Building Resilience of the Shimla City Towards Seismic Hazard: Challenges and Opportunities

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Abstract

The Himalayas are among the most disaster risk-prone regions in the world. The city of Shimla in state of Himachal Pradesh of India, home to about 169,578 people as per 2011 census, is a tourist spot. It is located in the foothills of the Himalayan Mountains fall under seismic risk zone IV and V and could be affected by seismic hazard with intensity IX and above. Any major earthquake originating in the nearby Himalayas can affect Shimla and setback years of development in the city. The rapid growth of the population has put tremendous pressure on the built environment. Unplanned urbanization has led to an expansion of the city onto more and more vulnerable land areas. In the absence of risk-sensitive land-use policies and plans, inadequate enforcement of building rules and regulations, lack of granular risk assessment, more and more communities within Shimla are building in hazard-prone areas increasing the risk profile of the city almost on a daily basis. The analysis of this study may be taken into consideration for civil engineering, local development planning and disaster risk reduction in this region for making the new urbanization earthquake risk resilient.

1. Introduction

The city of Shimla is located in the actively growing Himalaya Mountains, with a population of 169,578 people as of the 2011 census. The city is a tourist place that attracts several visitors in the summer season. The city has been growing rapidly over the years with an economy depends mostly on tourism.

Shimla is a multi-hazard prone city with a high seismic risk zone as per the Vulnerability Atlas Map of India (figure 1). It is located in the foothills of the Himalayan

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Mountains. The geoscientists believe that enormous earthquakes with magnitudes of 8.0 or above are overdue. Historically, an M_w7.9 Kangra Earthquake in 1905 had epicenter approximately 170 kilometers north of Shimla. The most recent earthquake, an M_w7.6 struck in Kashmir in October 2005 was significantly smaller than the impending earthquakes. There has not been a major earthquake for a long time in the region that worries seismic engineers. The long return period of earthquake has created a 'seismic gap' that appears to be a potential region for next great earthquake (Gahalaut, 2008).

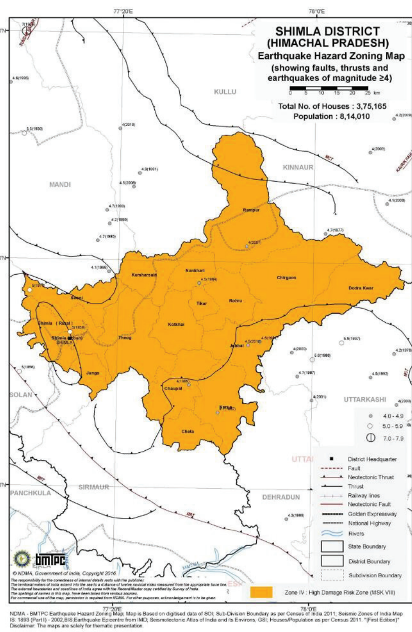

Figure 1: Earthquake Hazard Zoning Map, Source: BMTPC

The increase of seismic risk in the city continues to happen due to a spurt in unplanned development activities caused by urbanization, economic development, and tourism. Shimla is a representative of many cities in the Himalayan region that are rapidly growing and overwhelming the subject-matter experts. Landslide hazard (figure 2) is becoming more intense and frequent in and around the city. It poses potential risks that are mostly frequent in monsoon season triggered by heavy rainfall. If heavy monsoon strikes, it can also trigger many landslides in a short span of time. Besides these, the landslide event in Shimla has been exacerbated by human activity, with indiscriminate slope cutting and modifications in the ecologically fragile mountains. Moreover, Earthquake shaking can also trigger hundreds to thousands of landslides all at once (Rodgers et. al., 2014). The landslide events may result in damage to critical utilities such as water, electricity, roads, bridges, and telecommunication systems, which are interlinked systems.

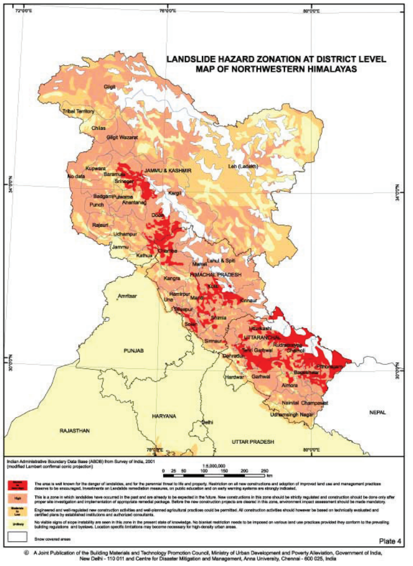

Figure 2: Landslide Hazard Zonation: Source, BMTPC

2. Methodology

The technical approach was used to develop this paper utilizing the World Bank's Building Regulatory Capacity Assessment Level 2 guidance. A comprehensive desk review of local building bye-laws, and regulations, city DM plan, and other publicly accessible policies and relevant guidelines were also conducted. *Lifelines: The Resilient Infrastructure Opportunity* report of World Bank was also reviewed to gain an understanding of the subject. We have employed multi-stakeholder approach and conducted some semi-structured detailed virtual consultations and interviews with key government agencies, non-government stakeholders to obtain insights on the gaps and capacity of the city towards building regulations, rules, and resilience, as well as disaster management system for synthesizing the interactions within this study. To analyze the wide range of data both from primary as well as secondary sources, 'the thematic analysis' technique was used. Thematic analysis is one of the most common forms of analysis within qualitative research. It emphasizes identifying, analyzing and interpreting patterns of themes within qualitative data.

3. Analysis

Thematic analysis (cf. Guest, 2012; Gibbs, 2007) was used for synthesizing findings within this research paper as the primary qualitative research method to identify and organize key themes from qualitative data under BRCA Level 2 guidance. To analyze the wide range of data both from primary as well secondary sources, this technique has allowed for a rich, detailed, and complex description of the topic. The findings of the research have been generated using combined approaches (i.e. research-driven and participatory), with a combination of illustration and visualizations in their construction.

4. Result

4.1. Building Resilience

There are 3,75,165 houses in Shimla city (BMTPC, 2019). As per the City Disaster Management Plan (CDMP), the land distribution of Shimla shows that major land use is residential that is 75% of the total built-up area. The CDMP highlights that 90% of structures in the city are 'poorly built' that can collapse during moderate to high earthquake shakings. The most damage could be experienced in the areas such as Lakkar Bazaar, New Shimla, Vikas Nagar and Ruldu Bhatha, are the part of slopes of the ridge. The underlying factors that caused haphazard construction in the city include the huge demand for urbanization triggered by migration and tourism. As a result of these factors, a lot of construction of buildings has started on steep and unstable slopes with improper construction practices.

A survey conducted by Town and Country Planning (TCP) based on vulnerability atlas for the country (based on building census for the year 1991 for Shimla) shows that less than 2% of houses in the city are safe. According to TCP surveys, 78.64% of the buildings fall in category A, 12.96% in category B, 6.88% in category C, and 1.25% in category X as presented below in table (1). The Vulnerability Atlas Map of India developed by BMTPC following the publication of Census 1991 data on buildings in India is based on predominant materials used for the construction of roofs and walls are widely used to determine the vulnerability of the built environment in the country.

Table 1: Seismic Vulnerability of Different Types of Buildings in Shimla

Category of Buildings	Features	Seismic Impacts	Percentage
Category A	Made of mud, stone and random stones	Suffer partial damages	78.64
Category B	Large blocks and poor quality of timber	Liable to develop deep cracks	12.96
Category C	RCC Buildings	Only small cracks	6.88
Category X	Seismically safe	Totally safe	1.25

There has not been a scientific study conducted so far on the seismic vulnerability of buildings of the city. A Rapid Visual Screening (RVS) *study of important buildings, transportation and communication systems for Shimla city* was conducted by UNDP India with Municipal Corporation Shimla with technical support by NIT Hamirpur in the year 2015-16. The draft RVS report is available on MC's website that has a list of buildings/structures that were assessed. However, it does not provide detailing on structural integrity, stability, and resilience of these important buildings and systems, and the final report that seems to have details is not available in public domain to avoid creating public fear. The MC Shimla instructed the authorities concerned to undertake retrofitting measures with the technical support of NIT Hamirpur for important buildings through official letter however; no actions have been taken yet.

There is no detailed and systematic scientific study showing vulnerabilities of buildings and systems in the entire state of Himachal Pradesh. Himachal Pradesh has a digital HRV Atlas that enables the generation of hazard, vulnerability, and risk maps of the State down to the block level. This is an effective tool for risk analysis for all stakeholders across all sectors at all levels. The HRV Atlas has mapped the intensities of six hazards, of which four are natural (e.g. earthquake, landslide, flood, drought, and GLOF) and the remaining two are human-induced (forest fires and industrial accidents).

This Atlas is based on data obtained from primary as well as secondary sources and overlays the same on the GIS platform showing physiographic, critical utilities and facilities, and administrative boundaries at various levels (state, district and local) at a scale of 1:50,000. However, the scale of the risk assessment is not appropriate for local planning and regulatory purposes.

Many of the residential and commercial buildings continue to come up in the city. It has a congested built-up area now with haphazard developments happening in sinking zones, steep slopes, and landslide-prone locations. For landslide safety, the basic factor checked prior to construction of roads and buildings is the stability of the slope, which is critical in Shimla terrain. The local building bye-laws restrict hillside constructions on slopes steeper than 45 degree, however, quite a large chunk of the buildings have been constructed violating the hillside construction norms. The building regulations have provisions for slope cutting and construction that allow slope cutting not more than 3.5 m. In addition, the local building standards contain provisions to check the stability of the slope and carry out site specific inspection for landslide resilience. However, there are no geotechnical engineers available in the planning team. It is the Executive Engineer Roads and Buildings (EE - R&B, MC Shimla) along with the design engineer responsible to carry out inspection. In case of violation of this provision, a joint inspection is carried out by a committee led by the Executive Engineer to stop such illegal construction in dangerous slopes, or restrict the slope cutting within permissible limits. Moreover, landslide hazard maps are available but the scale of these maps is inadequate therefore not useful in construction activities per se. In case of critical infrastructure projects, technical support is sought from government technical institutes such as Indian Institutes of Technologies etc.

The Municipal Corporation (MC) Shimla is responsible to oversee planned and systematic development in the city. Most of the staff in the MC office is on deputation from other government departments of Himachal Pradesh. In most of the cases, the MC office finds it difficult to keep checks on constructions provided that they have acute shortage of staff. During building approval, producing a structural stability certificate is the responsibility of the owner. Structural engineers who are registered with the MC carry out the certification of the structural safety components in the building plans and drawings. This gap highlights the need for structural safety inspections and certification to be handled by a qualified structural engineer.

The enforcement capacity of the city is inadequate provided that construction fraternity such as site engineers, overseers, artisans, and other workforce are largely unaware about the seismic resistant constructions. In addition, the rules in the building bye-laws do not explicitly point out site inspections at various stages (pre, during and post) of constructions. The Development Authority, Housing Department and Engineering and Designing Wings in PWD and TCP do not have adequate number of staff members and lack sufficient expertise in structural safety components to check the constructions that make local enforcement and implementation poor further resulting into unsafe construction without meeting the required seismic code standards. For example, The Urban Development Directorate which controls development in jurisdictions of all urban and municipal bodies does not have a dedicated town planner. 61 ULBs under Urban Development within Himachal Pradesh have 1 junior engineer each and 5 Assistant Engineers altogether in Shimla.

In addition, the Public Works Department in Shimla is engaged in planning, construction and maintenance of roads, bridges, hospitals, ropeways and buildings (both residential and non-residential buildings including government departments) in the state. This department is one of the biggest and important departments that adhere to the latest NBC. However, the PWD does not have any specific hillside construction guidelines and therefore adheres to prevalent seismic zone codes by BIS for any hillside constructions. The department has a design wing division, but does not have any structural engineers. It is the Chief Engineer who works as a Structural Engineer approves structural drawings for any construction projects. The department conducts structural safety audits of the buildings. These audits are carried out by the department itself without the involvement of the third party in the audits process.

The development authorities (i.e. UD, PWD, TCP, MC Engineering Wing etc.) in the city do not have in-house mechanisms to test the materials and soil of the construction sites. They also lack a required instrument or lab with them so all testing work is outsourced through various pre-identified agencies. The authorities do not have a pre-identified list or data of registered masons with them. They hire contractors via an online tender process who bring in labor, mostly from plain areas and these masons are seasonal labor and keep floating. The staff members in the development authorities lack sufficient knowledge on the structural safety aspects. Only a few numbers of construction professionals from various departments have been imparted training on safe construction practices on theoretical aspects. There is an immense need to provide hands-on training on various practical aspects covering cost-effective earthquake resilient construction in hill areas, safe and resilient constructions, retrofitting techniques, and post-disaster reconstructions and repairs.

4.2. Critical Infrastructure Resilience

Critical infrastructure system provides vital services and resources to the communities, public and private entities, and commercial activities. This term is being widely used to describe assets and services that support important societal functions. Critical infrastructure not only covers technical assets but also functional sector and essential services (Pescaroli and Alexandra, 2016). These systems heavily depend upon interconnections with one another; therefore, an effect of disaster on one system generatescascading and escalating failure that could scale up the impact. It is therefore important to prepare, invest, and protect all types of infrastructure including lifeline networks (e.g. electricity, water, telecommunication, roads and bridges) and life support networks (e.g. emergency services, public health).

The term resilience has been used in various fields since the last few decades. Now this concept has been well incorporated into the management of critical infrastructure systems (Dahlberg et al., 2015). This paradigm shift in traditional risk management to include resilience is fundamentally based on the observation that it is impossible to be protected against all risks or to predict what is by definition unpredictable (Porod et al., 2012).

The resilience of critical utilities such as roads, water, electricity, and telecommunication etc. is crucially important for remotely located hill cities such as Shimla. It is a system of systems that are interconnected and interdependent. However, the resilience of a system is dependent on the weakest link of that system. The critical systems are only as resilient as their weakest link. The effects of seismic hazard may cause damage to critical systems, and the environment on which the system relies. For example if the electrical system is affected because the power transmission lines, poles or transformers could be damaged due to seismic shaking or landslide. The failure of the electrical system will further affect the water system as it depends on electricity to function. Similarly, the other critical system such as telecommunication consists of mobile towers and the internet also depends on power. If seismic shaking does not cause any direct damages to mobile towers, the failure of power will lead to mobile networks to remain non-functional once back-up sources run out.

In addition, the roads and bridges could also be damaged as a result of earthquake shaking or landslides making the road connectivity impassable for several days or weeks. In this scenario, the repair supplies, equipment and other essential goods will not be able to reach the city. These are quite common vulnerabilities of the critical system in the Shimla City. This paper briefly presents key challenges to the water system in the city in the context of seismic hazard to show interconnection of risks.

The water system in Shimla city is sourced from both pumping and gravity methods. The water is pumped from the rivers and springs in the vicinity of the city, and is also transported from spring sources located at higher altitude via gravity method. The prominent vulnerability features to water systems are pumping stations, tanks, reservoirs, pipelines, and other ancillary equipment. These elements of the water system are vulnerable to ground shaking and permanent ground deformations. For instance pumping stations, tanks, and reservoirs can be affected by earthquake shaking. Poor roof connections, inadequate anchorage to floor, undersized structural components, non-ductile concrete frame structures commonly have poor seismic performance. Numerous pipelines may break all at once in the distribution network from shaking, settlement, and landslides as was observed in the 1994 Northridge, 2008 Wenchuan, and 2015 Nepal earthquakes where similar materials were used in pipelines.

Even though Shimla has back-up generators, they are as dependent on electricity as the primary pumps. As a result, Shimla's ability to provide water following an earthquake has no redundancy regarding power source. Redundancy is an important trait of a resilient network. A redundant water supply does not need to meet daily or annual peak demands but should be able to provide a sufficient quantity during emergencies to meet minimum public health and safety needs.

Moreover, the network of roads used to reach water system components for repairs will likely have also suffered damage. Fuel (i.e. diesel) that is normally purchased in the city to operate the repair equipment may quickly run out if fuel supply tankers from out of town are blocked from reaching the city by impassable road. Lack of fueling supplies strongly inhibits ability to rapidly respond to earthquake impacts. Fueling resources are expected to be limited and in high demand following an earthquake. Ability to replenish will be difficult due to expected damages to the regional and local transportation system.

4.3. Health System Resilience

National and local health systems that provide health services for millions of people have been affected by damage to and destruction of thousands of health facilities during 2001 Bhuj earthquake (Mw7.7), Gujarat, India (Singh, 2015), 2004 Indonesia's northern Aceh province earthquake (Mw9.3), 2005 Pakistan's earthquake (Mw7.6), and 2008 Myanmar earthquake (Mw6.9) in past disasters. More than 11000 health facilities were damaged or destroyed by the earthquake that struck China on 12 May 2008 (WHO, 2015). The Pan American Health Organization (PAHO) and the World Health Organization (WHO) have defined: *"a Safe Hospital as one that will not collapse in disasters, killing patients and staff; can continue to function and provide its services as a critical community facility when it is most needed; is organized, with contingency plans in place and health workforce trained to keep the network operational."*

Moreover, the hospitals are also important symbols of social well-being. Destruction of or damage to a hospital may result in a loss of trust in local authorities as well as exposing patients and health workers to further vulnerabilities. The city of Shimla provides effective health services. The main Government Hospitals in the city are Indira Gandhi Medical College, Kamla Nehru College, Deen Dayal Upadhaya Zonal Hospital, Regional Ayurvedic Hospital. Health facilities, especially hospitals, are critical assets for communities both routinely and in response to emergencies, disasters and other crises. Yet hospitals and health workers are often among the victims of emergencies, with the result that health services cannot be provided to affected communities, when they are most needed. The continuing functionality of the hospital depends on a range of factors, including the safety of its buildings, critical systems and equipment, the availability of supplies, and the emergency management capacities of the hospital (WHO, 2015).The elements of a functional hospital are presented below in figure 2.

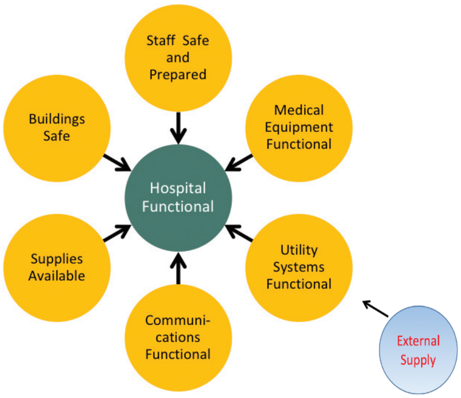

Figure 3: Ingredients of Functional Hospital

(Source GeoHazards International, 2010)

In the case of seismic hazard, the surge capacity of the hospitals in the city may be overwhelmed with a large influx of patients. The hospitals can themselves be affected by earthquake events and/or its cascading effects. After most earthquakes, it has been observed that medical resources are scarce to meet the needs of the earthquake survivors, especially in hilly terrain. In the absence of adequate medical resources, minor injuries can aggravate limb/life-threatening injuries among the affected community.

The health facilities indicated above in the city are highly prone to earthquakes. Hence, it is important that safety and functionality of these facilities should be enhanced on priority basis. The health facilities indicated above should be also examined from the seismic safety point of view, and required retrofitting measures must be undertaken. As a major earthquake has not affected Shimla city for almost a century, the health facilities' response to a mass casualty event such as would happen in the aftermath of an earthquake has not been tested. However, elsewhere in the world, in the last two decades, critical hospitals have become victims rather than saviors that their communities expected these critical facilities to be in earthquakes as examples cited above.

Besides structural safety of these health facilities, the resilience of water and electricity becomes important to ensure their functionality. Water supply is critical for the smooth functioning of any hospital, as hospitals not only represent a concentrated area of patients but also a concentrated area of infection sources. In order to maintain an optimum level of safety in disaster situations, hospitals must maintain a basic health environment with a reliable supply of good quality water, facilities to provide access to safe hygiene, sanitation and health care waste management in order to control the spread of infections, which are major causes of morbidity and mortality after disasters. These health facilities are dependent on the supply of the water from municipal sources. Most of the water (nearly 90%) is pumped from river sources that heavily depend on electricity. Moreover, the water piping in the city is exposed to both seismic hazard and landslides that can break water pipes and distribution network. If the water system fails, the healthcare services will be rendered unless.

The hospital's most important utility system is the electrical power system. Without power, the hospital's essential medical equipment, life support equipment, lighting and other safety-critical items will not function. Following a moderate or major earthquake, it is highly likely that the supply from the electrical grid will be disrupted; and grid power will be lost for a significant period of time. During the critical response period immediately following the earthquake, and perhaps for weeks afterward, the hospital will need to rely on backup power supplied by the emergency generators. However, the generators and backup power system in the hospitals are vulnerable to earthquake damage that could prevent them from supplying the hospital with power when it is needed most.

A Case of IGMC Shimla hospital

Indira Gandhi Medical College (IGMC), the State Hospital and Medical College, is an 800-bedded health facility that not only caters the city's residents, but also population across the state. It was constructed by PWD and consists of five blocks that house 37 departments including ED, OTs, ICUs etc. The blocks of IGMC are connected via ramps and staircases. The hospital campus is located on a hillside and is prone to seismic and landslide hazards. A new campus is being constructed to shift EDs and OTs. Being an important facility, it is essential that IGMC should be critically examined based on structural safety standards. An annual safety audit must be conducted at least for critical departments. The emergency plan of hospital developed in 2018 needs to be reviewed and updated. The non-structural elements (architectural, contents, peoples and medical equipment) and critical utilities in the hospital are not seismically protected. The hospital has shortfalls of water and power storage capacity as indicated below.

The water tanks store about 554800 liters. WHO recommends that hospitals have in-campus storage of water of three days' supply calculated at the rate of 300 liters daily per bed capacity of the hospital. For IGMC, this works out to 800x300x3 =720,000 liters. Therefore, the IGMC currently has a shortfall of 165,200 liters water compared to accepted standards for water storage.

In case of power failure, the hospital has nine generators. The total consumption of fuel if all nine generators in the hospital are working will is about 4.78 liters per hour (1000 total diesel / 209 total consumption per hour). Presently, the campus keeps 1000 liters fuel in storage in addition to the fuel in the generators. This will hardly be enough to keep the hospital functional for a maximum of 5 hours. In normal times, diesel is brought from nearby petrol pump (20-minute drive) from Sanjauli. In addition, the petrol pumps and roads may not be functional following post-earthquake scenarios. It is extremely important to have adequate diesel in storage to run the critical facilities of the hospital for at least 72 hours.

5. Discussions

The review analysis shows that while the local development authority intends for digital Atlas map to be used to control development in areas of high hazard, information is not available at a sufficient scale to be used for this purpose. This lack of actionable and high resolution hazard information at the local level affects many regulatory functions including planning, zoning, and plot-level building permit approvals, and also post-disaster relocation and rebuilding in the city. This shortcoming also affects the development of regulations; if there are no actionable hazard maps, building and land use regulations are not written to mandate their use. Other key gaps relate to older, hazard-vulnerable, and unsafe buildings. The CDMP highlights the needs in this area, but the lack of scientific study, inadequate standards for assessment and retrofit, and limited provisions to deal with them are desired to improve regulatory frameworks. It is envisaged that there are key potential interventions needed for building resilience of the city to earthquake.

5.1. Revision of Municipal Regulations

Unlike other places in Himachal Pradesh, Shimla Municipal Corporation (MC) has its own bye-laws; known as MC Shimla Building Bye-Laws 1998 brought out under the HP MC Act 1994 and published in 1998. In addition, the Himachal Pradesh Town and Country Planning Rules (TCPR) 2014 are also applicable to Shimla. There have not been any revisions made since then in these laws and rules making them insufficient for ensuring building resilience of the city. Following revisions in the National Building Code in 2005 (third revision) and 2016 (fourth revision) besides a few national standards for hillside construction by central agencies (BIS, NDMA), the critical review of the local building bye-laws in the context of the latest NBC and IS codes remain wanting.

The building safety codes (NBC and IS) and guidelines developed at the national level agencies must be adapted to Shimla context, and have to be reflected in the local building rules. But many of the codes referenced in the local building rules and regulations are a decade old, and during the last decade, the state has witnessed many geophysical events that have affected communities and infrastructure, including property losses. The city needs to establish a techno-legal and techno-financial regime in consultation with NDMA. These should be tailored to address the hazards to which they are at risk and sensitive to priorities of the city. It is best to evolve these through consultative process. Municipal regulations, such as development control regulations (DCRs), building bye-laws and structural safety features, are primary determinants of the safety of the built environment. They should be reviewed periodically to identify safety gaps (especially from the point of view of earthquake, flood, landslide and other hazards) and modifications made to align them to the revised building codes of the Bureau of Indian Standards.

5.2. Licensing and Certifications

The construction fraternity such as engineers, architects, planners and artisans are the backbone of the built environment. It is therefore imperative that all-service engineers, architects and planners working in various departments of the state government, dealing with construction are to be trained through a capacity development process, and only the competent ones among them are to be licensed through an assessment process. Besides these, the local construction workers (artisans) in their respective trades should be trained and their skills to be upgraded, and certify them after a due competence verification process. The city should create a database of the registered masons involving them in ongoing and future construction processes.

The provisions in the local Building Bye Laws and DCRs, should be incorporated requiring that only licensed engineers shall be permitted to undertake the structural design and construction of buildings and structures, and only certified artisans shall be employed to undertake the skilled work. The provisions and rules should be laid out to fix accountability of Licensed Engineers to empower the ULBs to take appropriate legal actions (such as blacklisting, debarring from services, cancellation of license etc.) for any violation by the Licensed Engineers.

5.3. Structural Safety Audit

For regulating safe and resilient construction practices require establishment of a techno-legal system. The municipal body of the city (to which the structural design calculations and drawings are submitted for approval) examines the documents and confirms compliance with the prevalent national standards. The audit is performed by Structural Safety Peer Reviewers. Two structural safety peer reviewers are needed, namely: (1) structural safety peer reviewers for the structural design, and (2) structural safety peer reviewers for the construction quality. Only legally licensed engineers should be commissioned to carry out these peer reviews. Currently, there is no legal system in Shimla (not even in the country) of Licensing of Engineers. Until a system is in place to license engineers, available engineers of repute should be trained to carry out these audits.

When Structural Design Peer Review and Construction Peer Review pertaining to design or to construction are performed by licensed engineers under the aegis of a statutory body, it is called the third party Structural Safety Audit. The CDMP emphasizes the importance of this Structural Safety Audit in the plan. Structural Safety Audit of the designs should be done ideally by a statutory body for each new structure before construction and each existing construction after specified durations of time.

5.4. Retrofitting of Existing Structures

Retrofit is a powerful proactive effort that builds resilience in communities by enhancing the capacity of the buildings and structures to resist the demand imposed on them when the expected hazard is realized. It is a resource-intensive technical activity.

Therefore, prioritization of buildings and structures (lifeline and important ones for which risk tolerance is zero) in the city is required, based on a formal Risk Assessment. An RVS study has also been carried out in the city. It is prudent to undertake retrofit as programs, each stretching over 5 years with mid-term strategic changes and technical improvements, extendable beyond 5 years with the revised plan, until the entire stock of prioritized buildings and structures are retrofitted.

5.5. Seismic Resistant New and Existing Structures

The entire stock of the building and structures in the development is seen in two parts, namely the existing and the new. It is relatively easy to design and construct new building and structures to be disaster-resistant. This requires robust design and construction standards, which are disaster-sensitive and regulate only desirable performance when the hazard expected at the site is realized. The five virtues of the built environment – safety, functionality, sustainability, aesthetics, and cost-effectiveness must be considered. The local government should have system perspective approach considering both physical and service functionality of new structure.

The existing built environment can be a biggest source of vulnerability in the city. For existing structures, besides retrofitting measures discussed above, it is important to develop some predictable financial mechanisms for quick recovery and restoration of large critical infrastructure. This can be managed through various financial institutions and mechanisms in place. Partnership with financial institutions and insurance companies provide whole recovery window of opportunity to build back forward, greener and safer.

5.6. Resilience of Health Facilities

The resilience of health facilities in Shimla city should be enhanced both in terms of safety and functionality. The periodic structural safety audit of these facilities can help facilitate the physical stability, integrity, and resilience of these important institutions. To make hospitals safer in Shimla, there are certain steps that must be followed. 1). Conduct a seismic risk assessment of health facilities; 2). Construct health facilities to withstand future seismic hazards. *Making new hospitals and health facilities safe from disasters is not costly. Incorporating mitigation measures into the design and construction of new hospitals accounts for less than 4 percent of the total investment*

(NDMA Guidelines – Hospital safety, 2016); 3). Enhance preparedness and emergency management for multi-hazard scenarios; 4). Retrofit and maintenance for critical facilities, secure medical equipment, and plan for critical utilities.

6. Conclusion

Systems and processes need to be built to assess, document, synthesize and share information to all stakeholders on the risk prevalent in the city against seismic hazard, and to use the same in local development planning in the city. The local authorities should carry out scientific micro zonation studies of the city to determine the following information; (a) Site-specific liquefaction; (b) Local geology and geotechnical properties of surface and subsurface strata; (c) Availability of known seismic faults; (d) Possible secondary hazards i.e. landslides; (e) Specific seismic behavior for engineering design, land use and urban planning.

Hazard maps should ideally be 1:5,000 scale, or 1:10,000 at minimum, to be useful for regulatory purposes. Current HRV Atlas scales are not detailed enough to be useful for planning or regulatory purposes in which decisions need to be made at the plot (parcel) level. There is a need for micro-level georeferenced cadastral and topographical maps showing hazard areas. Georeferenced cadastral and topographic maps should be the base map for building permit approval systems. The scrutiny officer at the local government could easily consult such maps to identify whether a particular area is hazard-prone, and what the hazard intensity would be, to guide development decisions and construction of hazard resilient structures in such areas.

Risk-informed land-use planning is essential to reducing Shimla's seismic risk by looking more holistically at the physical environment, hazards, and development practices. Risk-based planning would require new strategies in the city, such as (1) Conduct a comprehensive assessment at micro- levels of the nature of the hazard and its intensity at micro-levels. It will be important for the planning team to have access to 1:10,000 scale or better maps to depict local situations clearly on a cadastral map. (2) Assess levels of risk (acceptable level, medium risk, or high risk) based on measurable indicators. These indicators should be used to develop parametric models for land parcels and should be linked to land-use policies. (3) Monitor the risk levels over time, enabling the communities and authorities to undertake sustainable development practices to reduce identified vulnerabilities.

The city will have to create social demand on a large scale for seismic resilient constructions. Promoting and encouraging safe and resilient building construction will be a win-win situation for local governments, building owners, developers, and in the end for consumers and occupants. It is recommended that the suitable financial or in-kind incentives (such as enhancement of FSI, reduction in power/water tariffs, property tax, and speedier approval etc. can be built into the building regulations of Shimla after reviewing examples from other states of India. Incentives appeal to the owner, developer, builder, occupant, or corporation. For existing and future buildings, especially for lifeline structures, the city should develop a comprehensive program in which building infrastructure should be mandated to have an annual safety audit by engineers to ensure their structural integrity. Besides these, to address safety problems in the current and future buildings and encourage voluntary structural maintenance of buildings, the local development authority should set up incentive mechanisms for building owners for safety, resilience, maintenance, and auditsshould be carried out by structural engineers.

Local government capacity to implement and enforce the Bye-Laws is not sufficiently adequate. There are only a few engineers and no geologists available to support the design and construction of buildings. Since the local governments are solely entrusted with the task of enforcement, the capacity of the Municipal Corporation is critical for safe buildings. The local government should make disaster resilient infrastructure as economic case by underscoring the cost-benefit analysis principal that shows *$ 4 benefit for each 1 $ invested in resilience* (Lifelines report WB, 2019).

It is important to build local capacities in risk-sensitive land use planning so as to enable and capacitate the policymakers, associated planners, engineers, and architects to effectively address seismic resilience. The city should develop a comprehensive land-use management policy, introduce necessary amendments in the existing regulations, and formulate a model and localized development control regulations for different areas within cities.

Technical Assistance is needed for specific sectors. As local bodies cannot afford to have a team of in-house experts for seismic resilient construction, options for receiving technical assistance should be explored, such as constituting a peer review group for advisory inputs including from national as well as state technical research agencies, institutes, and universities.

To address the lack of clarity and gaps in existing construction safety provisions, it is recommended that Standard Operating Procedures be laid out on (i) Regularization of informal, unsafe, and unauthorized construction including maintenance of database (ii) Provisions for demolition of old (dangerous) buildings and (iii) Procedures for retrofit, repairs, and restoration of buildings.

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