BARRY GUTIERREZ

THE QUAKE HUNTERS

Meet the seismologists who work around the clock to pinpoint major earthquakes anywhere on Earth.

BY ALEXANDRA WITZE

At 17 minutes past midnight on Saturday 25 April, Rob Sanders's computer started chiming with alerts. On his screen, squiggly recordings poured in from seismometers in Tibet, Afghanistan and nearby areas that were feeling the first vibrations from a tremendous earthquake.

Sanders was part way through his shift as an on-duty seismologist at the US Geological Survey's National Earthquake Information Center (NEIC) in Golden, Colorado. It was his job to work out what was happening — and fast. Within 30 seconds, he began analysing the seismic data and realized it was time to call his boss.

When the phone rang, Paul Earle was dozing in the room of his four-year-old son, where he had nodded off earlier that evening. Earle rolled out of bed and logged onto his home computer. As chief of 24/7 operations at the NEIC, Earle knew that time was short. For any major earthquake in the world, the US Geological Survey (USGS) is committed to publishing the shock's magnitude and location online within 20 minutes. The team also puts out rapid estimates for how many people may have been hurt. Various nations issue alerts for quakes in their vicinity,

Seismologists at the National Earthquake Information Centre are on duty 24/7 to monitor quake activity.

but Earle's crew is the only one that analyses tremors around the globe.

The NEIC information helps governments and humanitarian groups to decide how to respond in times of crisis. It determines whether search-and-rescue teams pack their bags, and whether financial markets begin responding to a catastrophic natural disaster. When minutes count, hundreds of key responders — from the White House to the United Nations — rely on the NEIC team to tell them exactly how bad an earthquake was. On 25 April, the work that began on Sanders's screen ended up with the US government dispatching a response team to the quake's epicentre in Nepal within hours.

The NEIC seismologists do not always get it right. Sometimes, deceived by the rawness of the data, they put out an alert containing the wrong quake location or size, before quickly retracting the information. But they are continually refining their techniques to speed up response times while maintaining accuracy. "Being reliable is more important than pure speed," says Earle.

THE NIGHT SHIFT

The NEIC takes up the fifth floor of a blocky building on the campus of the Colorado School of Mines in Golden, not far from the original Coors brewery and bronze sculptures of the miners who shaped this region of Colorado. A decade ago, television satellite trucks regularly clogged the car park after any large earthquake. Now, most of the journalists stay at home — they can get information from the centre faster over the Internet.

Computer monitors have replaced the slowly rotating paper drums that once displayed the vibrations measured at seismic stations around the world. But the centre has kept one relic on display: a large wooden globe that often appeared in television reports. Patches of its coloured surface are worn away from decades of seismologists jabbing their fingers at earthquake locations. Southern California has basically disappeared. So has Japan.

Established in 1966, the NEIC originally operated during normal business hours, with seismologists on call at other times. But in 2004, a magnitude-9.1 earthquake hit Sumatra, triggering a ruinous tsunami that killed almost a quarter of a million people around the Indian Ocean. In an effort to improve its response times in major disasters, the earthquake centre moved to operating around the clock. Fourteen seismologists now cover three shifts, with at least two people on duty at any given time (coordinating their toilet and meal breaks).

The NEIC analyses more than 20,000 earthquakes a year, everything from imperceptible ones in California to the monsters that occasionally shake the globe. It reports on any earthquake of magnitude 5 or greater worldwide, and down to magnitude 3 in parts of the United States.

On 25 April, the only earthquake that mattered began beneath Nepal. The jolt started 15 kilometres underground, on the huge Himalayan fault where the tectonic plate carrying India rams into Asia. At 11:56 a.m. local time (11 minutes past midnight in Colorado), the stress of that geological collision ruptured a 120-kilometre-long segment of Earth's crust beneath the Nepalese district of Gorkha. Waves of seismic energy raced outwards in all directions.

Within 16 seconds they reached Kathmandu, almost 80 kilometres to the southeast, and began toppling thousands of buildings. Just over a minute later they passed Lhasa, 600 kilometres northeast of the epicentre, and shook seismometers bolted into granite in a hillside tunnel. Those machines, part of the Global Seismographic Network, immediately relayed their data to the NEIC.

At the Colorado centre, an alert dinged and a window popped up on Sanders's screen, which filled with information from stations around Asia. Sanders started sorting through the data, choosing the best seismic records to include in his analysis.

A second seismologist on duty that night called and woke Earle, who began to work on the seismic data from home. As the minutes ticked away, the three of them faced a crucial task — deciding on the quake's magnitude. The USGS measures eight types of magnitude, each of which conveys different information about the strength of an earthquake's vibrations and the amount of energy it releases. Certain magnitude scales are most accurate for smaller quakes, whereas others are better at describing long-lasting, larger shocks.

At 12:29:42 a.m. — 18 minutes and 16 seconds after the earthquake began — the NEIC released its first answer. Location: 77 kilometres northwest of Kathmandu. Size: 7.5 on the moment magnitude scale. This particular scale relies on computer modelling of a certain type of seismic wave, and Earle chose it because of a gut feeling for what he thought would represent the most meaningful magnitude.

"THAT'S WHEN WE KNEW IT WAS GOING TO BE DEADLY."

But as is often the case with large quakes, the first official magnitude was not the last. The team had only just started its analyses. Earle called and woke up two more colleagues — Harley Benz and Gavin Hayes — then jogged the two blocks from his home into work. Even as news agencies began broadcasting alerts of a magnitude-7.5 earthquake in Nepal, the NEIC researchers were sifting through fresh data.

From his home, Hayes ran a separate set of model calculations, which use data on longer-period seismic waves that arrive at stations later but are more appropriate for the world's largest quakes. At 1:04 a.m., on the basis of this 'W-phase' analysis, the NEIC updated the Nepal quake's magnitude to 7.9.

"None of those numbers are wrong," says Earle. "They're all right for that particular magnitude scale." (Three hours later, the centre would announce a final magnitude of 7.8, also based on the W-phase approach but incorporating more-detailed modelling with newer data.)

Even as Earle was wrestling with the quake's magnitude, he called NEIC seismologist David Wald, who happened to be awake. Wald runs a set of programs that take the initial magnitudes and estimate possible fatalities and economic losses. The system, called PAGER (Prompt Assessment of Global Earthquakes for Response), relies on databases of where people live, the types of building in the region of an earthquake and how many people had been killed in similar quakes in the area before.

If a quake is big enough, PAGER sends out alerts automatically. At 12:34 a.m., the system used the initial magnitude of 7.5 to predict between 100 and 1,000 deaths, and damages between US$10 million and $100 million. That ranked it an 'orange', the second-highest alert on the PAGER colour-coded system. "That's when we knew it was going to be deadly," Wald says.

As the minutes crept by, aftershocks kept pummelling Kathmandu. PAGER automatically updated three more times at the orange level, the last at 2:16 a.m.. Then Wald took some data on how much the ground had moved and how widespread the aftershocks were, and manually fed the fresh information into PAGER. The alert immediately escalated to red, estimating between 1,000 and 10,000 deaths. It was 4:14 a.m..

GLOBAL RESPONSE

In Washington DC, Gari Mayberry's mobile phone woke her up with the first NEIC alert. Mayberry, a USGS volcanologist, advises the US Agency for International Development on natural hazards. The agency funded PAGER's development, precisely to simplify split-second decisions after earthquakes. "Do I need to call my boss at 3 a.m.?" asks Mayberry. "That's what people want to know."

For Nepal, the answer was yes. As the Colorado team released its analyses, Mayberry quickly fed information to her bosses, who help to coordinate search-and-rescue teams for international disasters. In such situations, she says, every minute counts. Within hours, the US government had a team on the way to Nepal.

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Paul Earle and the team at the earthquake centre issue alerts for major quakes within 20 minutes.

Other groups also rolled into action. Gisli Olafsson in Reykjavik, who directs emergency response for a consortium of 43 humanitarian groups called NetHope, says: "I always look at PAGER once it becomes available." Studying the USGS information, he was relieved to see that the shock had originated relatively far from Kathmandu. But he also learned that the quake had struck in mountainous terrain on a fault close to Earth's surface, which meant that it had probably destroyed roads. NetHope immediately started preparing for the complicated logistics of getting in and out of rural areas with limited access, and Olafsson flew to Kathmandu to coordinate its response.

Even the financial world got involved: the Inter-American Development Bank uses PAGER numbers to trigger payouts on catastrophe bonds, a type of insurance against natural disasters such as earthquakes.

The most recent estimates suggest that the 25 April earthquake and its aftershocks, including a magnitude 7.3 on 12 May, killed roughly 8,700 people — close to the PAGER estimates of around 10,000 deaths. Other catastrophe experts had estimated 50,000 dead or more, using independent assessments of population exposure and building vulnerability.

One factor that may have saved lives in Kathmandu was how buildings were constructed, says Kishor Jaiswal, a civil engineer at the NEIC. Many of the newer buildings in the city have concrete frames reinforced with steel bars, which kept a lot of them from collapsing. Jaiswal had previously analysed this construction, and his work was one reason that the PAGER fatality estimates were relatively low. Although the toll was great, he knew that much of the city would survive.

NEED FOR SPEED

Most of the NEIC's work is much calmer than on the night of the Nepalese disaster. Of the thousands of earthquakes that the team tracks every month, the vast majority do not kill anyone. Earle, Benz and Hayes spend their time developing ways to analyse earthquake ruptures as quickly and accurately as possible. Hayes, for instance, specializes in 'moment tensor' and 'finite fault' calculations, both of which convey information about exactly how a fault has ruptured.

One of Earle's top priorities for the earthquake centre is to avoid making major mistakes, although his team sometimes does err. Notable bloopers include issuing an alert on Christmas Day 2013 for a magnitude-22 earthquake. It was supposed to say magnitude 2.2; the typo caused the NEIC to remove all human typing from the real-time system.

And in May this year, the USGS reported several phantom quakes in California — in reality, they were vibrations from more-distant shocks in Alaska and Japan. An on-duty seismologist had caught the problem, but the software that distributes the alerts had not responded to the correction.

Cutting back on false alerts while making sure that the real ones get out in time takes a nuanced mix of skill and speed. The NEIC gets data from nearly 1,800 stations worldwide, but there are gaps that slow the seismic analyses. China's national seismological alerting network puts a 30-minute delay on much of the information, so Earle's team can rarely use it. And India does not release its seismic data. Nepal, where seismologists have long warned about the earthquake risk, did not have a single station feeding real-time data into the USGS system. Had the agency received more real-time data from locations closer to the epicentre, seismologists could have accurately located the Nepal quake faster than they did, says Thorne Lay, a seismologist at the University of California, Santa Cruz.

Even with all its speed, the NEIC is not the fastest earthquake-alert system in the United States. That title goes to the National Oceanic and Atmospheric Administration's two tsunami-warning centres. Drawing on the same seismic network, they release rougher magnitudes and locations within 3 minutes of an earthquake striking, but they handle only shocks in oceans near US territory.

The NEIC keeps pushing to shave as many seconds off its own notifications as possible. One ongoing project involves Twitter. Earle has set up an automated system that hunts for words such as 'earthquake' in various languages in tweets from around the world (P. Earle *Nature Geosci.* **3,** 221–222; 2010). He has to filter out unrelated instances, including references to the video game *Quake*, but once that is done he can get a heads-up that something big is beginning. When someone in Indonesia tweets '*gempa*', or earthquake, "it's on our server in five seconds," he says.

Tweets can arrive at the NEIC faster than seismic waves can reach recording stations. In 2012, a magnitude-4.0 jolt in Maine set off a stream of tweets from the region around the epicentre. Earle got an automatic text notification before the shaking spread across New England. "I was at Safeway buying groceries, and I knew about the quake, from nothing but Twitter data, before other people felt it," he says.

The Twitter experiment is most useful in places where the USGS does not receive a lot of real-time data, such as parts of South America or Indonesia. Although it will never replace the NEIC's conventional methods, it can alert the seismologists there to keep a lookout for incoming data.

The earthquakes never stop coming. Towards the end of a long Friday afternoon in May, Earle is at his standing desk when his iPhone buzzes with a report of a magnitude-6.9 quake in the Solomon Islands. "That one isn't going to be near a populated area, but it's a big quake," he says. "I'm gonna get someone." He is heading out of the door nearly before he finishes the sentence.

Earle speed-walks down the hallway, past the row of display monitors set up for television cameras, and pokes his head into the office of seismologist Jana Pursley. "Jana, have you got that?" he asks. "No, Sean does," she says, waving her hand at the on-duty seismologist down the hall. "OK," says Earle. "Sean will release it, and then I'll have Bruce review the moment tensors for it, and then we'll be done."

With that earthquake sorted, Earle heads back to his office. He switches on the electric kettle that sits next to two containers of freeze-dried, generic-brand coffee. "I get the cheapest possible coffee because I don't even taste it anymore," he says. "I just drink it."

And he turns back to his monitor, to wait for the next one. ■

Alexandra Witze *writes for* Nature *from Boulder, Colorado.*