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GUEST EDITORIAL

Earthquake prediction: a game of chance?

'There was a time when the weather belonged to gods. ... There was a time when the earthquake was equally enveloped in mystery, and was forecast in the enigmatic phrases of the astrologer and the oracle; and now that it too has passed from the shadow of the occult to the light of knowledge, the people of the civilized earth – the lay clients of the seismologist – would be glad to know whether the time has come yet for a scientific forecast of an impending tremor'.

— G. K. Gilbert, 1909.

Nearly a century has passed after G. K. Gilbert, a pioneering geologist who studied the great 1906 San Francisco earthquake, wrote these lines but the ability to issue a scientific forecast hours or days before an earthquake still remains the greatest challenge for the seismologist. The clientele of the seismologist continue to remain perplexed about the intricacies of earthquake prediction. How close are we to making reasonable forecasts on the size, location and time of an impending earthquake? Seismologists remain divided on the prospects of successful short-term prediction, more of them skeptical, crediting an occasional success to sheer chance.

The recent devastating earthquake in the India–Pakistan border of Kashmir has triggered fresh rounds of discussion on the prospects of earthquake forecast in the Himalaya. Media and website reports warn of future earthquakes in the Himalaya that could affect many of the modern cities in the plains of the Ganges river. Speculation that the Himalaya is overdue for large earthquakes has been in the air for a while, an observation based on the seismic gap hypothesis. In its simplest form, the seismic gap theory suggests that segments along a particular fault that have not broken in the past are likely candidates for future earthquakes. Many such gaps have been identified along the Himalaya; the October 2005 earthquake partially filled one such gap between two large earthquakes, 1905 Kangra and 1885 Kashmir.

If indeed the earthquake occurred in a zone that was previously identified, can it be treated as a successful forecast? Are there more such earthquakes in the offing and do we have a time frame for such events? From the layman's point of view there is yet another fundamental question, to which the scientific community owes an answer. This question, which echoes in many discussions is the following: if it is possible to forecast where the next large earthquake might occur, what prevents scientists from predicting its time and precise location, leading to a timely warning?

The Himalaya has generated many great ($M > 8$) and large ($M > 7$) earthquakes in the past, but it has been going through a general quiescence for more than half a century. Such quiescence and the longevity of unruptured segments form the basis for long-term earthquake forecast. The implicit assumption here is that the plate boundary is subject to uniform deformation. That is not prediction; it can at best be called 'long-term forecast', the period involved here is years to decades in advance. Long-term forecasts help to identify potential sites where prediction may prove more logical. However, prediction must follow much more rigorous monitoring of the faults in question, it must be based on data that explain observed spatial and temporal patterns of earthquakes and other related processes. It must also state, with some error estimates of course, the probability for an earthquake of specific magnitude to occur at a location, within a defined time window. Is that a realizable goal yet? Or is it still a game of chance?

A recent paper, 'Implications for prediction and hazard assessment from the 2004 Parkfield earthquake' by Bakun and 18 others (*Nature*, 13 October 2005) eloquently demonstrates why short-term (hours to weeks in advance) earthquake prediction continues to be a tricky affair. The authors do not mince words in stating that short-term earthquake prediction is still not achievable. These conclusions, coming from the pioneers of a meticulously planned prediction experiment, spotlight complexities in earthquake processes and our inability to comprehend them.

Clearly, understanding earthquake processes is fundamental to prediction and that is why such experiments have better chance of success at locations with known earthquake histories. Parkfield, a tiny town along the San Andreas Fault in central California, features a segment that has generated earthquakes in 1857, 1881, 1901, 1922, 1934 and 1966. With its apparent regularity at intervals averaging 22 years, Parkfield seemed ideal for a prediction experiment. The primary goal of the experiment was to obtain a detailed understanding of the processes leading to an earthquake. Issuing a public warning shortly before the earthquake was its secondary goal. Regarded as the earthquake capital of the world, Parkfield attracted much attention, when the forecast for an earthquake of M 6.0 was issued, during 1988–1993. It was again in the spotlight as the prediction window closed without much ado. When an earthquake of M 6.0 finally occurred on 28 September 2004, its size and rupture extent were as anticipated, but it was running late by more than ten years, and its direction of rupture propagation was opposite of what was expected.

Despite its apparent failure to make a successful prediction, the Parkfield experiment yielded a wealth of data on precursors or lack of them, thereof. With a variety of geophysical instruments, strain meters, GPS sensors and observations in a deep bore-hole, Parkfield produced one of the world's best-documented data, preceding a moderate earthquake. This data include subtle strain changes, foreshocks, and changes in groundwater, electrical field and more. That is the level of understanding that an experiment in earthquake prediction demands. With a detection threshold of M 0, the seismic network recorded no shocks during the six days that preceded the earthquake. No precursory signals were detected in the magnetic field, apparent resistivity and creep measurements. This lack of precursors, as Bakun and his coauthors note, is what makes short-term prediction difficult. In fact, the lack of precursors is not quite the Parkfield style; some of the earlier M 6 earthquakes were preceded by significant foreshock activity.

The scenes of devastation from Kashmir bring to mind haunting images of destruction in central India generated by the 1993 Latur (Killari) earthquake. Because this part of the country lacked a known history of past earthquakes, there had been little consideration of seismic design, and the severity of damage was primarily attributed to poor standards of construction. In terms of magnitude and earthquake recurrence, Killari has its parallels, in Australia, Canada and other stable continental interior regions, considered to be generally stable. If plate boundaries such as the Himalaya and the San Andreas Fault offer opportunities to identify potential gaps, Killari type of situations provide no such clues. Here the schedule is also different, with recurrence intervals of the order of several hundreds or thousands of years.

There is a next-door neighbour, at Koyna, which never gets exhausted. It boasts of a 44 year-history, dotted with 20 earthquakes of M 5 and above, including one of 6.3. There is no periodicity per se, but a causal association with the filling of the Shivajisagar Lake. The earthquake process here appears to be influenced by the rate of loading of the reservoir, retention of the highest lake level and the previous maxima. With near-laboratory conditions where external factors drive the earthquake machine, is prediction at Koyna a better gamble? Undoubtedly yes, but only as a special predictive game that's hard to play elsewhere. With a limited area influenced by the reservoirs, this region is almost like a wired laboratory with its own command lines and logic trees. After having chased Koyna seismicity for nearly half a century, maybe some patterns are emerging – of cause and effect, of self-similarity and a vague sense of order. These patterns continue to tease us, making the game of prediction rather alluring. Still a game of chance, because the processes that keep Koyna alive continue to defy full comprehension.

India has its own samples of purely natural earthquake sources – plate boundaries, subduction zones, ancient rifts, unrifled stable regions and more. So, when a large earthquake occurred in Bhuj, in 2001, there was less surprise because the region was visited by a similar earthquake in 1819. Again, the question is, if there is a history, can it be used to forecast future earthquakes? Historical, archeological and geological data open an archive of information, pulling out ghosts of earthquakes. The same is the story with other active regions such as northeast India, whose pasts are also dotted with a few earthquakes, but the calendar remains vague. A vague calendar is good enough to make some intelligent guesses, but not a forecast, let alone a short-term prediction. Yet, building a chronology of past events is important because information on past earthquakes and causative faults form the basis of future experiments. They also help in selecting appropriate design codes and in developing hazard scenarios.

Perhaps, predicting earthquakes and issuing timely warnings may not be realizable in the near future, but that doesn't mean we can't take useful steps toward identifying and defining earthquake and tsunami hazards. Today's seismic-hazard maps already identify most regions that are likely to generate future large earthquakes. Moreover, today's engineers have the capability to assess how the built environment is likely to respond, and how to make structures that can withstand earthquake. The question is whether we are following the required standards. Images of destruction from Kashmir, Bhuj and the Andaman and Nicobar Islands do not seem to suggest so. Discussions on the impending threat to major cities like Delhi and Mumbai continue unabated, but a large percentage of buildings in these cities do not meet the minimum standards. Whether or not scientists succeed at predicting earthquakes, there must be a commitment to apply minimum standards, because that alone can actually minimize the damage.

Short-term earthquake prediction may continue to be a game of chance, but the improved instrumentation and the data generated around the world are helping to understand the processes leading to earthquakes, in ways that were not possible before. With the level of data collection and ability for real-time communication, today it looks possible to use the lag time between the primary (P) and secondary (S) waves, to give a few seconds alert of an approaching train of damaging waves. That is how we might inch towards progress, in this tough game of chance. Indeed, the game of earthquake prediction demands trained and skilled players, well-maintained playgrounds, good referees and rigorous standards. The opponent is unpredictable, deadly and does not always play by the rules.

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