# Future Earthquakes on the Indian Subcontinent: Inevitable Hazard, Preventable Risk

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## Introduction

In five years the Indian subcontinent has been hit by massive earthquakes that have left a trail of ruin on its west, northwest and eastern boundaries. Like an alarm clock that won't be silenced, this activity represents a wake-up call to the governments and citizens of South Asia. If steps are not taken now to reinforce cities, future earthquakes will cause future disasters on an unprecedented scale.

Earthquakes in and around India are as inevitable as the autumnal fall of fruit from a tree, but while the precise timing of earthquakes in the Himalaya, as elsewhere, remains unpredictable, catastrophic loss of life, such as that following the 8 October 2005 Kashmir earthquake, is neither inevitable nor defensible. When the earth shook, half a million dwellings, including schools and hospitals, offered little or no resistance to shaking, leaving over 73,000 people dead and 1.5 million homeless. Not all of casualties and deaths were caused by building damage; landslides and rockfalls added to the ruin. Still, the roots of the tragedy lie not so much in an Act of God as in the inaction of man. There has been woefully little awareness of earthquake hazard among the peoples and governments of the Himalaya region, and correspondingly little action taken to mitigate the corresponding risk to lives and property.

The blame for this falls as much on the seismologist as on the politician. Those who have best understood the potential threat from earthquakes in the world's highly active seismic zones have done little to communicate their understanding to the growing numbers of people who live in those zones. This article attempts to bridge that gap.

## Earthquakes as Bombs: A Natural Release of Nuclear Energy

Ultimately, earthquakes owe their origin to the escape of heat generated by nuclear decay deep within the earth. This heat keeps much of our planet plastic, its rock in motion just as heated soup bubbles in a pot, but far more slowly. The earth's colder, harder outer shell, or *crust*, is broken into enormous jigsaw puzzle pieces scientists call *plates*. These plates ride atop the cauldron that continues to churn underneath, conveyed hither and thither, ponderously but with determination. Geologists can now trace the past motion of continents back many millions of years; the motion of the continents has remained largely unchanged during this time. Abundant geologic evidence tells us that India was once in the southern hemisphere and attached to present-day Antarctica. It broke away from Antarctica 180 million years ago and rafted into its current position at speeds of 5-15 centimeters per year, about as fast as a human hair grows.

Roughly 50 million years ago the island of India began to collide with the southern shores of Asia. Via this prolonged process of collision, the Himalaya was born. With the advent of the Global Positioning System (GPS), scientists have measured the continuing northward motion of India at approximately 4 centimeters per year. That is, the northward migration of India has slowed but not stopped. This continuing motion places the Himalaya in a vice grip. The collision of India into Asia would be of little consequence if the earth's crust were able to warp gradually in response to the resulting pressure. Unfortunately for the inhabitants of India, Pakistan, Tibet, Nepal, Bangladesh, Bhutan, and Burma, the earth's plates remain tightly locked at their boundaries, moving in the abrupt paroxysm of an earthquake only when the forces have developed sufficiently to ov

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come enormous frictional forces that keep the plate boundaries locked. When this happens, huge blocks of crust lurch along surfaces known as faults. Thus, while India as a whole continues to move relentlessly northward, its edges remain stuck. Just as a water reservoir can collect a steady flow of water that eventually has the capability to release a large flood, the boundary between plates acts as an energy reservoir, deforming the rocks until their stored energy is released in large earthquakes.

The collision of India and Asia squeezes and wrenches many thousand cubic kilometers of rock. Because of this, the process stores up, and eventually releases, enormous energies. The energy released by earthquakes in Indonesia and India just since the start of the new millennium is close to that of a 400 Megaton bomb. The magnitude 9.2 Sumatra earthquake of December 2004 alone released the equivalent of a 250 Megaton bomb. The magnitude 8.7 earthquake that struck the following March released a further 80 Megatons, while the 2001 Bhuj and 2005 Kashmir earthquakes released about 30 Megatons apiece. Large earthquakes not only release more energy than smaller shocks, they also involve the motion of larger segments of faults, and so spread their destructive wrath over larger regions.

The occurrence of four portentous earthquakes in just four years leads to obvious questions. Has the spate of activity come to an end, or will still more energy be released in coming years? Are any of the previous earthquakes related, and, if so, how? Many such questions cannot be answered because, while scientists understand the long-term forces that build the Himalaya, we do not understand the short-term processes that control the timing of individual earthquakes. Some earthquakes do appear to trigger other large earthquakes, but the delay can range from very short (seconds-minutes) to much longer (years-decades), for reasons that scientists do not fully understand.

But where present science fails to frame a certain future, past history can provide some clues about what the earth might hold in store for us. We can, for example, look to history to seek patterns of past earthquakes that resemble those occurring in recent times. Geologists can also look to history to determine how often, on average, large earthquakes have struck a given region.

The tools for historical earthquake investigations are often incomplete because so much data have been lost in wars, fires, or by the destruction of written materials by biological decay. Despite the frustratingly patchy nature of historical data, the very largest earthquakes tend to leave notice of their passage: chronicles of widespread and simultaneous destruction of cities, sometimes written down and sometimes preserved in oral traditions and legends. Sometimes the chronicle of earthquakes can mislead investigators through muddled information. For example, an earthquake in AD893 Armenia was placed accidentally in the Indus delta through a confusion in place names, and another in 1668 near Tatta may have been much smaller than hitherto believed (Ambraseys, 2004). Similarly, a translation error placed an enormous, though quite fictitious earthquake in Calcutta in 1737 (Bilham, 1994).

Figure 1 shows the most recent earthquakes that have struck along India's highly active plate boundaries and the locations where earthquakes are expected to occur in the future. In places like Kashmir, where no massive earthquake had occurred for 450 years prior to 2005, a measure of the size of the pending earthquake had been obtained by estimating the amount of energy stored since the last similar earthquake in that region (Bilham et al, 2001; Bilham and Wallace, 2005). However, to estimate the potential size of future earthquakes seismologists must know two things: the amount of energy that has been stored and the size of the fault on which that energy would eventually be released. For example, in the 2005 Kashmir earthquake, had the motion of the mountains near Muzafferabad extended all the way to the Kangra region of Himachel Pradesh, the earthquake would have exceeded magnitude 8.2. Prior to last October 8, scientists would have been unable to predict where a large earthquake would stop once it started.

The history of Kashmir shows that the region, in common with the entire Himalaya, is visited regularly by moderate earthquakes, and much less frequently by savage ones. Massive earthquakes, with magnitudes approaching or even exceeding 8.0, will be centuries apart along any given segment of the plate boundary. The potentially devastating effects of such events are therefore forgotten by successive generations. In Kashmir we have an especially long historical record : earthquakes of various degrees of severity occurred in

883, 1123, 1501, 1555, 1669, 1736, 1779, 1784 and 1885 (Iyenger and Sharma, 1993). Of concern to historians and seismologists is that the Kashmir region is unique only in that a written record of earthquakes has survived there. The historical record throughout the Himalaya, though patchy prior to 1500 suggests that no part of the Himalaya can be considered immune from future earthquakes (Figure 1). The 8 October earthquake could have struck in any one of a dozen locations between Afghanistan and Assam, with equal or even worse effects.

**Earthquakes between 1500-1950**

The largest Himalaya earthquake in modern times was the magnitude 8.7 Assam earthquake of 1950. Its effects were not well studied because it struck a remote and mountainous corner of India, Myanmar, and Tibet, but it damaged houses in a large region in the Medog province on the Tibetan plateau. The severity of its effects in Tibet were reported recently in Chinese translations of Tibetan texts. Two other 20th century earthquakes ocurred in the Himalaya – the first near Kangra in 1905 and the second in 1934 in eastern Nepal. The severity of shaking in the Bihar provide in 1934 led to the supposition that the earthquake was centered beneath the northern Ganges. However, a detailed study of seismograms placed the epicenter, or starting point, of this earthquake a few hundred kilometers south of Mt. Everest, and Nepalese accounts of the event tell of massive shaking in the mountains.

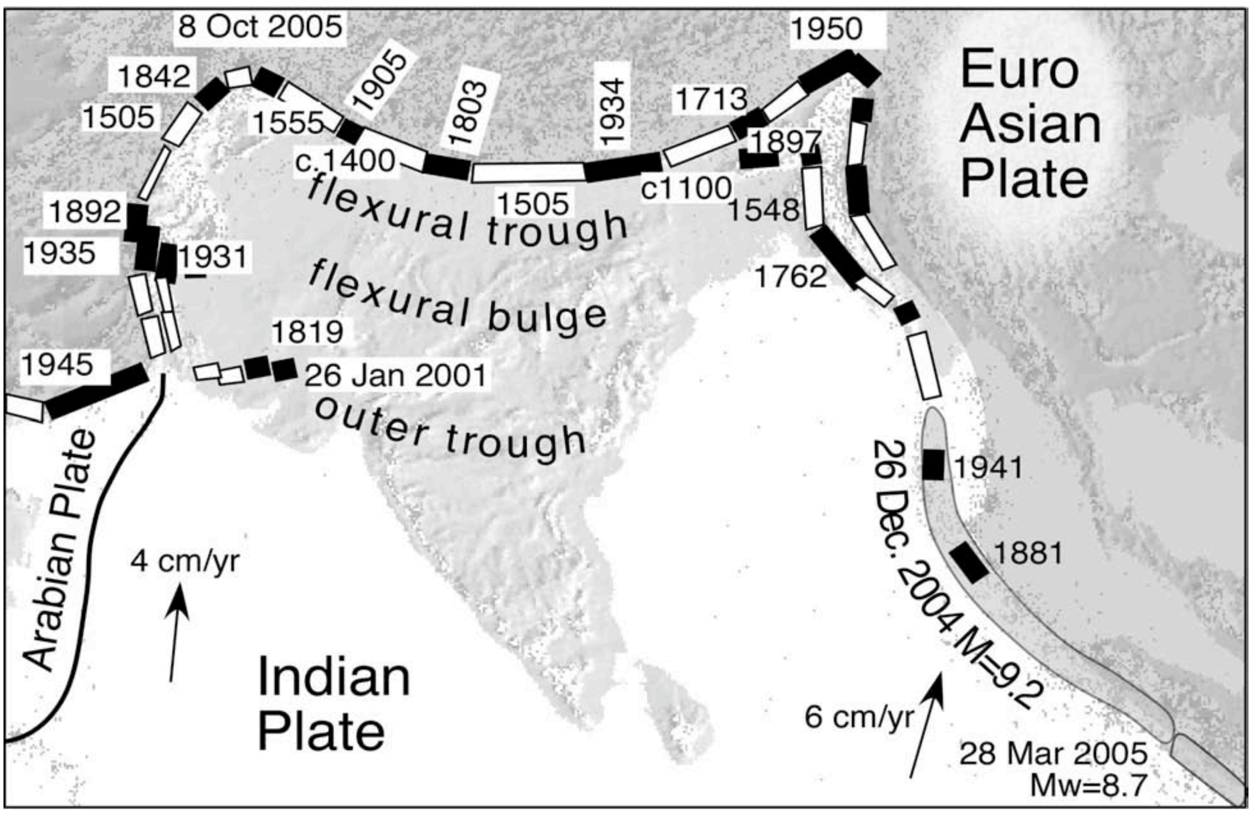


Figure 1 The collision between the Indian Plate and the EuroAsian plate is marked by a continuous belt of earthquakes between them, and by buckling of the Indian plate. Significant recent earthquakes (M>7.5) are shown as black bars. Historical earthquakes (date indicated), and/or regions where future damaging earthquakes 7.5<M<8.5 can now be expected are shown as white rectangles. The Sumatra earthquakes are shown as grey shading. India's northward movement has a slight counter-clockwise spin resulting in earthquake productivity increasing eastward. The collision buckles India into a 450 m high bulge in central India, with a trough to the north where India is forced to descend beneath the Tibetan plateau, and a minor trough to the south. Earthquakes within the subcontinent (e.g. Latur, 1993; Seeber et al., 1996) release stresses arising from these bending forces (Bilham et al., 2003).

The 1905 and 1934 earthquakes also tell us that damage from Himalayan earthquakes is not confined to the mountains. Once an earthquake strikes, the waves travel throughout the Ganga, Punjab, and Brahmaputra plains, causing especially severe shaking of the thick layers of soft sediments that underlie these regions. Waves traveling to the southern edge of the plains can shoal and crest in amplitude, much like ocean waves do when they approach the shore, causing severe damage to villages and cities more than 100 kilometers from the foothills.

Three notable earthquakes struck in the 19$^{th}$ century: a magnitude 8.2 earthquake north of Delhi in 1803, a sequence of three earthquakes with a magnitude 7.9 mainshock in northern Nepal in 1833, and a magnitude 8.1 earthquake beneath the Shillong Plateau in 1897. Earthquakes in the 17$^{th}$ and 18$^{th}$ centuries are insufficiently well documented for us to estimate magnitudes or locations.

The earliest great (M>8) Himalayan earthquake for which we have detailed information occurred at dawn on 6 June 1505. Descriptions of the earthquake come from survivors in Tibet who wrote of damage to monasteries scattered along a 600-kilometer swath of the southern edge of the Tibetan plateau and the Mustang province of Nepal. Although this earthquake is not recorded in Kathmandu, accounts tell of damage to several cities in India, notably Agra, then a prominent economic center. Agra was rebuilt after the earthquake as the capital of the Lodi administration. The length of the 1505 earthquake appears to have been roughly 3-4 times larger than that of the magnitude 8.2 Bihar-Nepal earthquake of 1934. Simple calculations suggest that the 1505 event may have been in the range 8.4-8.6.

An earthquake struck Afghanistan exactly a month later, on 6 July 1505. Some accounts have confused the dates of these two earthquakes, leading some scientists to conclude that a single massive earthquake occurred. A careful reading of available accounts, however, points to two separate earthquakes, not a single event extending all the way from Afghanistan to Nepal (Ambraseys and Jackson, 2003) . The Kashmir region, which lies between the two large events, appears to have experienced a fairly modest earthquake in 1501 and a larger event in 1555 (Iyengar and Sharma, 1998).

**Earthquakes in Medieval and Earlier Times**

When the historical trail grows faint, geologists instead look to the signature that great earthquakes leave behind not on people and structures, but on the earth itself. Geological excavations of the faults along the base of the Himalaya indicate that earthquakes allowed parts of the northern edge of India to slide abruptly more than 15 meters beneath the Himalaya in eastern Nepal around 1100 AD and north of Delhi around 1400 AD. No historical accounts confirm these earthquakes, the dates of which have been determined using Carbon-14 dating and other methods, and may be off by as much as 100 years. But while their dates are not precisely known, the motion that attended these earthquakes may have in places exceeded 20 meters, with rupture lengths much longer than any since the 18$^{th}$ century. This suggests that these earthquakes were probably also larger in magnitude than any of the recent historical earthquakes. The uncertainty in dating admits the possibility that the 1400 AD earthquake may have in fact been the 1505 event described in the historic record. The 1100 AD earthquake, however, was clearly a separate—and enormous—event (Bilham, 2004)

The geological results are ominous. If the historical record of large earthquakes in the Himalaya is complete since 1400 AD, the geological record tells us that, especially in the western Himalaya, a very much larger earthquake could occur than any witnessed in the last 200 years. In this region enough energy has been stored to generate an earthquake of at least magnitude 8.4. The 1934 Bihar-Nepal earthquake may have reduced the odds of another large or larger earthquake in eastern Nepal, but no great earthquake has struck in Sikkim in historic times, and it would not be surprising were one to occur there soon.

**Myanmar, Andaman and the Nicobars**

The Indian plate comprises far more real estate than the Indian subcontinent (Figure 1). The catastrophic tsunami of December 2004 reminds us that while the Himalaya is the most seismically active zone in the region, activity around the edges of the Indian plate is not confined to its northern edge. In the space of three months a 2000-kilometer-long segment of the eastern edge of the Indian plate shifted by 7 to 15 meters, the result of the December mainshock and a large aftershock the following March. The earthquakes extended north to Cocos and Preparis Island, small islands south of the Irrawady delta of Myanmar. We do not know why rupture stopped at this location but it is probably related to a kink in the plate boundary. The March earthquake extended 400 km to the southeast approaching a plate boundary segment that last experienced a large earthquake in 1833, which now could be considered a likely location for a future large event. There is no question that the massive Sumatra earthquake, the largest in the world for 40 years, has increased stresses on neighbouring parts of the plate boundary. However, we do not know if the plate boundary will continue to unzip to the south or to the north. There is precedent elsewhere around the world for a domino-style cascade of large earthquakes along plate boundaries. A progressive sequence of earthquakes occurred on the Northern Anatolian fault in Turkey, a sequence of earthquakes beginning in 1939 and culminating most recently with the 1999 Izmit earthquake. A similar series of dominoes could topple along the Indonesian plate boundary, although we have no historical evidence to show us that it has done so in the past. And although seismologists can identify sequences of earthquakes after they occur, and understand the pattern of triggering caused by increased stresses, we are far less adept at predicting in advance if and when the next domino in line will fall.

Earthquakes in the Indo-Burman ranges, as in Indonesia, occur in two belts, one in the west and one in the east. Damaging earthquakes have occurred along each of these zones, including one that destroyed Mandalay in the east in 1838 and one that struck near Chittagong in the west on 2 April 1762, whose rupture length is uncertain. Earthquakes in the past century have not exceed magnitude 7.5 in this region, and with the possible exception of the 1762 earthquake we have no examples of great (M>8) earthquakes here. However, prior to December 2004 the largest known earthquake in the Andaman and Nicobar Islands was the 31 December 1881 earthquake beneath Car Nicobar. This Mw=7.9 earthquake, like the Mw=7.7 June 1941 earthquake near Port Blair, produced a small tsunami along the coast of India, but there was no historical precedent for the enormous size of the 2004 earthquake or the devastating tsunami that followed. Similarities in geometry between the Andaman segment and the Indo-Burman segment of India's western plate boundary suggest that the Myanmar segment of the plate boundary could host an earthquake far exceeding any known magnitude in Burma's history.

**Makran, Kachchh, and Baluchistan**

The region near Karachi is particularly complex, the crossroads for four belts of earthquakes. Three of these separate the mighty Arabian, Indian and Asian plates, and the fourth, extending eastwards towards the Indian province of Kachchh, appears to represent a line of weakness in the Indian plate. Scientists still struggle to understand this region, but past events underscore the hazard. The Makran coast was jolted by a magnitude 8 earthquake on 28 November 1945 that produced a significant tsunami near Karachi whose severity decayed southward along the Malabar coast. (Byrne et al 1992). Large and highly damaging earthquakes are reputed to have occurred in historical times in parts of the Indus delta. Well documented earthquakes struck the Rann of Kachchh in 1819 (Bilham, 1999) and again near Bhuj in 2001 (Bendick et al, 2001) which suggest that others could occur. These three earthquakes (on an east-west line through Karachi) ruptured faults that extend deep into the Earth.

The boundary between the Indian and Arabian plates extends northward along the mountains separating Sindh from Baluchistan (Ambraseys and Bilham, 2003). Here a series of active faults known collectively as the Chaman fault system separate the Asian and India plates and, as along India’s eastern plate boundary, are separated spatially into two separate zones about 150 km apart. Unlike faults along the Indo-Burman ranges, however, the Chaman fault system does not extend as deep into the earth. Faults therefore store and release smaller reservoirs of energy: earthquakes larger than magnitude 8 are not expected. Smaller earthquakes do not, however, imply lower risk. In 1935 the Quetta earthquake caused 35,000 deaths even with a relatively modest magnitude of 7.7. This was the worst earthquake disaster in the region prior to the 2005 Kashmir event. The Quetta earthquake did not occur out of the blue: Two earthquakes struck nearby Sibi and Shiragh in 1931, raising awareness and underscoring the need for earthquake resistant structures. Indeed, earthquake resistant building methods were implemented by the railway authority whose stations in the Bolan Pass were badly damaged by the two 1931 shocks. When the more powerful earthquake 1935 demonstrated that reinforced station buildings could survive an earthquake, public officials mandated reconstruction of Quetta using similar construction codes. Regrettably this construction code was not mandated for future construction in the entire country.

**A disastrous Future**

If we ignore earthquakes far from India's plate boundaries, two important facts emerge from the foregoing review: we can readily identify *where* future earthquakes will occur, but nowhere can we recognize a pattern that can tell us *when* they will strike. The certainty that they will recur is linked to the relentless northward movement of the Indian plate. This essentially unstoppable motion means that the past 500 years of earthquake shaking, with a couple of exceptions, provides a very good measure of the next 500 years of shaking. The exceptions are in those segments where we have no knowledge of any historical earthquake, probably because no written description has survived. Historical data are silent about seismic segments north of Karachi, in Sikkim and Bhutan, and in the parts of the Indo-Burman ranges, but we would be foolish to consider that these regions will continue to be spared from large earthquakes. A rare condition of "creep" occurs in some parts of Pakistan, however, where some faults are apparently too slippery to sustain earthquakes. This condition is believed to occur on part of the plate boundary north of Quetta.

The death toll from historical earthquakes, however, is a very poor guide to the future death toll from future earthquakes. The last century has witnessed very significant changes in not only demographics, but also in the style and density of building construction--changes that, tragically, leave recent structures far more vulnerable to damage than those that were common a few centuries ago. The single-story timber, reed and thatch dwelling has been largely replaced by poorly assembled multistory concrete and steel structures. When the earth shakes, the simple traditional dwelling is far more forgiving, and far less lethal to its inhabitants, than the newer structures.

The demographic changes are alarming as well. Not only have populations increased by a factor of ten, but the shift of these populations to urban agglomerations has resulted in unprecedented population densities, in cities of unprecedented size. A single large earthquake could thus imperil far more structures and lives. A dozen megacities are found close to the earthquake belts of the subcontinent, and although some of these cities look comfortably distant from the epicenters of future earthquakes, they line the rivers of the Punjab, Ganges and Brahmaputra where shaking from distant earthquakes has been especially severe in the past due to the loose sediments found in major river valleys.

Increasing populations, increasing urbanisation, and the construction of buildings vulnerable to earthquake damage is a fatal combination. Its effects on cumulative fatalities in the subcontinent are evident in the exponential growth of earthquake fatalities with time in Figure 2b. The increments in this graph are erratic and have therefore no predictive value. It is nevertheless possible to come to some grim conclusions from our brief review:

1. Although past earthquakes have scored “direct hits” on cities of less than 100,000 people in the Indian subcontinent (Kathmandu, 1934,Quetta 1935, Muzafferabad 2006 etc) there is no historical example of a major earthquake near or beneath a megacity with a population exceeding 5 million.

2. Earthquakes that have occurred near urban agglomerations consisting of predominantly weak multi-story concrete frame buildings in India, Pakistan, Turkey and China, have resulted in the death of 10-30% of the local population. An unprecedented 500,000-1.5 million death toll could occur were an earthquake to occur near a megacity of 5 million people.

3. With a few exceptions, existing earthquake resistant building codes are not applied uniformly to new construction. Unsafe building practices are favored, especially in the private sector, because they may reduce building costs by 10-20%. They can occur because of indifference or corruption in public offices, or simply because an insufficient number of building inspectors are available to enforce a safe construction code.

4. Contractors and workers in the construction trade (as opposed to the earthquake engineering community) are frequently uneducated in often quite simple methods that can help ensure the integrity of concrete frame dwellings.

5. Between 1950 and 2001, a time during which a building boom was fueled by urban population doubling and redoubling, there were no massive earthquakes. This lulled the building industry into a state of ignorance and apathy concerning the reality of earthquakes in the Himalaya and elsewhere.

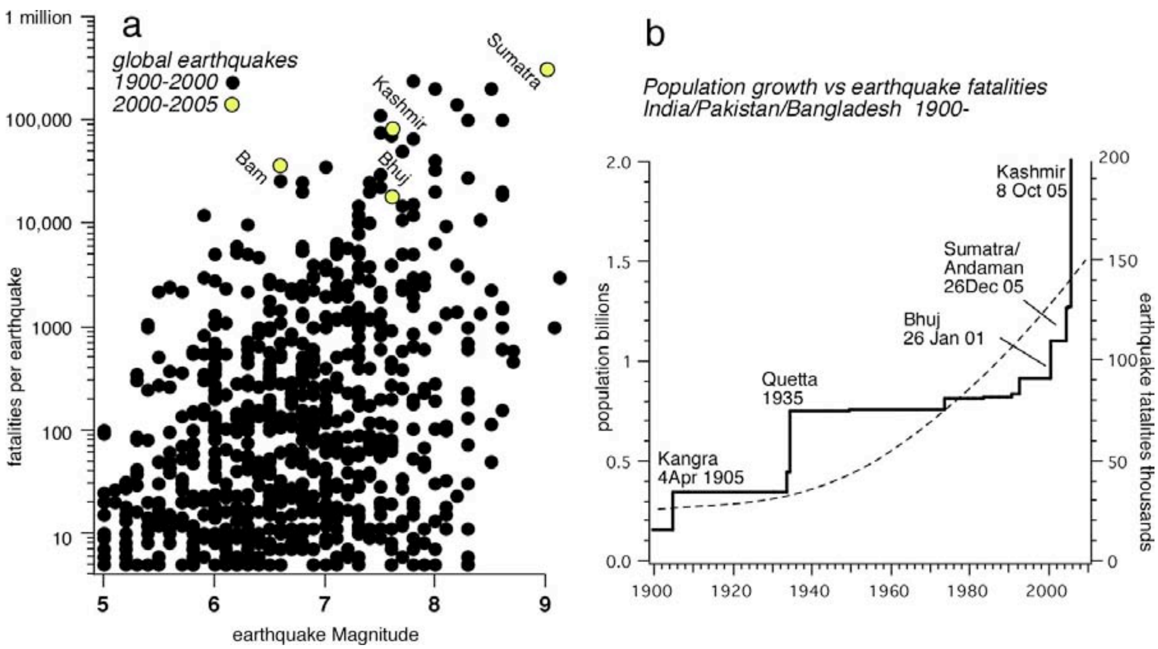


Figure 2a Earthquake fatalities worldwide since 1900 as a function of earthquake magnitude, with earthquakes since 2000 shown as open circles. 2b shows the increase in population on the Indian subcontinent and the recent alarming rate of increase of fatalities from earthquakes. For the 2004 event all fatalities are included in 2a, but only fatalities from the Coromandel coast and Nicobar Islands are included in 2b.

The recent Kashmir earthquake is the third major earthquake in 5 years to illustrate the catastrophe that can happen when large earthquakes and large populations coincide. In Kashmir, many of the buildings that collapsed had been constructed in the previous 2-4 decades. This provides both a warning, and a clue to the necessary "fix" for future earthquakes.

The warning is that the building stock of Kashmir differs very little from the building stock along every other segment of the Himalaya. Urban Bhutan is a prominent exception, where building construction in the capital undergoes stringent earthquake resistant design and inspection. In other Kingdoms and administrations in the Himalaya, dwellings, schools and hospitals are constructed often to a code of minimum cost.

Kathmandu has a building code but much new construction, and nearly all existing construction, will be severely tested should a repeat of the 1833 or 1934 earthquakes occur. Estimated fatalities exceed 200,000 in some scenarios and have shocked local authorities unused to disasters of this magnitude. But the requested preparedness response has shocked them more: the need designate vast trash dumps to accept the concrete and steel from the ruined city, the need to reinforce hospitals and schools so that some fraction survive as shelter for the injured, and homeless survivors, and the need to construct several additional crematoria for those who do not survive

Karachi is a city, that like Los Angeles, was a village less than a century ago. Like Los Angeles it lies near and within the path of future earthquakes, but unlike Los Angeles it has no clear example of what a moderate earthquake can do to its urban setting. The four belts of seismicity near Karachi paint an ominous X on the map near this city of 15 million. Whether one considers a progression of earthquakes westward from Bhuj or southward from Quetta one might reasonably conclude that Karachi should be building in readiness for an earthquake close to Mw=7.5 within 100 km of its suburbs. A five times more hazardous repeat of the Makran Mw>8 earthquake may be further from its immediate present, but will almost certainly happen some day. Recent earthquake hazard maps inexplicably place Karachi in a lower intensity shaking zone than evaluations done just a few decades ago.

**The fix**

The certainty of earthquake location, but ignorance of earthquake time, points to a simple solution for governments concerned with the safety of their citizens. Cities must be made more resilient. In many cases cities must be substantially re-built. This sounds impossible but it is indeed possible if the task is spread over several decades. The lifespan of most buildings extends no more than a half a century, and many structures succumb after 30 years to the pressure for denser or more efficient or more luxurious dwellings in the centers of growing cities. With *mandatory* earthquake resistance on all new construction, cities on the Indian subcontinent can evolve toward safety with minimal effort. In many cases this evolution will require no more than the enforcement of existing laws. We envisage a time when, looking back at the 19th to 21st centuries, people will marvel at the waste and short-sightedness of governments that allowed their people to construct, and then live in, buildings that fall down in earthquakes.

Were a more enlightened policy adopted there would still be earthquakes in the next half century that strike before some cities have fully implemented earthquake resistance. These will be perceived as a failure of policy, although recriminations could be much reduced by a program of education that might accelerate the retrofit or replacement of unsafe structures. But for those countries that do not implement a program to gradually strengthen their cities and villages, the economic penalty and the lives lost will be catastrophic. Kashmir was caught unprepared, and is currently having to rebuild, not from choice, but from necessity. Side by side, in plain view of owners and builders alike are clear examples of how to build (standing structures), and how not to build (collapsed ruins). Ongoing aftershocks are frequent reminders that this is an earthquake zone, and that it would foolish indeed to replicate poor construction practices. After reconstruction survivors in areas that have recently been severely damaged by an earthquake typically live in safer structures than those in adjoining regions.

Ironically, a region that has recently been shaken is less likely to be shaken soon compared to adjoining regions. In Iran, despite a half century of earthquake resistance applied to the reconstruction of earthquake damaged cities, the risk to individuals expressed as a fraction of the total population remains unchanged. The lesson to be learned from Iran is that, almost without exception, the next earthquake visits a different city from those that have been rebuilt. Only by applying earthquake resistant uniformly to a region can one mitigate future disasters.

The solution to earthquake hazard is simple but not easy, nowhere more so than in regions faced with many competing unmet basic needs. Considered against day-to-day concerns such as food, safe drinking water, and basic health care, the cost of keeping the world's citizenry safe from earthquakes can easily appear prohibitive.

However, in parts of the world where populations are poised to grow substantially over the coming decades, an Age of Construction is already underway. The next 50 years will witness a global building boom on a hitherto unprecedented scale. We thus have a unique opportunity to pay the 10% surcharge to protect the present *and future* inhabitants of the dwellings now under construction. The cost of retrofitting existing structures far exceeds that of building them right in the first place.

Some risk mitigation efforts are already underway. But without a redoubled commitment to earthquake risk mitigation, the future of earthquake impact worldwide is as grimly predictable as are the earthquake statistics on which they are based. Eventually a large earthquake will strike in the heart of an urban center, and claim a million lives. Perhaps a disaster on this scale is already inevitable given existing structures and conditions in cities like Karachi, New Delhi and Kathmandu. Nevertheless, Homo Sapiens stand poised on the cusp of a transition of historic proportions: quite possibly the largest and last baby boom on this planet. We will not get a second chance to get it right the first time.

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