Earthquake Sources in India and Strategies for Hazard Mitigation

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The Indian subcontinent features many characteristic earthquake sources: those associated with the continental collision boundary (Himalaya); subduction zone (Andaman and Nicobar); ancient rifts (Narmada, Kutch); non-rifted regions (peninsular shield) and reservoir triggered (Koyna). Each of these regions is characterized by varying rates of recurrence, styles of deformation and coseismic effects. During the last decade and a half, we have witnessed earthquakes typical of each of these seismic sources. The earthquakes at Killari (Latur), 1993; Jabalpur, 1998; Chamoli, 1999; Bhuj 2001 and the Andaman-Sumatra, 2004 are typical earthquakes that originated in some of these characteristic seismic sources. The seismic hazard assessment and mitigation strategies in these regions have to evolve from a proper understanding of their characteristics. For example, large earthquakes in the Himalaya may recur during intervals of a few hundreds of years; those in the interior of the plate (like Killari) may be associated with recurrence intervals of the order of several thousands of years. The effects of the earthquakes can also be dramatically different in these regions. For example, liquefaction of soils was a primary cause of damage during the 2001 Bhuj earthquake. Response of engineered structures in each of these regions can also differ based on the attenuation characteristics, site response etc. Thus, damage mitigation strategies need to be based on the source characteristics (size, depth, style of faulting, nature of recurrence etc., and site effects (liquefaction, site amplification, ground failure etc.). Each earthquake provides site-specific data useful to develop appropriate strategies in hazard mitigation. This talk is about how the observations at each site can be used to develop strategies for hazard reduction, with specific emphasis on the earthquakes in the peninsular India.

The 1993 Latur earthquake occurred at a site not previously known as a potential source and this lack of anticipation and inadequate preparedness were factors that added to the severity of damage. Earthquake monitoring in these regions were also treated with a relatively lower priority, with the result that there was no seismic stations in the close proximity of the 1993 source. Thus, any foreshock activity that may have preceded this earthquake was not recorded; the observatory at NGRI, Hyderabad recorded a couple of smaller events. However, the activity was not significant enough to raise an alarm. Post-1993 earthquake studies in the source zone of Killari earthquake and its adjacent regions suggested the existence of a NW oriented structure, not mapped on the surface, but evident from remote sensing imageries as well as the pattern of historically documented earthquakes. Paleoseismological investigations in this region helped to identify another possible source at Ter, located about 50 km NW of the 1993 source, where an earthquake dating to about 1500 years B.P. was inferred from geologic evidence. The seismic source at Killari seemed to be generating earthquakes at long intervals of time, possibly in the range of a few thousands of years, in agreement with similar settings in other continental interiors (Rajendran and Rajendran, 1999a). The important conclusions, derived from these studies are (1): that the interseismic intervals in such settings can be longer than what may be perceived from the subdued surface geological features (2) the shallow source and efficient energy transmission together with the multiple reflections caused by the surface layer can be damaging to the non-engineered small dwellings that dominated the built environment at Killari (3) the seismic hazard assessment in such cases must follow rigorous practices, starting with the identification of active faults, development of recurrence models and evaluation of site effects and develop possible scenarios of ground shaking. This practice assumes importance while planning for
critical facilities such as nuclear power plants in regions with no record of recent or historic seismicity, but presumably have featured moderate earthquakes in the past, whose surface expressions have been eroded and fault traces are not exposed.

Unlike the 1993 Killari earthquake, the 1998 Jabalpur earthquake occurred in a well-defined tectonic structure, the Narmada rift that cuts across the Indian subcontinent (Rajendran and Rajendran, 1999b). This structure has generated earthquakes in the past and thus, its occurrence was not a surprise as in the case of the Killari event. However, the damage was relatively lower, primarily because of its deeper crustal source. Unlike the Killari earthquake that occurred in the non-rifted continental crust, the Jabalpur earthquake occurred within a Precambrian rift system that possibly features many preexisting weak zones as well as relic mantle plumes at the crust mantle boundary. Such residual high-density material are known to cause earthquakes in other rifted regions such as the New Madrid seismic zone in the USA where high density rift pillows seem to lead to stress localization (Zoback and Richardson, 1996). Whether the stress accumulation associated with such high density bodies are responsible for the deep crustal earthquakes within the Narmada rift needs to be further explored.

The 2001 Bhuj earthquake and its predecessor of comparable magnitude that occurred in 1819, occurred in the Kutch Rift, where the stresses associated with the rift system has changed from extensional to compressional, in response to the interplate deformation along the Himalaya. However, the earthquakes associated with Kutch rift differ from those in the Narmada rift in many respects. One, that these mid-crustal earthquakes occur in an younger (Mesozoic) rift that apparently is associated with multiple seismic sources that seem to have the capacity to generate large earthquakes (compared to the moderate size events in the Narmada rift). Two, that these earthquakes have the capacity to lead to extensive liquefaction and site amplification, within the sedimentary basin. Our studies have indicated that the Kutch rift features multiple sources that are associated with varying recurrence intervals- the predecessor of the 1819 earthquake is likely to have occurred about 1000 Yrs. B.P and that of the 2001 earthquake about 4000 yrs. B.P (Rajendran et al 2007). Such variations could possibly be related to the nature of the seismogenic sources in the rift- for example, the response of the boundary faults of the rift and the mafic bodies at the crust-mantle boundary must be responding differently to the stress field. The dimensions of the fault and the source characteristics also seem to vary within the same rift. For example, the 1819 earthquake generated a 60-90 km long scarp; the 2001 earthquake was associated with a much smaller source volume confined to about 25 km². Thus, disparities in source characteristics, rupture directivity, aftershock decay etc., which deserve important considerations in the hazard evaluation seem to be related to the nature of source in question. The relative proximity of the Kutch rift to an active plate boundary is another factor that may discriminate it from the mid-continent Narmada rift.

In terms of learning from recent earthquakes and using these lessons for assessing the seismic hazard, earthquakes such as the 2001 Bhuj event has much to offer. This is probably the largest and most-damaging rift-related modern-day earthquake to have affected a semi urban environment. The response of the built environment close to and far away from its source offered a demonstration of the site response, effects of liquefaction and the response of a variety of buildings- from conventional to poorly engineered as well as properly designed multistoried structures. Unfortunately, the Kutch region was poorly instrumented prior to 2001 and thus, much of this information that should have been based on the strong motion data are not available. However, the post-earthquake studies using the ground deformation as well as aftershock data provide useful images of the ground characteristics useful for future hazard evaluation (e.g., Mandal, 2007). The hazard evaluation in such regions must take advantage of the geological and seismological data together with the response of the built environment to facilitate hazard zonation.

Lessons learned from studies of recent earthquakes are useful also in the evaluation of the seismogenic potential of regions where no earthquakes have been reported since historic times. Assessing the
earthquake histories of such regions has become important when planning for critical facilities such as nuclear power plants. For example, we are attempting to evaluate the seismic hazard associated with the Panvel flexure, a NW trending structure in the proximity of the Tarapur power plant, using uplifted coastal terraces and other indicators of movement as proxies of recent tectonism.

In summary, the seismic sources in India are associated with a variety of settings- from non-rifted to rifted continental crust and collision and subduction zones. Although the fundamental source for the stress can be traced to the India-Eurasia collision, the deformation rate and therefore the recurrence as well as the earthquake effects vary from one site to another. A comprehensive evaluation of the characteristics of each source zone is imperative to realistic seismic hazard evaluation.

References