Seismic Risk Management in Areas of High Seismic Hazard and Poor Accessibility

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SUMMARY:
The 2011 M6.9 Sikkim (India) earthquake exposed poor disaster preparedness in remote villages of high seismicity. Similar experiences have been recorded in the 2005 Kashmir earthquake and 2001 Bhuj earthquake, amongst others. Often, areas of high seismicity have relatively low density and low development priority. There appears to be a reluctance to expend disproportionately large resources on disaster mitigation and management for this miniscule section of society. While trying to alleviate the burden such communities may be placing on the urban fabric, it is still the responsibility of the State to ensure access to safety, relief and rescue in a disaster for its every citizen.
The paper studies the three earthquakes and suggests a policy approach identifying the key issues to be addressed to make such communities less vulnerable in disasters and makes a compelling case for building resilient infrastructure on part of the state and capacity building of the local community for disaster mitigation.

1. BACKGROUND

An Mw 6.9 earthquake occurred on 18 September 2011 near the Nepal-Sikkim border. Sikkim was the worst affected state of India. The earthquake triggered an estimated 354 new landslides and reactivated 48 old ones in the state, besides causing significant damage to buildings and infrastructure. The damage (and fatalities) due to landslides, rock falls and mudslides exceeded the damage due to ground shaking. North Sikkim areas of Lachung, Lachen and Chungthang which are popular tourist areas due to their pristine landscapes, remained isolated from the rest of the world for more than 20 days as all the mountain highways leading to these areas were blocked on account of landslides. Telecommunication systems were also non-functional after the earthquake for over two weeks. Food packets had to be air-dropped from helicopters in these regions during that period as it was not possible for supplies to reach the affected region. There was no means of communicating with people trapped on the other side of the landslides. Some local people lost their lives trying to walk across to other villages or towns, only to be buried in a landslide. Villages in far flung areas of Sikkim often comprise of a cluster of less than ten homes, which creates challenges in terms of outreach. The harsh living conditions in the cold, steep and poorly accessible terrain, and annual landslides during the rainy seasons have made inhabitants independent and resourceful to deal with lesser disasters quite ably. Numerous bamboo bridges made by villagers across streams are testimony to this. However, the local community was clearly unprepared to deal with a disaster of the magnitude such as the earthquake and the ensuing landslides which affected their main lifeline- the mountain highways.

Breakdown of State-owned infrastructure is a recurring theme in earthquake. The situation was similar in the 2001 Bhuj earthquake when the only road bridge – the Surajbadi bridge connecting Kutch, the epicenter of the earthquake was badly damaged and had to be closed temporarily for traffic immediately after the earthquake and with restricted functionality thereafter. This isolated the affected region from the rest of India, severely hampering rescue and relief. Fortunately a new bridge was under construction and commissioned five weeks after the earthquake. In successive earthquakes around the world, it has been observed that areas of high seismicity but relatively remote and with low population density suffer from lack of redundancy in their planning. There are no alternate road networks or communication lines and loss of a critical bridge or road essentially means complete isolation of that region from civilization.

The Kashmir earthquake of 2005 was another similar event in which landslides closed critical highways and roads necessary for search and rescue operations. Some remained closed for up to three months after the earthquake. Lifeline services such as water supply, telecommunications and power were also down for a few days to a few weeks. As in the Sikkim earthquake but at a larger scale, landslides were a key feature of this event. As per the estimates of the government of Pakistan, more than 80% of the total houses destroyed were located in rural regions.

2. TRADITIONAL WISDOM IN EARTHQUAKE RESISTANT HOME-BUILDING IN HIGH SEISMIC REGIONS AND ITS LOSS IN RECENT TIMES

Many historically seismic regions traditionally have earthquake resistant features inbuilt in their vernacular architecture and design. In Sikkim for example, the traditional construction is popularly called Ekra; it comprises of a wooded frame with cross-woven wood matting (originally made from Ekra grass, hence the name) infill wall panels, and a light roof. The matting is plastered on both sides with mud or mud with sand, and more recently by cement mortar. Another variation is the use of wood planks – Shee Khim. This is more expensive and not as common. The homes rest on a masonry plinth (made of stone and mud mortar), and when made along hill slopes, rest on a tapered stone plinth. During the earthquake, both these typologies have performed exceptionally well, except for some distress in the stone masonry plinths in some cases or when traditional methods were tampered with such as where the cross-woven wood traditional matting was replaced by clay-brick masonry in cement mortar. The highly satisfactory performance of this typology of housing validates the appropriateness of this typology in the Himalayan region and makes a compelling case for its sustenance. The notification by Government of Sikkim of this typology as “informal” (as against formal housing) is unfortunate and makes this typology unqualified for any government subsidies. Most of the traditional houses in the capital city of Gangtok have been replaced by non-engineered reinforced concrete building. Almost all buildings that suffered serious damage in the earthquake were of reinforced concrete construction. Fortunately, homes in the remote villages are still built in the traditional way (Ekra or Shee Khim) but with growing restrictions on use of wood and a tacit discouragement by the State for such traditional construction, it is feared that the traditional earthquake resistant homes will be replaced by unsafe RC homes. A change in the mindset of the stakeholders in urgently required to reverse the situation.

Figure 1. Shee Khim House after 2011 Sikkim earthquake

Figure2. Ekra House after Sikkim earthquake

In Kutch, before the arrival of the ubiquitous reinforced concrete, a large number of houses, especially in the Banni region were Bhungas. The Bhunga is circular in plan and has an eaves height of about 1.8 meters with a sloping thatch roof. The walls may be of various types but the wattle and daub was the most earthquake resistant. Multiple bhungas may be built in clusters in a compound as living and sleeping quarters. No Bhunga was destroyed in the 2001 Bhuj earthquake.

Figure 3. Newly built non-engineered RC house in Sikkim Earthquake 2011

Figure 4. Government RC house after Sikkim Earthquake 2011 – Out of plane infill collapse, and column failure

However with the onset of "development" and growing aspirations of the people coupled with a general belief that reinforced concrete (RC) frame homes are stronger and desirable as markers of prosperity, the vocabulary of construction across the rural regions in India has changed to non-engineered reinforced concrete construction, even though it is fairly established in successive earthquakes that un-designed RC homes are perhaps the most vulnerable typology in an earthquake.

Figure 5. A Bhunga in Kutch

Figure 6. Behaviour of poorly-engineered RC Building in Bhuj 2001 earthquake

Likewise, most of the buildings in the affected area of the Kashmir 2005 earthquake were non-engineered buildings with load bearing unreinforced masonry (URM) wall construction of stone, brick or solid concrete block masonry. The houses were single or two-storied with flat or sloping roofs. Flat roofs in rural areas were built with wooden beams and mud slabs reinforced with straw or precast concrete slabs or metal sheets. Semi-urban and urban areas had reinforced concrete in-situ slabs. Small villages also had adobe construction. Buildings with URM walls of random rubble stone masonry performed badly and collapsed or suffered severe damage where shaking had been strong. Unreinforced, properly dressed stone masonry laid in even courses was able to accommodate some movement without becoming unstable and falling apart. The quality of the construction and of the materials thus played a part in the behavior of the structures. Mud mortar and weak cement mortar construction performed poorly. Houses with brick masonry performed better than concrete block masonry.

A popular traditional construction method in Kashmir is the Dhajji dewari. This is a timber –latticed masonry, i,e, bricks filled in a framework of timber. This results in confined masonry that displayed excellent performance in the 2005 earthquake, showing no or very little damage. No collapse was observed for such masonry even in areas of higher shaking. Progressive destruction of the walls was arrested by timber studs which subdivided the wall and prevented diagonal (shear) cracking of the wall as also out-of plane failure. Dhajji-dewari system is very light and sometimes used for the upper floor even when the lower floor may be of brick masonry. A variation of Dhajji is the use of stone pieces in lieu of brick between the wooden framework. Another traditional building system in Kashmir is Taq in which large pieces of wood are used as horizontal runners embedded in the heavy masonry walls, which add to the lateral load resisting ability of the structure.

Figure 7. Dhajji Deewari in Kashmir (Rai, Murty)

Figure 8. Taq Construction in Kashmir (Rai, Murty)

It is in no way implied herein that all traditional building practices in high seismic regions are earthquake resistant and should be revived. Use of Adobe construction, though traditional, has proven to be extremely vulnerable unless of the wattle and daub type. Random rubble masonry practiced in some regions of Kutch and Kashmir has also caused large number of fatalities in the 2001and 2005 earthquakes. Similarly, in the M6.4 Latur earthquake of 1993 in Maharashtra, India, the local construction methodology of heavy roofs with rubble masonry walls proved to be fatal for thousands of residents. It may however be noted that the region was hitherto never known to be seismically active thus perhaps leading to the evolution of the building technology as practiced.

But there are clearly some extremely effective earthquake resistant traditional systems which need a strong boost for their renewal as sustainable building practices. The Ekra and Shee Khim in Sikkim, the Dhajji Deewari and Taq constructions in Kashmir and the Bhungas in Kutch are some such earthquake resistant traditional systems.

What is being increasingly recognized by stakeholders is that it is not possible to ensure code based earthquake resistant design using materials such as reinforced concrete and structural steel in areas where there is no availability of expertise in the design and construction with them. The reason that traditional earthquake resistant practices have been eased out is not due to lack of their performance - it is because of their absence in formal education curriculum, as a result of which stakeholders such as architects and engineers are not exposed to such building technologies and are wary of experimenting with materials other than familiar materials of reinforced concrete and steel. Engineering and architectural syllabi make only a passing reference (if at all) to existence of such traditional systems and do not equip students with a knowledge base to make them confidence of promoting the technologies. There is no impetus to invest in research and development of traditional technologies in national engineering institutes and research laboratories and they are left to non-technical, non-government agencies further promoting the perception that traditional technologies are romantic indulgences of technically non-qualified agencies. This is a problem which the State needs to address. Unfortunately it suffers from the same deficiencies of information and knowledge, drawing its expertise from the same pool of architects and engineers.

While the State has well laid out building codes that are applicable across the country and which are completely biased towards urban-centric constructions, it does not have the regulatory mechanisms nor the resources to ensure and insist on engineered RC design homes, which it implicitly appears to be promoting in rural, remote areas. The State is also aware that there is no capacity in such regions for designing and building "engineered RC homes" even if the residents wished to do so. The State therefore has two choices- Either it provides prescriptive "type designs" and through various information and communication technology (ICT) tools, creates a demand for such constructions. Confined masonry (CM) construction is even better suited to remote regions than RC frame construction and detailed design and construction manuals for a myriad type designs will provide a palette from which the villager may pick and choose and build a safe home. Already Gujarat State Disaster Management Authority is in the process of publishing such manuals alongwith building demonstration homes in a few select districts. The other choice it has, and this is not being explored adequately – is to aggressively promote high-performing traditional construction methods as an effective, seismically superior alternative to un-designed RC construction.

3. DESIGN OF INFRASTRUCTURE AND ITS RESILIENCE IN REMOTE AREAS

Remote, non-urban remote areas have borne the brunt of earthquake devastation in most of the earthquakes in the Indian subcontinent over the past 15 years. As access to these areas is limited or non-existent immediately after an earthquake, these are the stories that do not get written about. The density of population is low while the spread of habitat is wide, hence damage and loss assessment is a challenging task in the region. What is a recurring theme in all the interplate earthquakes in the Himalayan belt (the collision of the Indian plate moving northwards and the Eurasian plates is the main cause of the earthquake activity in South Asia), is that the earthquakes trigger very massive landslide activity.

While landslide activity is largely a product of the geological features of the topography and rock formations of the region, poor application of engineering skills in development of roads in this region cannot be discounted as one of the main culprits for the ensuing challenges in relief and rescue in the aftermath of an earthquake.. Cuts on mountain slopes for roads should be native cuts for the full width of the roads, rather than on fill soils with retaining walls to ensure stability. However, quite the reverse was observed in Sikkim. Poor drainage system to inner edges of the cuts also causes erosion leading to vulnerability to landslides. Engineering expertise and good construction techniques are found wanting. Typically, ad-hoc and trial-and error methods are employed, and important detailing of the roads, drainage and mountain cuts is left to the wisdom of the local supervisor, compromising safety of the build. Oftentimes, specific geological data and support from structural geologists is not sought for assessing slope stability.

From the experiences of the recent 2011 Sikkim earthquake and the 2005 Kashmir earthquake, it is fairly clear that governments need to focus their attention on seismically engineered highway building along the mountains of the region. It is of paramount importance that road communication lines must be open at all times for search and rescue immediately after the event as well as for relief and longterm rehabilitation. There is need for redundancy in road transport systems and alternative roads should preferably be available in the event of one road being closed due to a landslide or rock fall.

Figure 9. Landslide in Sikkim Earthquake 2011

Figure 10. Landslide in Kashmir Earthquake 2005 (Rai, Murty)

Other lifelines such as telecommunications and power must also be more robust. In the 2005 Kashmir earthquake and the 2011 Sikkim earthquake, telecommunication lines were down for a few critical days in the remote regions immediately after the earthquake. Large number of schools collapsed or were severely damaged in the 2001 Bhuj earthquake as also the Kashmir and Sikkim earthquakes. Several hospitals were too damaged to be functional. The government needs to impose stricter design and constructions requirements for lifelines and critical structures such as schools and hospitals.

4. SUGGESTED POLICY FOR SEISMIC SAFETY IN REMOTE AND POORLY ACCESSIBLE AREAS WITH HIGH SEISMIC HAZARD

From the review of recent earthquakes in the Indian subcontinent that have affected remote, rural areas, it is seen that the magnitude of the disaster could have been subverted if well-defined strategies for mitigating and managing disasters in such places were in place.

The first issue that needs to be recognized is that the strategies for disaster management and mitigation in urban and remote rural centres have to be very different. In urban areas, an earthquake of the same magnitude can affect several times more people and can cause far-reaching damage and loss. There needs to be very strong disaster mitigation systems in place alongwith disaster management. The resources of trained manpower and capital available for such a program are far more as it the political will to operationalise such a program.

In remote areas, there is poor capacity of the local government to handle such disasters. They are handicapped with almost no equipment or trained personnel for rescue and relief and agencies such as Border Roads Organization which do a stellar job in maintaining roads under civilian times are overwhelmed with the scale of landslides in an earthquake. So the first focus should be to build infrastructure better in the first place. There is little to suggest that mountain roads in the region are being cut in a stable and safe way considering all geological and seismological features of the terrain. So infrastructure should be considered the responsibility of the State, while building safe houses should be the responsibility of the private citizen. The State may support the capacity building of the villager through intensive ICT and dissemination of safe building practices. Search and rescue training alongwith basic equipment (cutting and drilling tools, cranes and so on) should be imparted to the villages. Most villages in remote areas have a well-established local self-government who should be co-opted into the scheme and practice drills should be conducted by them at regular intervals.

The following policy may be adopted by emerging countries to ensure seismic safety which does not require very high capital investment but would provide longterm sustainable road map for seismic safety

1) For individual houses in remote areas of seismic hazards, prepare and disseminate detailed, prescriptive manuals for self-build homes with a range of choices of construction materials and architectural options. It may be prudent to restrict building heights to two or maximum three storeys in remote villages in view of limited access to technical support.
2) Aggressively promote resurgence of traditional building technologies which have proven their earthquake-resisting attributes in past earthquakes. The state may need to relook at their policy for use of forest products such as wood in homebuilding in areas of high seismic hazard and instead have more aggressive reforestation projects to replenish what is lost to building construction.
3) Lifelines Structures such as schools, hospitals, power and telecommunication systems and their structures must be designed by qualified and registered engineers and vetted by a subject expert. A regulatory framework for granting permissions for such structures and a monitoring mechanism needs to be put in place at the state level or even at national level.
4) An audit of the stability of mountain slopes along existing main highways must be carried out in all areas of high seismic hazard and steep mountainous slopes. New roads must be engineered with help of seismic geologists and seismic engineers. A basic manual for roads and bridges in regions of high seismicity may be prepared and disseminated for use for such construction.
5) Develop local resilience by training residents in disaster rescue and relief. (It is often found that the local residents do not possess basic tools for cutting through the debris to save people underneath and sometimes help takes days due to blocked roads by which time it may be too late.)
6) Limit new development in far flung areas of high seismic hazard with poor access and vulnerable slopes. Planning norms needs to be judiciously formulated so as to protect the existing residents while at the same time mildly discourage large industrial developments in these regions.

5. CONCLUDING REMARKS

Most often, areas of high seismicity are of relatively low development priority. There appears to be a reluctance to expend large resources in disaster mitigation and management for a small segment of society. In democratic societies, these communities, due to their insignificant population, are rendered irrelevant in the electoral process and are not able to demand better infrastructure or services. Governments, while in reality remain unconcerned, pay lip service to such regions announcing ambitious plans to improve the seismic safety of such areas after a large event. These communities and their problems cannot be wished away. While trying to alleviate the disproportionate burden such communities may be placing on the urban fabric, it is still the responsibility of the state to ensure their access to safety, relief and rescue in the event of an earthquake. It appears that the governments of India and Pakistan need to be more sensitized to the high seismic hazard of the region coupled with the existing stock of vulnerable buildings and infrastructure. While they may leave seismic strengthening of private homes to the home-owner, it is incumbent on the government to ensure that mountain highways, public infrastructure and lifelines are designed for the seismicity of the region.

As the magnitude of earthquake risk in urban centres increases with the growth of their agglomerations at an astounding pace and the attention of the State is focused on urban risk reduction, the risk exposure of people living in remote areas of high seismic hazard is also increasing. The State has to first acknowledge that it is not possible to provide the same level of rescue and relief in such far-flung areas and hence there is a greater need to build self-reliant communities trained in constructing earthquake resistant homes using traditionally proven technology or using simplified new methods of construction as well as rescue training as first responders in an event. It is clearly the responsibility of the State to ensure good, resilient infrastructure in such regions and for this a comprehensive policy, a regulatory framework and a robust implementation mechanism need to be put in place. Presently the road construction in hilly regions is done using heuristic approach which is prone to landslides in earthquakes. This approach needs to be revised. Additionally, some amount of redundancy needs to be provided for critical road communications.

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