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THE BIG HIMALAYAN EARTHQUAKE IS COMING

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It might come tomorrow, or it might come in 300 years, but a big Himalayan earthquake is overdue. Lounge delves into the heart of the gigantic tectonic forces that are shaping our world

25 April 2015, Lo Manthang, Nepal, 11.56am

Photographer and trek leader Sujoy Das was taking photographs of a ‘thangka’ painter in a studio in the fabled high-altitude town of Lo Manthang in Mustang, north-western Nepal. Members of his trekking group were spread across town, visiting monasteries and shops on their day off from the trek. “The ‘thangka’ painter was sitting on the ground and painting, with these small bowls of paint around him. I remember there was a bowl of yellow paint and a bowl of red paint," says Das. “I was on the ground as well, taking photographs. Suddenly, I noticed through my camera viewfinder that the paints in the bowl were jumping up and down. I started wondering if I am seeing things." The floor began to vibrate. Then it started shaking so hard that all the paint sloshed out of the bowls. “Meanwhile, people had started shouting in the street. We ran out and that's when I finally realized it was an earthquake. Opposite me there was a dilapidated building. Some of the walls just keeled over and started to crumble." Das says the vibrations continued for a few more minutes and then came the aftershocks, spreading further panic. “The locals were convinced that there was more coming," he says. Later that day, Das organized an emergency evacuation of his group to Pokhara, a three-day trip. On the way, his colleague Shyam Tamang received a call. His village, Kaule, in Langtang had been destroyed by the earthquake. His father had been killed.

25 April 2015, Patan, Nepal, 11.56am

Researcher and scholar Padmini Ray Murray was conducting a workshop on archiving for the Nepal Picture Library in Patan in the Kathmandu valley. “We were in an old building that’s part of the library, on the second floor," she says. Suddenly, the ground lurched. “Then there was another big lurch, and it kept happening. And the building began to kind of crumble around us. Cracks started to appear on the walls." Her local Nepali audience ducked under tables, so did she. “All around me people were praying and crying." Then there was a pause in the earthquake’s pulse. “We were told to just run," Murray says. “We ran down those two floors and thankfully we were next to a tennis court. So we ran out into that space." The earthquake continued for a few more minutes, and then came the aftershocks. That evening, Murray walked back to her hotel to get her luggage. She had been told that the hotel was too unsafe to sleep in, and that everyone would sleep in the parking lot of the library guest house. Walking down her favourite route through the old quarter of the city, she kept noticing disappearances. Buildings that had existed that morning, no longer did. A shrine she had passed every day, gone. They were so reduced to rubble that they seemed atomized, vanished. “Like a human being burnt to ashes," she says.

The Nepal earthquake of 2015, also called the Gorkha earthquake, is the most studied Himalayan earthquake ever, since it occurred in the modern era of geodetic data, with pinpoint GPS images of the rupture and its effects. With a moment magnitude (Mw) of 7.8, it was a major tremblor. In Nepal, it killed nearly 9,000 people and injured some 22,000. In the Kathmandu valley, it destroyed buildings and infrastructure, reducing several historical temples and monasteries—many of them Unesco World Heritage sites—to rubble. It also triggered an avalanche on Mount Everest, killing 21 people. Another avalanche in the Langtang valley wiped out the village of Langtang, killing 243 people.

The quake was strong enough to shift Kathmandu south by 1.5m. And yet, it wasn't a big earthquake, over Mw8, monsters that can turn the ground into mud. If anything, the 2015 earthquake set the ground conditions that make a far larger earthquake, a "big one", more favourable.

In the middle of a global pandemic, and with climate change flexing its muscles in the form of extreme events like cyclone Amphan, 17 small earthquakes ranging mostly from Mw2-3.5 have shaken the National Capital Region between April-July. Of these, two, on 29 May and 3 July, were above Mw4.5. While these triggered some panic, they were localized tremors which didn't cause any harm, nor are they the harbinger of a bigger local earthquake. What seismologists are increasingly worried about, however, is the effect of a big Himalayan earthquake in the region. At least one, if not a few, is overdue. And mountain villages and towns, like Shimla, as well as cities like Delhi are woefully unprepared.

The Big One

With its epicentre in Gorkha district's Barpak in Nepal, the 2015 earthquake was a continental "mega thrust" rupture, caused by the ongoing tectonic collision of the Indian plate with the Eurasian plate. The two tectonic plates started converging some 65 million years ago and the slow-motion collision raised the prehistoric Tethys Sea into the Tibetan plateau and began the creation of the Himalaya, when the two continents were welded together, about 50 million years ago. As the convergence proceeded, the Indian plate started sliding under—or subducting—the Eurasian plate, giving rise to a series of underground faults, running roughly north-west to south-east along the line of collision. This is where the Himalayan range sits today, and the riverbeds of the Indus and the Yarlung Tsangpo (Brahmaputra), mark the line of the ancient suture.

The three main faults of the Himalaya are the Main Central Thrust (MCT), which runs roughly under the point where the lesser Himalaya meets the greater Himalaya; the Main Boundary Thrust (MBT); and the Main Frontal Thrust (MFT), which runs roughly under the meeting point of the north Indian plain with the Siwalik foothills. These are branches of the deeper Main Himalayan Thrust (MHT), the fault that marks the boundary between the two continental plates. India is currently converging with Tibet at the rate of approximately 17mm/year. As they converge, the MHT constantly gathers massive amounts of strain. Earthquakes are the most effective way of releasing this strain. The 2015 earthquake, for instance, ruptured a 50km segment of the MHT. But it was an underground, "blind" rupture. It would take the really big, infrequent earthquakes of Mw8 and above, the so-called "crack" ruptures, for the strain to be relieved.

Roger Bilham is a geological scientist at the Cooperative Institute for Research in Environmental Sciences (Cires), University of Colorado Boulder. He has been researching Himalayan earthquakes for decades. In February 2019, he published a review of earthquakes in the Himalaya in the past 1,000 years, for The Geological Society in London. The review shows that over the past 500 years, there haven't been enough big earthquakes (Mw8 and above) to ease the accumulated strain in large sections of the Himalayan arc. He writes that due to the average rate of convergence between the Indian and Asian plates, every year adds additional strain on the MHT that needs an Mw7.3 earthquake for release. In 100 years, the accumulated strain would need an Mw8.6 earthquake for release. In 350 years, a Mw9 earthquake would be required.

"Most of the Himalaya slipped in great earthquakes over a period of 200 years starting in the 12th century. Since then India has moved 12m northward. In only two locations (eastern Nepal and eastern Assam) has this accumulating elastic energy been released.The remainder could be released in Mw8.2-8.7 earthquakes at any time," Bilham says via email.

The two locations which did see these great earthquakes were the 1934 earthquake in Nepal-Bihar (Mw8.4) and the 1950 earthquake in Tibet-Assam (Mw8.6). Both were extremely destructive. In 1934, an estimated 7,253 people died in Bihar alone. In Nepal, the death toll exceeded 8,500. Fissures over 250ft long and 9ft wide appeared in Bihar, venting sand, while the soft sediment of the Gangetic plain liquefied. The force of the earthquake knocked off the top 23ft from the historical Kesariya Stupa in Bihar’s East Champaran district. It also toppled the original spire of St Paul’s Cathedral in Kolkata.

The 1950 earthquake was one of the strongest known on earth and remains the largest intracontinental earthquake ever recorded. It caused landslides of such magnitude that several of the Brahmaputra’s tributaries were dammed by landslides and ran dry for days. When the dams burst, prime minister Jawaharlal Nehru described in a radio broadcast that year, “They (the waters) came down with rush and a roar, a high wall of water sweeping down and flooding large areas and washing away villages and fields and gardens." It occurred in the evening and it was only the sparse population of the region at the time that prevented high casualties.

But the rest of the Himalaya now needs big earthquakes like these two to release the strain. Bilham writes in his review: “Historical earthquakes in the past 200 years have ruptured less than 30% of the Himalayan arc, and those that have unequivocally ruptured the frontal thrusts account for less than 13% of the arc. In contrast, medieval earthquakes from 1100 to 1600 CE (AD) apparently ruptured 78% of the arc’s frontal thrusts."

There have been some strong earthquakes in the western and central Himalaya in the past 100 years. The Kangra earthquake (1905, Mw7.8, 20,000 deaths), the Uttarkashi earthquake (1991, Mw6.8, 768 deaths), the Chamoli earthquake (1999, Mw6.8, 103 deaths) and the Muzaffarabad/Kashmir earthquake (2005, Mw7.6, 86,000 deaths) were actually moderate to major earthquakes. Seismologists are increasingly certain that what these earthquakes have done is to load greater strain where they occurred, making a big earthquake even more necessary. Smaller earthquakes just won’t do. Look at it this way: One Mw7 earthquake packs as much power as 30 Mw6 earthquakes; one Mw8 earthquake is equal to a thousand Mw6 earthquakes. A big earthquake is simply a more efficient way of relieving the elastic strain built up in the faults.

Where will it occur?

Earth scientist C.P. Rajendran, from the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bengaluru, says that if a big earthquake were to occur now, it would be like the 1934 one. “It’s about scale. 1934 was very damaging to the floodplains, the alluvial plains where ground cracks occurred along with liquefaction. It impacted the Bihar plains as well as Nepal. So the most comparable example is the 1934 earthquake," he says.

Rajendran, in a 2004 paper co-authored with seismologist Kusala Rajendran, discussed a so-called “seismic gap" in the central Himalaya. This is a section of the Himalaya, bracketed between the 1905 and 1934 earthquakes, which hasn’t seen a big earthquake in at least 500 years. “The historical records we have in India are not very reliable," says Rajendran. “They contain lots of stories, some exaggerated. So we need to go through all the maze of truths and untruths, through all the available archaeological records of earthquakes in India and Nepal, to construct a picture of medieval earthquakes."

These include taking note of British reports from the 1860s that the cupola of the Qutb Minar in

Delhi had collapsed during a strong Himalayan earthquake in 1803 (Mw7.8). This same earthquake caused massive damage to the Tungnath shrine in Garhwal and partly damaged the nearby Kedarnath and Badrinath shrines. Then there are reports in Lodhi-era accounts of widespread destruction in Agra in 1505 due to multiple earthquakes, correlated with Tibetan accounts of a big earthquake that ripped through western Tibet that year, destroying monasteries from Guge, just north of Badrinath, to Mustang. Some seismologists think this was a big one (Mw8.2-8.9), with one or more big aftershocks of Mw7.6 (hence the medieval reports of several earthquakes hitting Agra). Others think it was more like the Gorkha earthquake (around Mw7.8).

Bilham writes in his earthquake review that the Mw7-7.9 earthquakes which didn't fully rupture the frontal thrusts, like the ones in 1803, 1905, 2005 and 2015, have left behind reservoirs of "'dark' strain energy". In his email, he says, "It appears rather probable that great (Mw>8) Himalayan earthquakes nucleate (originate) as Mw7 earthquakes and during their southward propagation encounter reservoirs of elastic energy left over from 'failed' earthquakes." These reservoirs might then act like force multipliers.

Bilham has identified 15 Himalayan segments that might fail, or collapse, because of such reservoirs, either individually or in tandem with neighbouring segments, in future earthquakes. Ten of these 15 ruptures could be in the form of big earthquakes. These include Kishtwar in Jammu (a probable Mw8.4), Nahan in Himachal Pradesh (Mw8.4), Almora in Uttarakhand (Mw8), the Central Gap stretching from east Uttarakhand to central Nepal (Mw8.5-8.7), Sikkim (Mw8.4), West Bhutan (Mw8.4) and Arunachal (Mw8.2).

Rajendran uses a banking metaphor to describe the inevitability of a big Himalayan earthquake. "It's like you are putting money in your savings account and never taking it out. So it gets accumulated. In central Himalaya, you have had very little release of that kind of energy. Not to speak of the smaller ones like the Uttarkashi and the Chamoli earthquakes. They were all moderate earthquakes, which accounts for only 5-10% of the total stress accumulation. So in order to release this kind of stress that has been built up over centuries, you need to have a massive earthquake," he says.

Some Himalayan observers are trying to understand the mechanisms that underpin the two types of Himalayan earthquakes: the "blind" failed ones and the big "complete rupture" ones. The point is to try and map whether Himalayan earthquakes follow something like a "super-cycle" of blind earthquakes followed by big earthquakes, and prepare accordingly.

Luca Dal Zilio is a geophysicist at the California Institute of Technology's (Caltech's) seismological laboratory. Along with fellow researchers, he co-authored a paper in *Nature Communications* in 2019 titled *Bimodal Seismicity In The Himalaya Controlled By Fault Friction And Geometry*. On the basis of a two-dimensional seismic cycle model of the Nepal Himalaya, the study finds that moderate earthquakes begin a process that "leads up to a final complete failure of the MHT". These are the mega earthquakes.

"These simulations illuminate two puzzling features of the Himalayan seismicity: how large yet blind earthquakes (Mw7+) tend to cluster in the deeper part of the MHT, whereas infrequent great earthquakes (M8.5+) propagate up to the MFT," says Dal Zilio on email.

This has grim implications for both Himalayan cities and villages as well as for cities on the Gangetic plain. "The violence of shaking is about the same in a Mw8.6 and a Mw7.8 earthquake, but the duration can be five-eight times longer in a large Himalayan earthquake. The difference between 1 minute of shaking and 5 minutes of shaking is that many more structures will be damaged. It is probable that significant liquefaction will occur in the Ganges plain as it did in the

1934 earthquake," says Bilham. He writes in his survey that Himalayan earthquakes so far have mostly occurred in daylight hours, preventing mass casualties. Over 200,000 people might die if a big earthquake were to strike at night in a heavily populated segment of the Himalaya, like the Almora/Dehradun segment.

“The MFT is approximately 220-250km from Delhi," says Dan Zilio, adding, “I personally believe that the seismic gap in the region of the 1803 and, in particular, the 1505 events are the most important ones because they are closer to Delhi, they are capable of generating large events, and they did not experience any large earthquakes over the last two centuries (or even longer for the 1505)."

Are we ready?

When Sujoy Das heard of the destruction of the village of Kaule due to the Gorkha earthquake, he raised 20 lakh in relief funds for the village. Three weeks after the earthquake, he flew back to Nepal, with Ashish Sharan Lal, a Kolkata-based conservation architect who often treks with Das’ company. The two made their way to the village in the devastated Langtang region. “It was the third week of May and the monsoon was coming and they said we have no houses. We used the money to build makeshift roofing for their houses, so they could see out the monsoon," says Das.

But Lal wanted to do more. “We decided that let’s take one house and reconstruct it from scratch. And in the process of doing that, educate ourselves and the village how to construct houses that can withstand seismic forces," he says. In doing so, he decided to use only local materials, which were readily available and which the locals were used to working with.

“They already knew how to build stone walls, how to use mud," he says. “We covered the gap in knowledge about construction provisions that can handle seismic forces." Like using bamboo to construct the frame of the house. “Most of these houses are two floors. The stone walls and gables went right up. And those are the ones which fell on the first floor. So the upper- floor gables crashed on the floor and then the floor gave way and the whole thing crashed on the ground floor," says Lal. The new house was made from treated bamboo, and better-engineered stone walls that were restricted to the lower floor. “We made the upper floor using an engineered bamboo frame with bamboo panels plastered in mud. In terms of appearance, it was the same, but bamboo is a very resilient material. It will bend but it will not break."

The house was called the Kaule Prototype and in 2017 the Nepal government included the design in its Earthquake Resistant Design Catalogue. The prototype won Lal’s firm and his collaborators Areen Attari and Manu Narendran the 2017 Hudco (Housing and Urban Development Corporation) Design Awards for Disaster Resistant Self-Help Housing. Lal wishes the Indian agency hadn’t stopped at the award. “I would have expected them to initiate some kind of project based on the award," he says.

Planning for disaster resilience, especially for earthquakes, presents a glaring gap in Indian preparedness. Rajendran says floods are more frequent than earthquakes, and in terms of Himalayan planning, the government doesn’t pay any attention to those, let alone earthquakes. “Look at the destruction caused by the 2013 Uttarakhand floods. Most of this was because of construction on the floodplain. So when you are talking about an infrequent earthquake, you can imagine!" he exclaims.

Last September, the National Disaster Management Authority (NDMA) published an Earthquake Disaster Risk Index (Edri) report. It looks specifically at 50 cities, which includes the metros and cities in seismic zones IV and V (the two most active regions in India). Of the cities surveyed, 30 cities (including Delhi) are at medium-level risk and 13 (mostly Himalayan cities, including Shimla) at high risk.

Architect and urban planning expert Garima Jain is a consultant with the Bengaluru-based Indian Institute for Human Settlements (IIHS) and specializes in what she calls the geography of urban risk. Speaking on the phone from New York, Jain says places like Shimla are unregulated “time bombs".

Such cities are becoming more dense and precarious by the day and are extremely exposed to risks as a result. “There are all sorts of multi-storeyed buildings, with blatant violation of building by-laws. The high court in Shimla is an 11-storeyed structure on the edge of a hill! Even though buildings there aren’t allowed to go beyond one or two floors, they received an exception for the high court," says Jain. Certain parts of Shimla, like Sanjauli, are so dense that “people there say that if you have to take a dead body out, you have to take it through the window of one house to the next and so on because there is not enough space between the buildings for sufficient turning radius".

The only thing to do in such densely built-up areas is to come up with evacuation routes. “It’s called safe failure. The buildings may fail but at least the loss of lives might still be minimized," she says. As soon as there is a tremor, people can follow predefined routes to reach open ground. Beyond that, and insurance, there’s not much else that can be done.

A city on the Gangetic plain, like Delhi, has its own problems, emblematic of Indian cities in seismically active zones in general. Jain had studied Delhi’s disaster risk in terms of large-scale infrastructure and real estate in a 2012 report. “The bulk of the city is self-constructed, without technical inputs. Which makes it not resilient at all to shocks," she says.

It’s the Capital’s largely unregulated built environment and density of population that makes it vulnerable to seismic forces. No more than 10% of Delhi’s buildings are actually designed structures, says Jain. Most are self-constructed structures, JJ (slum) clusters, unauthorized colonies, resettlement colonies, urban villages and regularized unauthorized colonies. “In terms of exposure and vulnerability, cities like Delhi, which are denser, have more population, have older structures, they may actually even have greater losses than other smaller cities," she says. Buildings with “soft-storeys", i.e. with pillars on the ground floor for parking, are at great risk of collapse. These need to be retrofitted quickly, says Jain.

She suggests better enforcement of building by-laws, the formation of a council for structural engineers to better fix accountability, and earthquake-resistant retrofitting of old and self-built structures as possible preventative measures. However, says Jain, these are slow processes and people from weaker socioeconomic sections may not have the wherewithal for them. Again, well mapped out evacuation routes and trained rescue response teams would be of great help, as would educating people to invest in financial instruments like multi-hazard insurance schemes to cover residual risks.

Again, it is the Gorkha earthquake which provides an example of what can go wrong. Three days after the earthquake, Jain had gone to Nepal as part of an IIHS damage assessment team. “If you saw the news, it looked like the entire city of Kathmandu had been flattened. That wasn’t the case," she says. Newly-built houses with soft-storeys had collapsed. The low-lying parts of the city, with softer soils, had liquefied. “Many of the buildings, due to the lack of planning guidelines, were built partly on natural drainage channels. They were practically cut in half. Like half the building just sunk and went down," she says, adding: “Those are the kinds of buildings which had the biggest loss of lives. When the building just sinks, it doesn’t take that long."

The people living in these buildings probably didn't even have time to register that an earthquake was upon them. This is a scenario that may well be repeated in India if the lessons of Himalayan earthquakes are ignored. Earth's tectonic forces move in geological time frames that are impossible to imagine but when the ground shrugs, the effects are instantaneous.It's impossible to predict when the megaquake will come, though we keep our eyes peeled for signs. It may come tomorrow, or in a few hundred years. But come it will, sooner rather than later. We had better be ready.

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