OPINION

Lessons from the Haiti earthquake

Roger Bilham, one of the first seismologists to visit Haiti after last month's earthquake, calls for UN enforcement of resistant construction in cities with a history of violent tremors.

SUMMARY

- Engineering could have averted much of the damage in Port-au-Prince area
- There is now a greater risk of further earthquakes there
- A building code should be mandated in earthquake-prone cities

With an official death toll of 230,000 and thousands still buried beneath collapsed structures, the Haiti earthquake of 12 January was more than twice as lethal as any previous magnitude-7.0 event (Fig. 1). In my visit to the region in the weeks after the earthquake, the reason for the disaster was clear in the mangled ruins — the buildings had been doomed during their construction. Every possible mistake was evident: brittle steel, coarse non-angular aggregate, weak cement mixed with dirty or salty sand, and the widespread termination of steel reinforcement rods at the joints between columns and floors of buildings where earthquake stresses are highest.

For earthquake engineers[1], the damaged city constitutes a nightmare of diabolical proportions. Arguably, the amplification of surface seismic waves crossing the soft sedimentary plains on which most dwellings were constructed contributed to their collapse. Partly because of this, and partly because of the westward propagation of the rupture, damage was less on the bedrock hills south of the city, and far more on the coastal plains near Léogane 30 kilometres to the west. But the survival of top-heavy water towers amid areas of pancaked ruins in low-lying areas illustrates that the disaster could have been averted had sound construction practices been adhered to throughout the region.

The death and injury of about 15% of more than 2.5 million people in Port-au-Prince and its urban agglomeration, and the roughly 1.5 million people now homeless, is a consequence of many decades of unsupervised construction permitted by a government oblivious to its plate-boundary location. Seismologists have written and spoken extensively about the possibility of damaging earthquakes occurring on this part of the Caribbean plate boundary. Even had there been listeners empowered to act on these warnings, it is clear in hindsight that the monumental problem of retrofitting killer buildings would never have taken precedence over Haiti's economic woes.

The lessons from this tragic event are manifold — for seismologists, for the construction industry and for the international development community. Community leaders responsible for the safety of their citizens need to act on seismologists' forecasts of future earthquakes, based as they are on a history of repeated damage from previous events.

More shocks soon?

Of the many questions that now arise, one of immediate concern is whether other large shocks are imminent. The 12 January mainshock and its aftershocks occurred on the Enriquillo Fault that runs east–west bordering the northern edge of the Caribbean tectonic plate. Earthquakes cause this fault to slip an average of 8 millimetres a year[2], with the remaining 12 millimetres a year of the Caribbean Plate's eastward motion being absorbed by a parallel fault system in northern Hispaniola[3] (Fig. 2). In 1751, a violent earthquake to the east of the city tumbled nearly all the buildings of Port-au-Prince. In 1770, the reconstructed city was again demolished, possibly by the segment that ruptured this year[4,5]. Since 1770, this fault has been locked, 'holding back' almost precisely the amount of Caribbean Plate motion that slipped, about 2 metres, on 12 January. So the good news is that the most recent earthquake seems to have released all the elastic energy accumulated on this segment of the plate boundary since 1770.

Two unsettling aspects of the earthquake make this calculation less reassuring. The first is that the field searches of the area around the epicentre found no rupture of the surface above the plate-boundary fault. This is consistent with radar images from space taken before and after the earthquake[6] showing that rupture started more than 8 kilometres underground, but ended at least 2 kilometres below the surface. Offset roads, fences and streams are usually the smoking gun of surface rupture, and it is rare for large earthquakes to show none. However, there are several precedents, for example the 1989 magnitude-6.9 Loma Prieta earthquake in California and the magnitude-7.6 Bhuj earthquake in India in 2001.

The absence of surface rupture is dire news for those geologists who are eager to dig up the traces of former earthquakes in the long and deep rift south of Port-au-Prince that marks the northern edge of the Caribbean Plate (Fig. 2). By excavating a surface fault, it is possible to read the story of successive earthquakes back in time, through the offset of datable geologic units, sometimes for thousands of years. With such a record of past earthquakes, it is possible to calculate the probable interval and size of future ones. But if this recent earthquake left no record of its passage, then many more will be missing from the palaeoseismic record.

Moreover, the absence of a surface rupture means that elastic energy is still stored in the uppermost few kilometres of the fault. Such pent-up energy will be released, either abruptly, adding to the severity of a future earthquake, or more benignly as aseismic creep[7] — slow sliding of the shallow layers of a

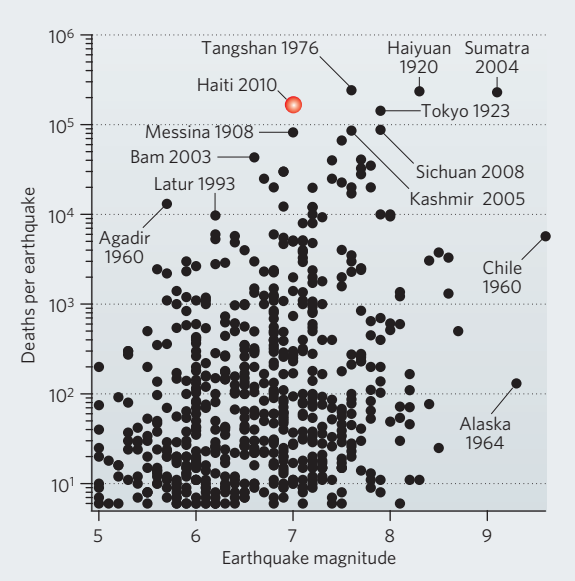

Figure 1 | Deaths from earthquakes since 1900. The toll of the Haiti quake is more than twice that of any previous magnitude-7.0 event, and the fourth worst since 1900 (refs 10, 11).

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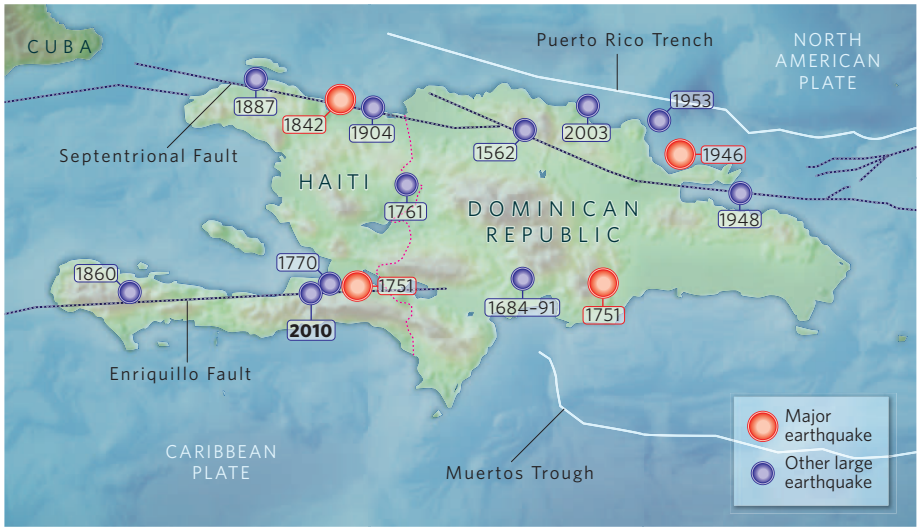

Figure 2 | Earthquake history of the island of Hispaniola. Positioned close to the edge of the Caribbean Plate, the countries of Haiti and the Dominican Republic are always at risk of earthquakes.

fault, above the deeper region where bigger jolts occur. Surface scars within the rift valley that marks the northern edge of the Caribbean Plate suggest that previous earthquakes have repeatedly ruptured the surface in the segment that recently slipped. It is very probable that these were larger earthquakes than last month's. Many thousands will have occurred before historical records began with the arrival of Christopher Columbus.

Building pressure

Of greater concern is that adjacent segments of the fault to the east and west of the recent subsurface rupture are now near breaking point because of stress transferred to them. Earthquakes on these adjoining segments would be as large or larger than the 12 January event[8]. Calculations show a 1–2% chance of magnitude-7 earthquakes in these segments before 22 February[9]. Such forecasts are not an exact science and contiguous earthquakes induced in this way are often delayed months or years by processes that are poorly understood. Yet there is no doubt that the recent shock has enhanced the risk of another earthquake. Disquieting as this news is, a rupture of these segments now would be less disastrous to the flattened capital than one in 20–30 years, after it has been reconstructed, given that buildings are presently abandoned and survivors and rescuers alike live in tents.

Many more cities lie in the path of damaging earthquakes[10,11], and some of them, like Port-au-Prince and Tokyo (devastated by an earthquake in 1923), are capitals whose destruction could paralyse an entire nation. Kathmandu, Tehran, Istanbul and Srinagar are notable for their seismic settings and for the uneven application of appropriate building codes. Most islands in the northern and eastern Caribbean owe their existence to seismic processes on or near the edge of the Caribbean Plate. It is a matter of when, not whether, future earthquakes will shake the cities on these plate boundaries.

The catastrophic earthquakes that have occurred since 1999, in Turkey, Taiwan, Sumatra, Kashmir and Sichuan, demonstrate that elementary engineering guidelines for earthquake resistance in crucial civil structures (schools, hospitals and fire stations,) have been alien concepts to local authorities, or have been ignored. About 80% of all schools collapsed in the Port-au-Prince area, and a similar percentage in the 2005 Kashmir earthquake. Police stations and jails must be added to this trilogy of crucial structures. Never before have more than 4,000 criminals been loosed into the mayhem of post-seismic recovery, as occurred this year in Haiti, which also lost a substantial fraction of its police force.

"Adjacent segments of the fault are now near breaking point."

Since the turn of the century, earthquakes have directly or indirectly (including tsunami) claimed the lives of more than 640,000 people, four times more than in the preceding two decades, and proportionately more than the global increase in population would anticipate. If buildings are not made earthquake resistant, the toll is likely to continue to rise as cities grow in population. Urban earthquakes also bring a huge financial burden to the world. As of 9 February, almost US$2.5 billion of financial aid[12] had been pledged to Haiti to assist its earthquake recovery efforts. Even if half of this aid goes into reconstruction of the estimated 250,000 damaged dwellings and thousands of commercial and civic structures, the sum will amount to less than $5,000 per structure. Given that less-destructive earthquakes in the developing world have typically cost $3 billion–$10 billion[11], earthquake-proof reconstruction in Haiti is likely to cost an order of magnitude more than has been promised so far, even using local materials and local manpower.

Because construction projects are likely to offer employment opportunities for many Haitians in the coming decades, earthquake engineers[1,13] have already articulated the importance of training contractors and labourers in sound construction methods. Even more pressing than additional aid for reconstruction is the need to introduce an adequate building code and a cadre of building inspectors empowered to enforce it.

The future global burden of local earthquakes could be significantly reduced if minimal construction guidelines were mandated in all the world's cities, and especially in those with a history of previous earthquakes. The projected doubling in world population means that we are constructing more buildings now than at any time in our history[10,11]. In recent earthquakes, buildings have acted as weapons of mass destruction. It is time to formulate plans for a new United Nations mission — teams of inspectors to ensure that people do not construct buildings designed to kill their occupants. ■

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1. Fierro, E. & Perry, C. *Preliminary Reconnaissance Report — 12 January 2010 Haiti Earthquake* (The Pacific Earthquake Engineering Research Center, 2010); available at http://peer.berkeley.edu/publications/haiti_2010/documents/Haiti_Reconnaissance.pdf
2. Manaker, D. M. *et al. Geophys. J. Int.* **174,** 889–903 (2008).
3. Prentice, C. S., Mann, P., Taylor, F. W., Burr, G. & Valastro, S. *Geology* **21,** 49–52 (1993).
4. McCann, W. in *Proc. NSF Caribbean Tsunami Workshop* (eds Mercado-Irizarry, A. & Liu, P.) 43–65 (World Sci. Publ. Co., 2004).
5. Kerr, R. A. *Science* **327,** 398 (2010).
6. Laursen, L. *Nature* doi:10.1038/news.2010.51 (2010).
7. Bilham, R. *Bull. Seismol. Soc. Am.* **79,** 425–450 (1989).
8. Ali, S. T., Freed, A. M., Calais, E., Manaker, D. M. & McCann, W. R. *Geophys. J. Int.* **174,** 904–918 (2008).
9. Lin, J., Stein, R. S., Sevilgen, V. & Toda, S. *USGS-WHOI-DPRI Coulomb stress-transfer model for the January 12, 2010, Mw=7.0 Haiti earthquake* US Geological Survey Open-File Rep. 2010–1019 (USGS, 2010).
10. Hough, S. E. & Bilham, R. *After the Earth Quakes* (Oxford Univ. Press, 2006).
11. Bilham, R. *Bull. Earthq. Eng.* **7,** 839–887 (2009).
12. www.guardian.co.uk/news/datablog/2010/jan/14/haiti-quake-aid-pledges-country-donations
13. Tucker, B. *Architecture as Aid: Preventing Another Haitian Crisis* Presentation to the World Affairs Council, 2 February 2010; available at http://geohaz.org/news/presentations.html