Presentation will also focus on integration of several potential precursor studies and way forward with challenges and opportunities.

Supriyo Mitra

An earthquake scientist (seismologist) working on continental tectonics, Prof. Mitra's research include study of earthquake source properties, seismic structure of the lithosphere and attenuation characteristics of seismic waves. Prof. Mitra did his undergraduate from Jadavpur University (1995-1998), Masters from Indian Institute of Technology, Bombay (1998-2000) and PhD from the University of Cambridge (2000-2004). For his Doctoral studies, Prof. Mitra received the prestigious Nehru Cambridge Scholarship awarded by the Cambridge Commonwealth Trust and the Overseas Research Scholarship from Committee of Vice-Chancellors and Principals (CVCP), UK. Subsequently, Prof. Mitra worked as a Visiting Faculty (2004-2005) and Assistant Professor (2005-2010) in the Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur. He then moved to Indian Institute of Science Education and Research, Kolkata as an Associate Professor (2010-2016) and is currently Professor (2016 onwards) in the Department of Earth Sciences, IISER Kolkata.

Prof. Mitra's significant research contribution has been (i) in unraveling the seismic structure of the Eastern Himalaya and north-east India, Sikkim Himalaya, North-western Himalaya and Kashmir Himalaya, using receiver function techniques; (ii) study of the seismic structure of the Indian subcontinental lithosphere using surface wave tomography; (iii) improving our understanding of source properties of moderate-to-large earthquakes in the Himalaya and Indo-Burman Convergence Zone, and (iv) unraveling the seismic attenuation characteristics across the Himalaya and peninsular India using seismic body and surface waves.

Prof.Mitra has 24 peer-reviewed publications in reputed Geophysics journals. Prof. Mitra has worked on a number of national and international research projects, namely the UK-IERI Thematic Partnership and the Nepal Earthquake Emergency Grant.

Prof. Mitra is the recipient of a number of awards and recognitions, which include the National Geoscience Award (2016) by The Ministry of Mines, Cambridge- Hamied Fellowship (2016), NASI-Scopus Young Scientist Award (2012) in Earth Oceanographic and Environmental Sciences, Associate of the Indian Academy of Sciences (2011 – 2014), INSA Young Scientist medal (2010) in Earth Sciences and the UK-IERI Post-Doctoral Fellowship (2008). Prof.Mitra is a member of the American Geophysical Union since 2002.

Earthquake hazard in the Himalaya: Lessons learnt from recent earthquakes

The Indian peninsula is surrounded by the tectonically active plate boundaries of the Himalayan mountains and Andaman-Sumatra subduction zone. The Himalayan mountains have produced some of the most devastating earthquakes over the last century namely Kangra (1905), Assam (1950), Uttarkashi (1991), Chamoli (1999), Kashmir (2005), Sikkim (2011) and Nepal (2015). These earthquakes have caused enormous loss of lives and property, highlighting the vulnerability of civilizations in areas where major earthquakes occur. More than a sixth of the world's population lives in India. The population is growing rapidly and this growth is accompanied by rapid urban development in these regions of high seismic hazard potential.

Over the past two decades, geoscientists have started to understand the urgency of the situation and have taken significant steps towards quantification of seismic hazard. Recent advances in instrumentation and computational techniques are being used by geoscientists, particularly seismologists, structural geologists and tectonic geomorphologists, to study active faults, earthquake source properties, seismic velocity structure and attenuation of seismic energy. This knowledge is used to quantify seismic hazard in the Himalaya and the adjacent Indo-Gangetic plains, which is the most densely populated region of the country. Engineering seismologists have used this information to develop 'Building Codes for New Structures', which requires mandatory compliance for all new urban constructions. Structures, build to these standards, will be able to withstand ground shaking from future major earthquakes. Through my presentation, I will highlight the lessons learnt from recent devastating earthquakes, sharing of knowledge and expertise with earthquake scientists across the globe and implementation of best practices in quantification of seismic hazard.

Although we have made some progress, we are still faced with the unsurmountable task of implementing these building codes uniformly to structures which are being built across the country and in raising the level of awareness among masses to ensure that they are a part of an earthquake safe society. Finally, I will discuss how prepared we are for the next big one in the Himalaya!

Prompt and effective SAR for minimizing human misery after any disaster

Harsh reality # 1. Surface connectivity is often disrupted due to disaster.

Harsh reality # 2. Weather conditions often hinder air operations.

Harsh reality # 3. Air operations are constrained by availability of helipads and refueling facility.

Harsh reality # 4. Formal response teams are not able to reach the site of the disaster in time.

Harsh reality # 5. This enhances the misery of affected population and reduces chances of survival.

Ensuring geographically dispersed availability of trained volunteers is the solution.

Search, rescue and first aid training programs of 10 days duration therefore being organized by USDMA at village level.

Volunteers are trained to take charge and manage the situation till formal response teams reach the site.

Volunteers are trained to improvise locally available material for rescue and first aid.

14550 volunteers in 582 Nyaya Panchayats (including repetition in many Nyaya Panchyats) of 77 Development Blocks trained with fair representation of women.

Online database of all the volunteers maintained *(https://dmmc.uk.gov.in)*.

Sl. No.	District	Development Blocks Covered	Nyayaa Panchayat Covered
1	Pithoragarh	08	65
2	Almora	11	65
3	Bageshwar	03	35
4	Uttarkashi	06	61
5	Chamoli	09	61
6	Rudrapryag	03	46
7	TehriGarhwal	09	78
8	Nainital	07	31
9	Champawat	04	14
10	Pauri	15	109
11	Dehradun	02	17
	TOTAL	**77**	**582**

B.K. Maheshwari

Dr. B.K. Maheshwariis currently a Professor at Department of Earthquake Engineering, IIT Roorkee. He secured Bachelor's degree in civil engineering from MBM Engineering College, University of Jodhpur in 1992, Master's degree in earthquake engineering from University of Roorkee in 1994 and PhD in geotechnical earthquake engineering from Saitama University Japan in 1997.

Dr.Maheshwari worked for about two years in industry in Tokyo, Japan and then joined Washington University in St. Louis, Missouri, USA as a post-doctoral fellow where he worked independently on a research project and taught a number of courses.

After a rich overseas experience of research, teaching and industry he moved to India in 2003 and joined BITS Pilani. He joined Department of Earthquake Engineering, IIT Roorkeein December 2004.

Dr. Maheshwari has more than 23 years of research experience and works in the field of dynamic soil-structure interaction, liquefaction, constitutive modeling, nonlinear finite element analysis and embankments. He has published more than 120 research articles including 40 papers in journals of international repute. He has supervised 08 PhD theses and 40 MTech dissertations.

Dr.Maheshwari has been awarded a Gold Medal from University of Roorkee, Monbusho Fellowship for PhD in Japan and EIT from Ohio State Board, USA. In view of his significant contribution to profession, he has been awarded IIT Roorkee's prestigious Shamsher Prakash Research Award for year 2009 for his outstanding work in the field of geotechnical earthquake engineering. He has been awarded "Excellent Research Contribution Award" of International Association of Computer Methods and Advances in Geomechanics(IACMAG) in Kyoto, Japan in year 2014.

Since February 2015, Professor Maheshwari is serving as Head, Centre of Excellence in Disaster Mitigation and Management, IIT Roorkee. He was part of delegation for India- Japan High-Level Policy Dialogue on Education led by MHRD secretary to Tokyo, Japan in July 2016.

Geotechnical issues during earthquakes in Uttarakhand

Lives and properties of hundreds of millions of people throughout the world are at a significant risk due to various disasters including earthquakes, landslides, floods, cyclones, droughts, tsunamis, fire and industrial disasters. The disasters have occurred from millions of years and may continue in future. However to mitigate the effects of disasters, it is necessary to understand that how a hazard is converted into a disaster. Our primary objective is to prevent from turning a hazard into a disaster.

Our country and particularly Uttarakhand is vulnerable to various disasters including earthquakes, landslides and floods. Geotechnical engineering plays a significant role during earthquakes and landslides particularly in hilly regions. Uttarakhand is seismically very active as it falls in zone IV and V. During earthquakes, there is a risk of ground failure, landslides (slope stability), liquefaction and failure of retaining walls, foundations and roads. To deal with these issues, knowledge of geotechnical earthquake engineering is necessary. In this lecture, this will be discussed in detail and remedial measures are suggested. Field evidence of geotechnical damages in past earthquakes e.g. Chamoli (1999), Bhuj (2001), Sikkim (2011) will be examined. Focus will be on seismic analysis of slope stability and retaining walls which are very important during earthquakes in hilly areas.

R. Jayangondaperumal

Having worked on active-faults and earthquakes of Basin and Range, Western United States through BOYSCAST Fellowship Dr. Perumal is a promising young scientist who was "Profussor Invitee" at the French National Centre for Scientific Research Lab (CNRS), Grenoble, France for six months and has been selected as one of the "Indian Scientific Delegates" to formulate international collaborative projects on active faults studies by the Department of Science and Technology, Government of India.

With his enthusiastic and young team Dr. Perumal has excavated about 30 trenches for paeloseismoligical studies along the Himalaya. His book on "Active tectonics of Kumaun and Garhwal Himalaya" is to be published soon by Springer. He has developed online-interactive active fault database for Uttarakhand state and is working on the characterization of active faults of Himalayan region.

Dr. Perumalhas demonstrated that great earthquakes transfer the convergence between southern Tibet and stable India along the MHT to the HFT in the Himalaya. He has also provided a chronology of earthquakes in the Himalayan region during the past two millennia. This study is now an important input parameter for seismic hazard assessment and has major bearing on the safety of the Himalayan foothills.

Primary surface rupture of 1344 AD Great Earthquake along Garhwal and Kumaun Himalayan front♣

About one hundred thousand lives have been lost due to large earthquakes in the Himalaya during the past one hundred years. These have been causedby ongoing crustal collision between Eurasia and the Indian subcontinent that has produced a thrust fault system. The Himalayan region accommodates a share of the strain associated with convergence. The foremost fault of a thrust system is the Himalayan Frontal Thrust (HFT), also referred to as the Main Frontal Thrust (MFT).

Discrete segments of the HFT that lies on the mountain front (i.e. junction between mountain and Indo-Gangetic plain) have produced numerous, large-magnitude earthquakes throughout the previous two centuries that are constrained through instrumental and historical records. The loss of lives and property can be minimised through the intervention of improved construction technology and incorporating appropriate building code.

The Himalayan region is undergoing fast economic development on a large scale in the areas of hydroelectric power generation, building of highways including tunnels, tourism infrastructure and other societal projects. It is in these types of infrastructure creation projects that the active fault studies including mapping and characterization of a fault scarp using paleoseismological investigation assume importance.

Here I compile recent, paleoseismological findings from seven published trench sites into a coherent OxCal age model for large-magnitude ruptures along the Central Seismic Gap (CSG), which extends from North-Central India into Western Nepal. The results indicate that the western half of the CSG (Kumaun and Garhwal Himalaya) likely ruptured in the event corresponding to historical accounts of an earthquake in 1344 CE. For the western section of the CSG in India, a model suggests rupture in the earthquake of 1344 CE, with no subsequent large-scale rupture in the last 672 years, reinforcing the concern for an impending large-magnitude event which would be catastrophic for nearby populations.

♣ *This paper is co-authored by V. Joevivek, Rao Singh Priyanka and V. C. Thakur*

Ila Patnaik

Professor at National Institute of Public Finance and Policy, New Delhi Dr. Ila Patnaik has served as Principal Economic Advisor to the Government of India. She is a regular columnist at the Indian Express and is a former non-resident Senior Associate at Carnegie Endowment for International Peace. She holds a BA (Economics) from Delhi University, an MA (Economics) from Jawaharlal Nehru University and a Ph.D (Economics) from the University of Surrey. Her research interests include international macroeconomics, finance and emerging economy business cycles. She has served on various working groups and task forces of the government of India. She is currently Member of the Task Force for setting up a coalition for disaster resilient infrastructure.

Financing disaster resilient infrastructure

Ensuring that we build infrastructure that is resilient in the event of natural disasters, and that does not create the downstream risks, needs to be an important element of India's development strategy. This paper would address some of the challenges related to financing of such resilient infrastructure. The first question would be how can the country pay for additional upfront costs, if any, for making the infrastructure resilient. As bulk of the expenditure on infrastructure is undertaken by government, this might involve creationof a clear framework for disaster mitigation fund. Second, limitations of state capacity imply that monitoring mechanisms would have to be created to ensure that projects meet the required specified material and design standards to be resilient. This role can sometimes be played well by insurance and reinsurance companies who might be called upon to insure projects. Insurance companies often develop monitoring capacity as these have the incentive to make sure that risk to the project is reduced. Third, even after infrastructure is made resilient, there always exists a residual risk of its being damaged in the event of a disaster.

To be able to recover quickly and minimise the loss to lives and livelihoods, is another element of resilience. For this purpose, especially for the immediate liquidity needs post-disaster, the government has to decide whether to hold the risk to itself or to transfer it. It has to choose between budgetary allocation, insurance, catastrophe bonds, contingent lines and other such instruments. In the next two decades India would have built the biggest share of infrastructure in the world. It is therefore important to start addressing these issues.

G. Satish Raju

G. Satish Raju is Head-South Asia, Global Partnerships, Swiss Re, based in Mumbai. His current role focusses on disaster-risk financing solutions for the public sector including state governments. Satish has earlier undertaken various client management and underwriting roles, since joining Swiss Re in 2001.

His prior work experience includes stints with ICICI in project finance, and with Kvaerner and Total India in the oil and gas sector. Satish graduated in Chemical Engineering from IIT Kharagpur in 1988 and in Management from IIM Ahmedabad in 1990.

Risk transfer for DRR

Comprehensive disaster risk management requires inclusion of a financing plan to deal with emergency response costs and rebuilding in the aftermath of disasters. Disaster relief funds often do not provide for long-term restoration of damaged infrastructure; and availability of emergency aid funding can be unpredictable. Disaster risk financing, in particularly risk transfer into insurance markets, optimizes the cost and accelerates the availability of post-disaster funding without compromising on development goals and fiscal stability. Many countries at both the Federal and Provincial level have instituted risk transfer facilities in recent years. An enabling framework in India which allows state governments the flexibility to use risk transfer to complement existing government relief funding, and thereby strengthen fiscal resilience to natural disasters, would contribute to a robust disaster risk management framework.

Kishor Kumar

Dr. Kishor Kumar, graduated from HNB Garhwal University, Srinagar in 1982, did his PhD from Russian State Geological Prospecting University, Moscow, Russia in the year 1991. Prior to joining his PhD in the year 1986 he was involved in R&D studies on various aspects of Disaster Management particularly landslide hazard and risk assessment in Himalayan terrain at CSIR-Central Building Research Institute (CBRI), Roorkee. He has joined CSIR-Central Road Research Institute (CRRI), New Delhi in the year 1992. He is a lead Scientist, at CSIR-CRRI, in the field of landslide hazard mitigation and management. Earlier, he has been heading the Natural Hazard and Risk Management group and also been Adviser and Head of Geotechnical Engineering Area of CSIR-CRRI. He was Designated as a professor of the Academy of Scientific and Innovative Research (AcSIR) in the Faculty of Engineering Sciences.

He has in his credit more than 30 R&D and consultancy reports, over 90 research papers in International/National journals/conferences. He is the member of many professional international/national bodies and technical committees like NDMA, IRC, BIS, ISRMTT and others. He was also elected as one of the member of International Technical committee on Engineering Practice of Risk Assessment and Management for the year 2011-2013 from India for TC-304 under the framework of ISSMGE (International Society of Soil Mechanics and Geotechnical Engineering). A few of his articles have also been awarded as best articles. He is a current member of the Scientific Advisory Committee of GB Pant Institute of Himalayan Environment and Development.

Dr Kumar has over 30 years of experience working on landslides all over the country. He has been involved in the studies of some of the most typical landslides in Uttarakhand like , Kaliasaur, Patalganga, Ukhimath, Malpa, Lambagar and many others.

Highway Slope Management - Key to Disaster Resilient Highway Infrastructure

The Himalaya, which spans over five countries namely India, Nepal, Bhutan, China and Pakistan have, for ages, been considered safer, peaceful, pleasant, treasure of unique floral and faunal wealth, hub of tourist attraction and the generous human population etc. are gradually turning hostile, unsafe and environmentally less protected sites. The biggest contribution to this overturning situation, apart from dynamic and fragile geo-environmental conditions of the region, is shared by humans itself. For last few decades, the Himalayan hills have become victim of frequent and widespread geohazards like landslides, floods, cloudburst and like phenomena to the extent that not only distracting people to visit here but also forcing inhabitants to migrate from their homes to new shelters far away in safer places.

The Himalayan slopes are the mixture of planar valley slopes, the colluvial slopes, the Rock slopes, the quaternary overburden slopes, thereby, combination of all form of slope profiles with unique ecosystem enriched with varied vegetation cover, water and mineral resources. Himalayan slopes which are considered to be at critical factor of safety result into numerous mass movements like landslide, rock fall, debris flow, avalanches etc. ranging from miner incidences to the extreme events when cut and kept unmaintained through numerous kinds of human activities like construction of hydro power, dams, tunnels, roads, irrigation facilities etc. The existing highways, across the fragile Himalayan terrain including Uttarakhand face severe landslide problems mostly during monsoon on recurring basis. These landslides have often climaxed in catastrophes such as Alaknanda event of July 1970, Malpa event of 1998 and 2017 and Kedarnath tragedy of 16-17 June 2013. While we address the existing landslide problems, the ongoing and proposed development projects are fast adding to their numbers. For example, the 900km Chardham highway development project, an ambitious initiative to improve connectivity to the Chardham pilgrimage center has been launched.

The Himalaya, including Uttarakhand are dynamic and still in immature stage and represent weak geological formations characterized by the presence of major regional dislocations, faults, mylonitised shear zones, large scale folds, jointed and fractured rocks with large steep slopes, V shaped valleys, high relief and vertical escarpments, make the region more vulnerable to not only landslides but to earthquakes and floods too. The irony is that, both earthquake and flood in turn feed the fury of landslides on our hill roads hampering rescue and relief operation, as experienced in several instances in the past. Seismically, Uttarakhand is one of the most active areas, witnessed over 35 events of larger magnitude (+5 in Richter scale) in the recorded history of about one and a half-century. In the last century, this region has experienced four major earthquakes measuring above 8 in the Richter Scale besides a number of moderate magnitude earthquakes including the recent Uttarkashi Earthquake (1991) and Chamoli Earthquake (2001) of the magnitude 6.6 and 6.8. Every time such seismic events recur they shatter the area and make it vulnerable to seismogenic landslides, but the vital consideration is generally missed out and no further research on earthquake induced or earthquake triggered landslides in done. As the highway slopes are generally left unmaintained after the construction of highways, mass wasting in the form of landslide and like process on the slope accelerates. The climate change in recent years has also uncovered some new slopes of which the vulnerability was not known so far; their sudden failure results in damage or blockade of highways at many locations resulting in huge loss of revenue on direct and indirect expenditures together with the hardship and threat to loss of life of the commuters.

The frequency of landslide occurrence/recurrence on highways is so high that the administrations generally find themselves helpless in addressing the issues, not speaking about the rehabilitation and short-term/ long-term mitigation/ management planning. The most disturbing fact is that the phenomena keeps repeating every year and the costs of restoration works increase exorbitantly high and even the best constructed highways keep suffering from onslaught of landslides. In spite of the modern technology of the highest level available the highways in this part continue to suffer uninterruptedly. This situation indicates towards the gaps in addressing the issues in holistic perspective right from planning of highway, selection of its alignment, construction and maintenance. What is more important to understand that the highway does not fail itself but due to landslides which are directly connected to the highway slopes. Therefore, the failure to lessen the problem of landslides on highways is not solely due to highway construction but due to the failure to recognize the highway slopes as part of road management. A proper, well thought Highway Slope Management System will serve the purpose of identification and classification of each highway slopes with respect to the degree of vulnerability based on in-depth scientific study of numerous parameters using amalgamation of geospatial technologies and ground based methods followed by the detailed account of each slope for the need of their upkeep together with the highways. The Socioeconomic and environmental challenges posed by lack of strategy or policy on slope management and mitigation require to be addressed emphatically for sustainable highway operation. This talk will focus on the need of policy makeover on highways slope management in Himalaya.

Girish Chandra Joshi

With doctoral degree in earthquake engineering from IIT Roorkee Dr. Girish Chandra Joshi is presently working as Deputy Program Manager in the Capacity Building and Technical Assistance component of the World Bank funded Uttarakhand Disaster Recovery Project. Prior to this Dr. Joshi has served at Disaster Mitigation and Management Centre and THDC Institute of Hydropower Engineering and Technology. Dr. Joshi has to his credit a number of research papers and reports, particularly in the field of seismic vulnerability assessment.

Rapid visual screening of public buildings in Uttarakhand[♣]

Continued subduction of the Indian Plate beneath the Eurasian Plate consumed the intervening oceanic plate and led to the collision of the alien landmasses. This was accompanied by and led to deformation, upliftment, metamorphism and shearing of the intervening sediments. Himalaya has been seismically active and has witnessed great earthquakes besides Uttarkashi, Chamoli, Kashmir, Sikkim and Nepal earthquakes. Falling in seismic gap of 1905 and 1934 Great earthquakes the state of Uttarakhand is identified as a potential site for a future catastrophic earthquake. Assessment of the vulnerability and retrofitting of the built environment is therefore important for planning and undertaking seismic risk reduction exercise.

Rapid Visual Screening (RVS) survey of identified important public buildings was therefore undertaken to evaluate their present condition together with necessary retrofitting techniques to be applied for ensuring safety of these in the event of a damaging earthquakes. The screening was done on Code based seismic intensity, building type and damageability grade as observed in previous earthquakes and covered under MSK/EMS 98 and experience gained in India.

A total of 11239 public buildings were thus surveyed using RVS which accounts to 25-30 percent of the total public buildings in the Uttarakhand. The surveyed public buildings are categorized into 6 types based on their departmental affinity/utility; education, health, fire station, police station, administration, and others that include cooperative banks, sales tax department, civic works (public works, agriculture, irrigation, power, forest). Around 36 percent health buildings, 18 percent administrative buildings, 23 percent school buildings, 60 percent police stations and 67 percent fire stations of the total respective buildings in the state have been surveyed.

[♣] *This paper is co-authored byRanu Chauhan andShaileshGhildiyal*

Individual buildings have further been categorised according to their construction type; RC frame buildings with unreinforced masonry infill walls (Type- C), unreinforced masonry (Type- B) and RR masonry (Type-A).Approximately 20 percentof the buildings are observed to be RCC and of the masonry buildings (80 percent) 25-30 percent are observed to be random rubble masonry type.

Qualitative assessment of buildings shows that almost all Type-A houses are vulnerable and only 1-2 percent Type-B buildings and64 percent Type-C buildings are safe. The assessment also reveals other vulnerability factors that include overhang (76 percent), pounding (26 percent), asymmetry in plan (36 percent), irregularity in elevation (5 percent), re-entrant corners (11 percent), distressed and damaged (> 50 percent) and low construction quality (37 percent). The non-structural members like cladding, ceiling, improper anchorage and thin parapet wall are deduced to pose falling hazard in almost all the structures. Hence all vulnerable buildings require detailed investigations; seismic vulnerability assessment (SVA) and detailed vulnerability assessmenton their seismic resistance.

Seismic vulnerability of Mussoorie and Nainital: Two Lesser Himalayan tourist destinations

1. Both are located in Lesser Himalaya in close proximity of Main Boundary Thrust (MBT).
2. Both were developed during British rule; first habitation in Mussoorie around 1836 and in Nainital around 1841.
3. Both were first to be electrified; Mussoorie in 1907 from Galogi and Nainital in 1922 from Durgapur.
4. Both had well organised local bodies (Municipalities).
5. Both have comparable population; Mussoorie 30,118 and Nainital41,377.

Both have large floating population of tourists and students.

- 3344 buildings in Mussoorie and 2865 in Nainital surveyed using rapid visual screening (RVS) technique.
- 282 surveyed buildings in Mussoorie and 487 in Nainital are constructed in pre – 1900 period.
- Most surveyed buildings are low rise; 1,135 in Mussoorie and 950 in Nainital are single storeyed. 30 in Mussoorie and 13 in Nainital are however more than five storeyed.
- Most construction (94 percent) is unconfined rubble masonry (URM); mostly stone and brick masonry with slate / CGI roofing.
- 18 percent of the surveyed buildings in Mussoorie and 14 percent in Nainital fall in the highest damage class, Grade 5 damage, in case of seismic intensity reaching VIII on MSK scale. Most buildings falling in this damage class are observed to be constructed in pre – 1951 phase.
- 16 percent of the surveyed single storeyed buildings in Mussoorie and 6 percent in Nainital fall in the highest damage class.
- 27 percent of more than three storeyed buildings in Mussoorie and 48 percent in Nainital fall in this damage class.
- Total built up area of the structures falling in Grade 5 damage class in Mussoorie and Nainital is 2,96,974 m^2 and 1,17,613 m^2 respectively.
- At the standard rate of US$ 108 per m^2 the replacement cost of these buildings is estimated to be US$ 32.07 and US$ 12.66 million respectively.
- Contents worth US$ 20.40 and US$ 8.74 million respectively would be lost in these structures in the two cities.

Piyoosh Rautela

Alumni of the University of Allahabad Piyoosh Rautela is an Earth Scientist by basic training. With a flair of writing, particularly in vernacular, Dr. Rautela has contributed significantly to the development of IEC material for mass awareness and has to his credit a number of books, reports, research papers and popular articles.

He has been associated with Disaster Mitigation and Management Centre since 2002 and is presently serving there as Executive Director (2006 onwards). Prior to this Dr. Rautela has worked with Wadia Institute of Himalayan Geology, Indian Institute of Remote Sensing and Asian Disaster Preparedness Centre.

Tradition of earthquake safe construction in Uttarakhand Himalaya

Despite often experiencing earthquakes (*chalak* in local parlance) multi-storeyed houses are common in Uttarakhand and apart from the cattle sheds (*chani* in local parlance) one can hardly locate a single storeyed traditional house in the region. Moreover, both the dialects of the region have distinct words for four different floors of the house; *ghot*, *chak*, *pan* and *chaj*in Kumauni and *koti*, *manjua*, *baund* and *baurar*in Garhwali. This indicates common occurrence of multi-storeyed houses in the region. In Yamuna and Bhagirathi valleys four to five storied traditional structures identified as *chaukhat* (four storeyed) and *panchapura* (five storeyed) can still be observed.

In depth investigations of the traditional structures suggest that the people had developed understanding of the fundamental premise of earthquake safety, i.e. ensuring safety of structures during an earthquake event. Utilizing accumulated knowledge and experimenting with locally available building material, the people of the region thus evolved a unique architectural style that exhibits structural evolution trends whereby dry-stone masonry, as also stone–lime/mud/clay mortar masonry is judiciously used with abundantly available wood to provide appropriate strength and flexibility to the structures. Traditional architecture of the region is thus based upon five fundamental rules for ensuring safety of the built environment that were evolved and propagated by the people of this region.

1. Safe siting: Despite both agricultural land and water being located on middle and lower hill slopes people traditionally settled down over stable and firm ground at a higher location. This was part of a well thought of strategy to ward off losses due to floods and landslides that have much higher frequency than earthquakes. This at the same time minimised ground acceleration and thus losses during an earthquake event.

Moreover, the location of structures was finalised only after getting the soil of the site examined by some identified persons who, based upon experience and accumulated knowledge of generations, had mastered this art of commenting on site suitability on the basis of physical examination of various aspects of the soil of the proposed construction site that include texture, granularity, colour, composition, presence of humus, moisture and the like.

2. ***Firm foundation:*** Foundation trench was generally dug until firm ground or in situ rocks were reached. There was also tradition of leaving the foundation trench open for some rainy seasons which ensured ground settlement and kept the structures free of settlement cracks.

Tall buildings were specifically constructed on raised and elaborate stone filled solid platforms that were continuation of filled in foundation trench above the ground. At places where in situ rocks were exposed the platform was raised directly over these. The height of such platforms constructed using dry-stone masonry is observed to vary between 6 and 12 feet above the ground. Massive solid platform at the base of the structure ensured centre of gravity and centre of mass of the structure to remain in close proximity and close to the ground. This minimised overturning effect of the particularly tall structure during seismic loading.

3. ***Robust plan:*** Simplicity of structures is an essential attribute of safe construction and buildings in this region were traditionally constructed on a simple rectangular or square plan with length and width varying between 4 and 8 meters. The ratio of the two sides of the structures is observed to vary between 1.1 and 1.4. The height of the structures above the platform is also observed to be restricted to double the length of the shorter side (length or width). This is in keeping with the provisions of the building codes that suggest that the building should have a simple rectangular plan and should be symmetrical both with respect to mass and rigidity so as to minimize torsion and stress concentration.

Openings in the walls reduce structural strength and therefore reinforcement is often resorted to around these. Most traditional houses of the region have single small entry and relatively small openings. Doors and windows in these houses are few and small and symmetrically placed away from the corners. Strong wooden empanelment is also provided around all the openings to compensate for the loss of strength.

4. ***Appropriate joints*:** Experimenting with the precepts of seismic safety the people of this region mastered the art of meticulously using locally available wood and stone pieces of different shapes and sizes for the construction of the walls of the houses in a manner that improved their seismic performance. Particular care was thus taken in the placement of through stones and corner stones.

Provision of wooden beams was generally provided in all the traditional structures. Both housing and nailing techniques were resorted to for joining the wooden components incorporated in these structures. This allowed for minimal angular displacement and had advantages of both pin joint and rigid joint. This acted as a semi rigid joint that was an additional advantage for shock resistance.

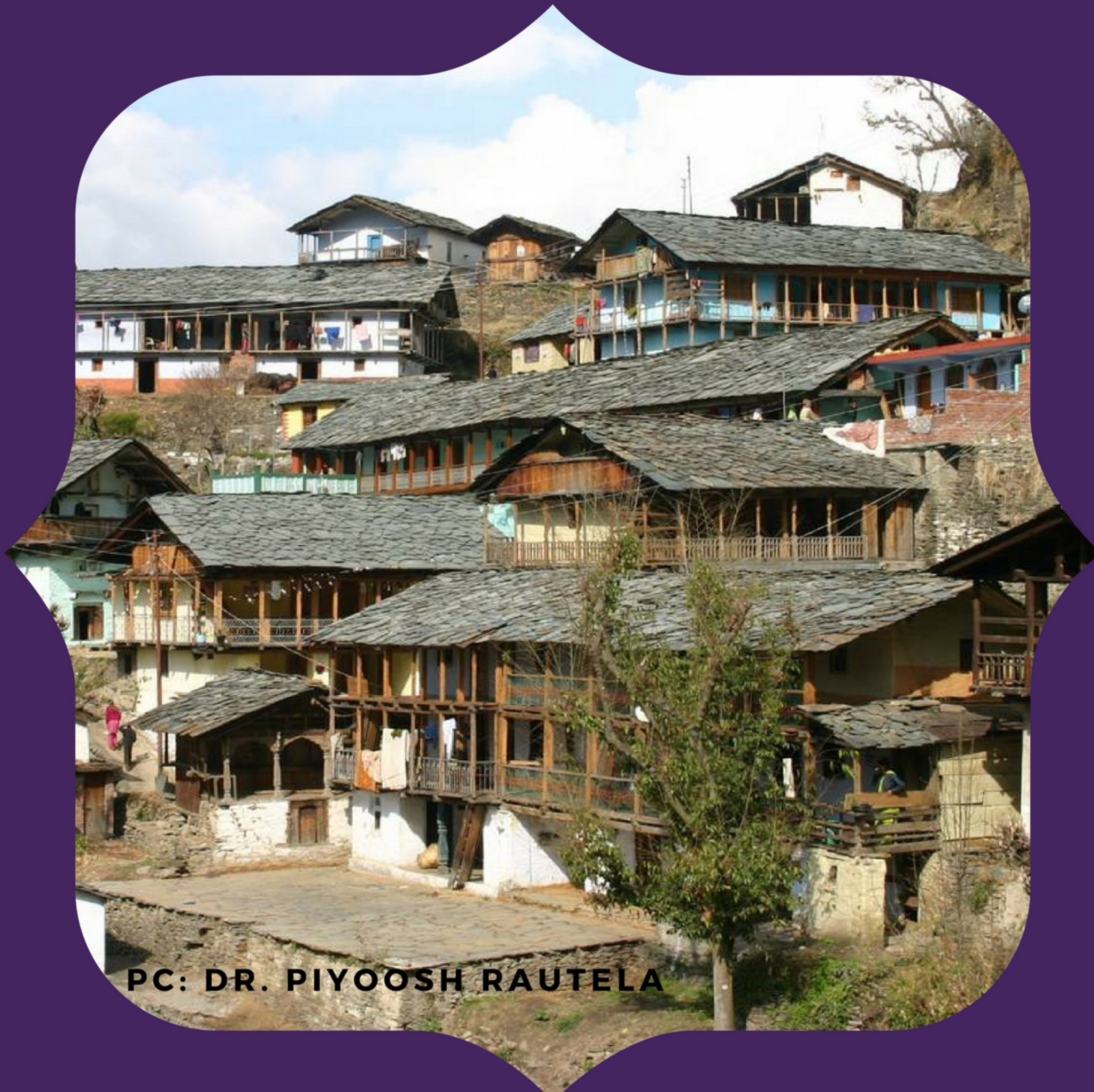
5. ***Smooth dispersal of seismic forces*:** The art of raising walls of traditional multi-storeyed structures was particularly elaborate. These were raised by placing double wooden logs horizontally on the edge of two parallel sides of the platform. The thickness of the walls was determined by the width of the logs. The other two walls were raised with well-dressed flat stones to the level of the logs placed on the other two sides. The walls were further raised by placing heavy, flat, dressed stones upon the wooden logs on the two sides and by placing another pair of wooden logs upon the stones on the other two opposite sides.

The four walls of the structure were thus raised using the wooden logs and dressed up flat stones alternately. Edges of the pair of logs on the adjacent walls were joined together by hammering thick wooden nails at the corners. This turned the structure into a single piece construction.

The structure was further reinforced with the help of wooden beams fixed alternately running from the middle of the walls of one side to the other, intersecting at the center. This arrangement divided the structure into four parts and provided for joists supporting the floor boards in each floor of the building. This resulted in a mixed structure with two types of load sharing mechanisms where vertical load was taken care of by thick walls running in all the four directions, while horizontal load was taken care of by interconnected wooden joists running in both directions.

On the two sides of the structure wooden beams were often provided from outside. These beams inserted from above were shear keys that were part of a special provision to enhance structure's seismic performance.

Present state and way forward: High social status having been attached with new building material masses have lost interest in traditional construction practices and cement based construction has proliferated even to remote hilly areas. Unaccompanied by technical know-how related to new construction material, this is enhancing seismic vulnerability of the region. It is therefore warranted that besides training masons in the basics of using new building material, the precepts of traditional construction be suitably amalgamated with those of modern cement based construction and an appropriate construction practice suited to building material availability in the hills be evolved to put forth an economically viable, socially acceptable and earthquake resilient construction option for the masses.



उत्तराखण्ड शासन

Uttarakhand State Disaster Management Authority, Government of Uttarakhand