Lessons from 1st May 2013 Doda (India) Earthquake Reiterate Urgent Need to Mitigate Seismic Risk

– C.V.R. Murty[1], Ajay Chourasia[2], Hari Kumar [3], Anup Karanth[4] and Pradeep Kumar R.[5]

ABSTRACT

The Doda Earthquake of 1st May 2013 at 12:27 Hrs. (IST) hit border region of two states of India (Jammu & Kashmir and Himachal Pradesh) (Mw= 5.8). This paper describes the findings of the 5-day post-earthquake reconnaissance survey undertaken in the affected areas with particular emphasis onbuilding typology, construction materials and construction practices. Post-earthquake damage assessment of the built environment suggests that recently built structures do not have adequateearthquake resistant featuresto resist severe earthquake shaking (of about IX on MSK scale) expected in the region. On the other hand, traditional constructions with good earthquake resistant features performed much better.The maximum intensity of shaking during the said event was only about VI on MSK scale, and the damage was less. But, the type of damage suggests that huge losses can be incurred in the region during a future earthquake of higher intensity, if the built environment is not retrofitted.

Keywords: *Doda earthquake, reconnaissance survey, construction materials, construction practices, building typology, seismic risk mitigation*

1 Department of Civil Engineering, Indian Institute of Technology Madras, Tamil Nadu.
2 Sr. Scientist, Central Building Research Institute, CBRI, Roorkee, Uttrakhand.
3 Geohazards Society, 71, B Floor, Vinobapuri, Lajpat Nagar-II
4 Associate Director,TARU Leading Edge, Gurgaon, India
5 International Institute of Information Technology, Hyderabad, India

Introduction

An M5.8 earthquake occurred on 1stMay 2013 at 12:27 hours IST. As per the report of India Meteorological Department (IMD), the epicentre was located at latitude 33.1°N and longitude 75.8°E which is about 17 km NE of Bhadarwah town in J&K state near the border of the states of Jammu & Kashmir (J&K) and Himachal Pradesh. The earthquake was a shallow-focus event (focal depth 15 km) with ground shaking lasting for about 40 seconds in the epicentral region and it was felt across north India. One death was reported in J&K state after this event due to rolling boulders. And, it was claimed that about 25,000 houses declared to be partially, severely or fully damaged. The Himalayan region in the Indian subcontinent is seismically active due to continental collision of the Indian and Eurasian plates, with the Indian Plate subducting under the Eurasian Plate[Valdiya, 1964]. In the past, the J&K region of the Himalayas has faced many earthquakes of M>7 of which 1770 Srinagar Earthquake (M7.7) and 2005 Muzaffarabad Earthquake(M7.6) are the largest documented events. M_w5.8 event of 1 May 2013 was relatively a smaller event in comparison. As per IMD report, this earthquake was followed by four aftershock events of magnitudes 3.7, 4.6, 3.7 and 3.5 till 5thMay 2013, and eleven aftershock events of magnitude 3+ till June 2013.

The presentpaper provides insights into the effects of the earthquake on the built environmentwith particular reference to the traditional construction practices (Dhajji-dewari houses), unreinforced masonry with burnt clay bricks/stones in mud/cement mortar, RC buildings, and important facilities like schools, hospitals and lifelines and highlights the initial important observations. Lessons learnt from the damage assessment of different building infrastructures due to this event provide answers to some of the important questions leading to reduce theearthquake risk in future earthquake scenarioand also propose a road-map to reduce ever increasing seismic vulnerability of the region.

The Earthquake

The earthquake was centered about 17 km NE of Bhadarwah (Doda District of J&K, India) caused a maximum intensity of shaking VI+ on the MSK scale, lasting about 40 seconds. The expected intensity of earthquake shaking as per the Indian Seismic Code (BIS 1893-2002) is about VIII in earthquake affected areas of Doda and Kishtwar districts (seismic zone IV). The event was recorded by strong motion accelerographs at 11 stations (http://pesmos.in/2013/) (Figure 1). The acceleration time histories of the station closest to epicenter, *i.e.*, Chamba, recorded the maximum peak ground acceleration (PGA) of 0.015g (Figure 2). The pseudo-acceleration, velocity and displacement response spectra of the recorded ground motion time history at Chamba station are also shown in Figure 2. The acceleration response spectra at Chamba station suggest that the input energy is the largest for short period structures (namely stiff structures, such as low-rise unreinforced masonry (URM) load-bearing and RC frames with URM infill walls). Thus, even though the recorded PGA is much smaller than the design acceleration; hence, reasonably significant damage to built environment in the current event reflects the vulnerability of the region.

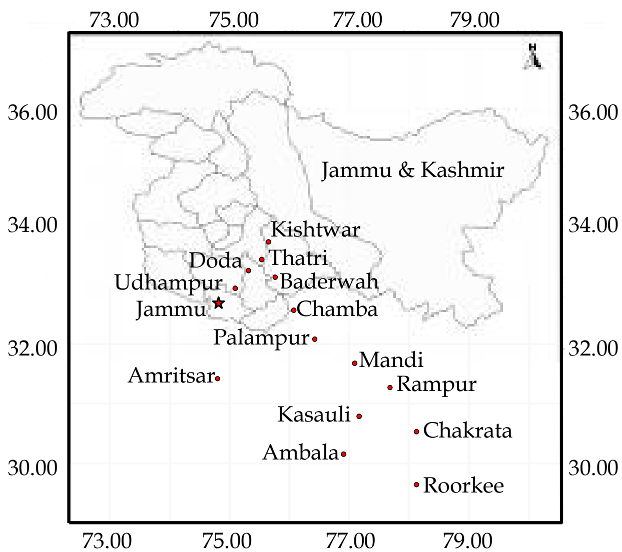


Figure 1: Location of 11 strong motion accelerograph stations operated by Department of Earthquake Engineering, IIT Roorkee, India around the area affected by the 01 May 2013 event

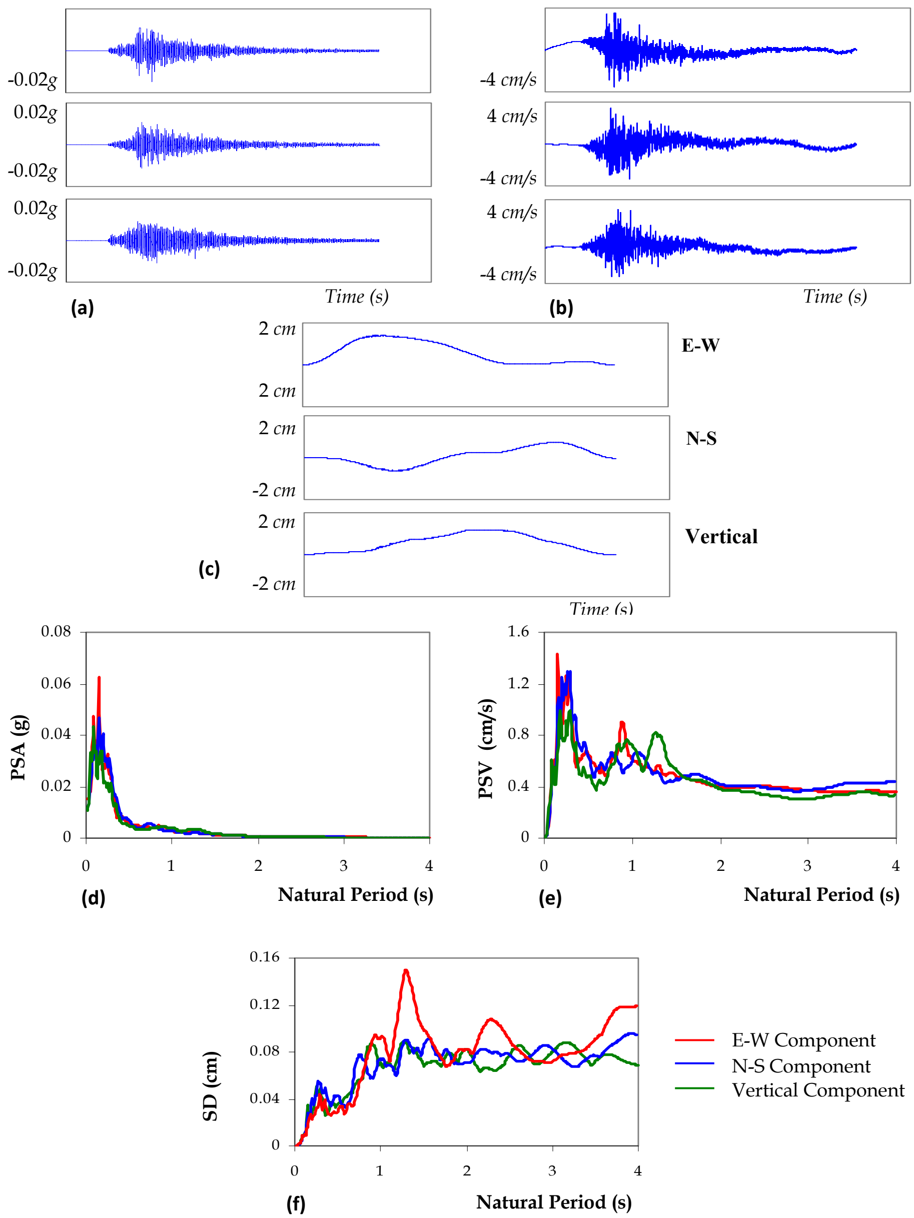


Figure 2: Ground Motion Time Histories at Chamba Station, closest to epicentral region (a) acceleration, (b) velocity, (c) displacement; and corresponding (d) pseudo-acceleration, (e) velocity and (f) displacement response spectra

Performance of Built Environment

The landscape of Doda town shows settlements on both hill slopes and river terraces (Figure 3) andthis is typical of most of the other towns nearby(like Gandoh and Premnagar). These hill slopes and river terraces are composed of heterogeneous materials – highly weathered sandstone rock, some granite outcrops, rounded to angular but smooth river boulders, cobbles, gravel, sand, silt, clay and other suspended matters that have been collected over centuries in the river terraces and hill slopes. For this reason, the ground shaking is not necessarily uniform all through the affected area. Another prominent feature of development in the area is the same constructiontypes is followed in the valley as well as on the steep hill slopes. In general, houses built along the rim of river terraces have showed signs of settlement, while houses on the flat land seemingly had no such foundation damage; and houses founded on soft soils in towns of valley areas (like Kishtwar town), vertical cracks were visible in foundation arising from the soil.

(a) (b) (c)

Figure 3: Ariel views showing dense development on hill slopes/river terraces (a) Doda (b) Gandoh (c) Premnagar town

Housing

In general, damage to buildings in the affected area was limited to poorly built houses. The pointers inidentifying poorly built houses include: (a) weak construction material, (b) informal construction practices with incremental changes made over time with different materials and styles of construction, (c) absence of earthquake-resistant features, and (d) significant vertical irregularities largely attributed to slopingground and floors meeting the ground at different levels, causing earthquake shaking input to the building at multiple floor levels; this causes excessive damage especially when the structure has features (a)-(c) mentioned above. Typical housing in Doda and Kishtwar districts of J&K state are 1 or 2-storeyed in the hills and up to 4-5 storeyedin town areas. Structural systems practiced in the region include: (i) Dhajji-Dewari houses; (ii) Unreinforced masonry (URM) with burnt clay bricks and mud/cement mortar; (iii) URM with stone and mud/cement mortar; and a few

(iv) Reinforced Concrete (RC) Moment Resisting Framedbuildings with URM infill walls. Some constructions are of hybrid type, *i.e.,* combination of two or more above systems.

Dhajji-Dewari Houses

This traditional Dhajji-Dewari style of building construction utilizes wood frame with burnt clay brick or stone masonry wall panels in-filled in the bays created by the wood members (Figure 4) and hasmaximum upto 4 storeys. Typically, the foundation and in some cases even plinth is made up of random rubble stone masonry. Walls in all storeys are made up of wood frame (consisting of horizontal, vertical and diagonal wooden members). The roof was originally made up of wood planks topped with mud. A typical floor is made of wooden joist (100x150 mm) placed at 400 mm centers. Over these joists, 25 mm thick wooden planks are laid, which in turn is topped with 50 mm thick stone chips. The final course is either a mud or cement concrete flooring of 125mm thickness. And, the typical roof has the same configuration as mentioned above for floors, with mud topping of 200-300 mm thickness. But, in recent times, roofs are made up of corrugated GI sheets over timber trusses resting on the wood wall plates atop the stone/brick walls.

(a) (b)

Figure 4: Variant of Dhajji-Dewari Houses: (a) without diagonal wood members, and (b) with no Dhajji (wood frame) in the ground storey

This is a housing typology with excellent earthquake-resistant features in which the traditional wisdom has been embedded gradually over centuries asearthquake disasters have been perennial concern for people living in the Himalayan region. The well builtDhajji-Dewari construction performed exceptionally well during the earthquake. But, over time, the traditional knowledge may not be completely efficient, when the modern construction has become an aspiration of the larger populace. Seismic deficiencies, identified in the recent editions of this typology, include large openings; large size rooms; tall storey; poor connections between foundation andwalls, wall towall and walls-to roof; absence of continuous plinth, sill and lintel bands; loosely packed infill masonry; low strength mud mortar, and heavy roof.

URM Houses with Burnt Clay Bricks and Mud/Cement Mortar

Use of URM with burnt clay brick upto 3-4 storeys are on the rise in Doda and Kishtwar districts (Figure 5).

(a) **(b)**

Figure 5: Brick masonry houses: (a) houses with RC floors did better even though they had no earthquake-resistant features like horizontal bands, and (b) houses with heavy wood floors did poorly; the walls dilated outwards in both plan directions and reduced the bearing of wood floors on the walls

Such houses are regular in plan constructed using poor strength of brick units with excessive mica content. Majority of construction are in mud mortar and with limited cement mortar of mix variationbetween 1:6 and 1:8 (by volume). In general, prominent deficiencies observed include (a) absence of horizontal bands and vertical reinforcing elements at wall corners; (b) absence of gable bands; (c) dilation of masonry walls at top floor due to lack of eaves band on which the roof is rested; (d) use of plain mud mortar in walls; (e) lack of complete roof truss; (f) excessively large opening in walls; (g) lack of reinforcement around door and window openings; (h) use of very heavy floors/roofs; (i) direct bearing of roof truss on the masonry walls, not adequately anchored into walls; (j) weakmasonry courses – all headers in one course, all stretchers in the other, resulting in joints not being staggered; and (k) outward bulging of walls at floor levels due to heavy wooden floors.

Unreinforced Masonry (URM)Houses with Stone and Mud/Cement Mortar

This is the most common housing construction type which are regular in plan, and mostly rectangular, and do not have any irregularities in elevation;constructed using random rubble type with slate stones (Figure 6). River boulders, angularly broken stone or semi-dressed stone (on the outside face); in rare exceptions, dressed stone load bearing masonry was also noticed.

(a) (b)

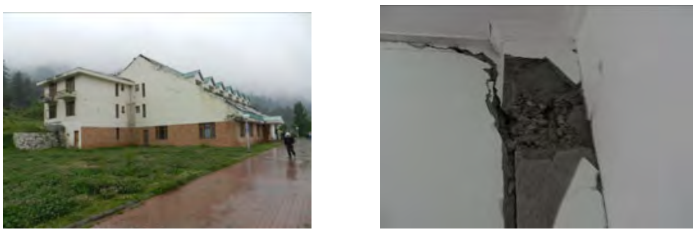
Figure 6: (a) Two-storey stone masonry house with basic earthquake-resistant features of seismic bands MISSING, and (b) Two-storey stone hybrid masonry house (with Dhajji-Dewari system adopted in upper elevations) but no earthquake-resistant features in lower storeys

This housing typology has good architectural design from earthquake safety point of view, but poor structural characteristics. The limited negative architectural features include adjacency and pounding; re-entrant corner; and mismatch of floor and roof levels. The main structural deficiencies include:(a) no use of through-stones leading to independent two leafs of stone masonry walls; (b) Inadequate or no connectivity of two perpendicular walls at intersections; (c) stone masonry is not dressed, but outside surface is ensured to be plumb; half dressed stones with pyramidal shape are prone to rotating outwards; (d) no bands are at any level; cut lintels in wood are used over openings

in walls; (e) weak mortar mix; (f) large mass, especially concentration of large mass at roof level of the building when heavy slate roofs are employed; and (g) poor connections between foundation-and-wall, wall-and-wall and wall-and-roof.

RC Buildings

RC buildings are becoming increasingly popular in the area. Most of these buildings are non-engineered, built on steep slopes, very close to each other. The buildings are up to 6-storeyed in the Doda town with a storey height of 3m, wherein 3-4 storeys are below ground level or otherwise buildings are constructed over slopingland connected at multiple (~2.7 m verticals) levels. Mostly the building seems to be constructed for gravity loads and no provision is made to resist lateral loads. The RC column with dimension 200×300mm with nominal reinforcement, lapped at beam-column junction, absence of seismic detailing and cast in poor grade of concrete is prevalent in the region. The RC frame is provided with brick laid in cement sand mortar as infill units. The column grid is generally closely spaced (around 3.0-4.5 m) with high degree of plan and vertical irregularitiesdue to excessive cantilever projection, indiscriminate use of unsupported partition walls leading to inadequate load path. Only a few buildings such as government, academic institution buildings may be categorised as engineered ones, *i.e.,* designed and constructed using prevalent codes and practices. The typical damage sustained by these RC buildings includes frame-infill separation, spalling of concrete at the top of the column (where concreting is poorly done and reinforcement detailing is such that there is extreme congestion of steel reinforcement) and cracking/falling of bathroom tiles, as observed in the yet-to-be commissioned Tourism Department Building (Figure 7). Similarly, damages are noticed in the newly constructed Sub-District Hospital buildings in Badarwah.



(a) **(b)**

Figure 7: (a) TRC building in Badarwah, (b) damage to column tops showing poor concrete and reinforcement detailing

School Buildings

Around 660 school buildings are reported to be damaged in Doda and Kishtwar districts due to earthquake to such an extent that they are abandoned and classes were held in tents. Most of the school buildings are 1-2 storiedconstructed using stone masonry in mud mortar and plastered using cement mortar, and most of which lags in earthquake resistant features, as discussed in preceding sections.

(a) **(b)** **(c)**

Figure 8: (a) Informal trusses rested directly on stone walls without any wall plates (at Gandoh), and (b) large stone gables not provided with gable bands and gable end trusses are not complete with bottom chord and vertical posts (at Bhalessa), and (c) falling of false ceiling due to poor anchorage

Figure 9: Wood frame single-storey school construction with brick masonry up to sill level and light roof

(a)

(b)

Figure 10: Transmission towers running across Doda and Kishtwar districts pass through difficult terrains: (a) soft soils, and (b) adjoining vertical cuts made for roads

Figure 11: Earthquake-induced landslide at Shalimar (Kishtwar) on National Highway

The injuries in these schools were also reported due to collapse of stone masonry gable wall, separation of walls at junctions, separation of wythes of walls, and falling of false ceiling due to poor anchorage (Figure 8).

But, there are also good examples of school buildings constructed using traditional constructions, in conformance with seismic resistant features;which can act as role-model for replication in future constructions (Figure 9).

Hospital Buildings

Hospitals are most critical facilities and are expected to be completely functional before, during and in the aftermath of earthquakes. However, most of the health facilities in Doda and Kishtwar districts, are of 2 storiedconstructionusing stone masonry in mud/cement mortar and recently constructed with RC frame structure and were damaged disproportionately even in small shaking thataffectedthe region. The causes of failure are similar as discussed in the preceding sections for URM in stone and RC structures.

Lifelines

The 132-KW high voltage transmission line of National Hydroelectric Power Corporation (NHPC) serves the districts of Doda and Kishtwar of J&K state. As such there was no loss in power transmission during or the aftermath of the earthquake, because there was no surface rupture due to the earthquake, which is normally expected in earthquakes with higher intensity of shaking. However, these transmission lines are founded on soft soil adjacent vertical cuts (Figure 10), which are vulnerable and may cause secondary hazard.

Roads are the only modes of transportation system constructed by freshly cut on the hill slopes, causing four earthquake induced massive landslides (Figure 11) in the region. These landslides are attributed to the geology and intense rainfall in the area. Further, the human intervention such as cutting for roads and embankments, excavation for buildings etc., adds instability toslopes extensively.

Lessons Learnt

The current trend of constructions is alarming, to say the least; there is no concept of earthquake resistance in the planning, design and construction strategies. The following are some major lessons learnt:

(1) Evaluation of landslide and rockfall potential and subsidence is essential in Doda and Kishtwar Districts, especially along critical roads and in areas withlarge population and built environment. Development of redundant road networks is critical in these vulnerable areas;

(2) Creation of a professional and regulated environment by Government of J&K for design and construction of new RC buildings is crucial in J&K state, if it has to be earthquake-resistant;

(3) Existing structures need to be assessed for earthquake safety in a prioritised and phased manner, especially because ~18,80,000 of the ~20,00,000 houses in the state are made of masonry, largely unreinforced. Thus, seismic retrofitting may benecessary.

(4) Partnership between Government of J&K, Archaeological Survey of India, and State Department of Archaeology, to plan and protect all cultural structures in state;

(5) Development of a Manual of Good Construction Practices on traditional Dhajji-Dewari construction;

(6) Dissemination of technical knowledge to professional architects and engineers in the state on the methodology for assessment and retrofittingof structures damaged during earthquakes;

(7) Development of a cadre of professionals, as part of Post-Earthquake Damage Assessment Teams, trained to have capabilities to provide sound judgement on usability of structures damaged during earthquake shaking;

(8) Prohibitany new unreinforced masonry constructions in J&K, and Retrofitexisting ones, especially critical, lifeline and governance structures with a sense of urgency, and rest in a phased manner;

(9) Documentation of all losses incurred due to damage occurredby non-structural elements, and dissemination of technical know-how to architects and engineers on methods of protecting non-structural elements in buildings and structures;

(10) Commission an investigation team to study thedetail reasons behind this loss of communication systems, and put in place systems to ensure no-blackout of communication systems in any area of the state during future earthquake events; and

(11) Encourage training of engineers each year in earthquake-resistant design and constructions; trained engineers advice all stakeholders in state on matters related to built environment.

Strategies for Risk Mitigation

Virtually, all lessons learnt from this *low-intensity earthquake* have been noticed after each of the past 10 damaging earthquakes in India, namely *1988 Bihar-Nepal* Earthquake, *1991 Uttarkashi* Earthquake, *1993 Killari* Earthquake, *1997 Jabalpur*

Earthquake, *1999 Chamoli* Earthquake, *2001 Bhuj* Earthquake, *2002 Diglipur* Earthquake, *2005 Kashmir* Earthquake, *2006 Sikkim* Earthquake and *2011 Sikkim* earthquake. The built environment does not have earthquake-resistant features and *no more earthquakes are required* to start the *tenuous* and *arduous* work in India of undertaking structural changes in governance of the country for (1)Creating the ethos for earthquake-resistant *education*, *training* and *research*, (2)Developing and enforcing *regulatory framework* to ensure compliance of earthquake-safety standards; and (3)Undertaking phased *seismic retrofitting* of at least the critical and lifeline buildings and structures.

Post-Earthquake Damage Assessment

A national program should be launched on *Post-Earthquake Damage Assessment*, to

(1) Develop *technical criteria* for post-earthquake damage assessment of different structures;

(2) Train *selected engineers and architects* in each state of the country in assessment of different typologies of that state with the help of specialists (within India and from abroad) with background to assess quickly the extent of damage and determine safety of buildings and structures for their continued use;

(3) Constitute *Post-Earthquake Damage Assessment Teams* (PEDATs) comprising of both engineers and architects;

(4) Accord legal status to *assessment criteria* and the *trained manpower to undertake the task*.

Competent technical teams should be deployed to study scientific aspects of the earthquake and their effects. Aspects to be studied include:

(1) Study of precise variation in intensity across the affected area;

(2) Study of geology of the hill slopes of affected areas that led to occurrence of landslides and affected the performance of roads along hill slopes, and give guidance on potential future slides and land use;

(3) Damages to critical and lifelines systems, e.g., bridges, water mains & reservoirs, electric supply, communication systems, schools and hospitals; and

(4) Damages to residential houses and buildings and other structures, in particular of the traditional Dhajji-Dewari constructions.

Intermediate Shelters

Urgent action is required for -

(1) Identifying acceptable engineering materials, technologies and architectural designs for construction of intermediate shelters. Also, inspiration should

be drawn from and confidence laid on traditional construction practices viz. Dhajji-Dewari Systems.

(2) Evidence based design guidelines for earthquake resistant features of these intermediate structures during the expected strong shaking.

Seismic Retrofitting

Based on the current construction practices, most of the existing structures are deficient in earthquake resistance, and demand seismic retrofitting, for which followings are suggested:

(1) Mandatory seismic retrofit should be undertaken for existing deficiencies incritical and lifeline structures.

(2) Arrangement for mobile retrofit camps or clinics with technical teams offering sound engineering advice to owners of private buildings and structures, which can be done at their own costs and consequences;

(3) Necessary legislation may have to be enforced to mandate retrofitting in at least government owned and rented structures; and

(4) Demonstration projects on seismic retrofit of existing structures of different typologies should be launched as a confidence building measure for the people, and the engineers.

Study of Housing Typologies and Guidelines for Good Construction Practices

Two prominent observations for improving the construction practices include:

(1) A large repository of good construction practices is already available related to the dominant construction typologies of the region, namely stone masonry houses, brick masonry houses, and RC constructions. The same should be translated into local language and disseminated.

(2) A strong techno-legal regime to be enforced urgently, to regulate both new constructions to be made earthquake-resistant and retrofit of existing vulnerable structures.

Development Control Regulations & Municipal Bye-laws

The urban population of J&K State (2011 Census) is indicative of the growing urbanization. The percentage share of total urban population by residence has increased from 24.81% in 2001 to 27.21% in 2011 census. Among hill states of India, J&K is the most urbanized state and cities are the focal points of urbanization. This increase in urban population puts increased pressure on urban services, social infrastructure and housing sector. Municipal bodies are challenged by this unprecedented growth and this is compounded further with acute shortage of capacity, especially disaster risk management. While cities have become engines of economic growth, urban development has assumed utmost importance. Thus, development control regulations and municipal bye-laws should focus on the following:

(1) All the schemes shall adopt and actively implement the Bureau of Indian Standards Code of Practice for construction and earthquake safety making additional provisions in development control regulations and structural safety in building regulations / bye-laws.

(2) Provisions can be made for defining mitigation measures for risks from natural hazards as part of Building Byelaws (land use zones, structural safety on basis of hazard zones).

(3) In all the existing Acts, Rules and Bye-Laws in the State of J&K, provisions should be made for hazard risk mitigation.

(4) The development and construction activities in high seismic prone regions have to be regulated and controlled by the respective urban local body. Separate provisions may be developed for rural, town and city developments in areas affected by the earthquake.

Mobile Clinics for Earthquake Resistant Technologies

Establishment of *Mobile Technical Clinics* is one way to promote earthquake-resistant design and good construction practices. Mobile clinics manned by a small group of trained personnel, will include a trained civil engineer and a trained construction artisan, who will give advice to house-owners, engineers, developers, contractors, masons, and material supplier on earthquake safety. The clinics shall house a portable desk with resource materials (IEC materials), building prototype models which demonstrate earthquake-resistant features, and a small working model (portable shake table) to demonstrate the impact of ground shaking on buildings with seismic and non-seismic resistant features. Also, the clinics can move to construction sites of owner-built building construction or community infrastructure, such as school buildings, and offer free advice. For existing small and non-engineered buildings, which require seismic upgradation, free consultations shouldbe provided to the owners.

5.7 Earthquake Resistant Design & Construction Education

Two pronged strategy is essential for enabling engineers to undertake good construction practices, viz. *short-term awareness* and *long-term training*. Towards this end:

(1) Training to trainers - Faculty members of Polytechnics should be trained in the subjects of earthquake resistant design and construction;

(2) All the engineers and architects in the region should be imparted training of basic concepts of earthquake resistant design and construction practices of the systems commonly adopted.

(3) Formulation of comprehensive *Human Resource Development*plan for *quantum improvements* in the existing situation. Such a plan should include:

   (a) Long-term *Training of Engineers* through degree programs,

   (b) *Licensing of Engineers*responsible for new constructions and retrofit of existing constructions in the state of J&K to ensure competence ; and

   (c) *Certification of Artisans* of different trades, *e.g.,* masonry and carpentry.

Earthquakes Awareness and Preparedness Campaign

The gap areas need to be plugged urgently, to make communities prepared to face future earthquakes with less uncertainty. These are:

(1) Earthquake awareness campaigns to make people aware of the prevalent high seismic hazard, the associated perils and the needed preparedness steps to be undertaken individually and collectively;

(2) Mock drills shall be arranged in schools, hospitals, communities and offices as a regular feature to help people internalize the needed actions in the aftermath of earthquakes; and

(3) Help people appreciate the possible earthquake damages to their houses and buildings, and being able to take informed decisions on retrofitting their own houses and buildings. In particular, house owners need to appreciate the distinction between *earthquake-resistantconstructions* and *earthquake-proof constructions*.

Conclusions

Most of the Indian subcontinent is in high seismic zones. But, there is considerable increase in earthquake risk due to vulnerableconstructions that do not have required earthquake-resistant features. This reiterates the urgent need to mitigate seismic risk by outlining and strictly implementing proactive measures. Since the current stock of built environment in J&K, in general, does not have earthquake-resistant features, systematic overhaul is required at the J&K state level to formallyenforce a techno-legal regime to ensure earthquake-resistant constructions. There is a need for implementation of applicable codes and regulation enforcement by alleviating involvement of intimate professionals. A major capacity building program is essentially required to undertake education in technical (engineering and architecture) colleges, polytechnics and ITIs of J&K state. Nonetheless, capacity building programs are required to upgrade practicing engineers and architects.

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References

IS1893 (Part 1), (2002). Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1 General Provisions and Buildings, 5th revision, Bureau of Indian Standards, New Delhi, India

Murty, C.V.R., Raghukanth, S.T.G., Menon, A., Goswami, R., Vijayanarayanan, A.R., Gandhi, S.R., Satyanarayana, K.N., Sheth, A.R., Rai, D.C., Mondal, G., Singhal, V., Parool, N., Pradhan, T., Jaiswal, A.K., Kaushik, H.B., Dasgupta, K., Chaurasia, A., Bhushan, S., Roy, D., & Pradeep Kumar, R., (2012). "The Mw 6.9 Sikkim-Nepal Border Earthquake of September 18, 2011", *Special Earthquake Report*, February 2012, *Earthquake Engineering Research Institute*, Learning From Earthquakes Project, EERI, 14pp

Murty, C.V.R., Chourasia, A.P., Pradeep Kumar, R., Karanth, A., Kumar, H., & Jain, A.K., (2013). '01 May 2013 Doda Earthquake-Post Earthquake Reconnaissance Survey Report', National Disaster Management Authority, New Delhi, India

Pesmos, (2013), Strong Motion Data from IIT Roorkee Array - http://pesmos.in/2013/

Census of India, Ministry of Home Affairs, Government of India web site: http://www.censusindia.gov.in/2011census/hlo/ (2011)

Valdiya, K.S., (1964). "The tectonic design of Himalaya: a survey of structures between Indus and Brahamputra, and their comparison with the Alpine structures". Report, 22nd International Geological Congress, 11, 283.