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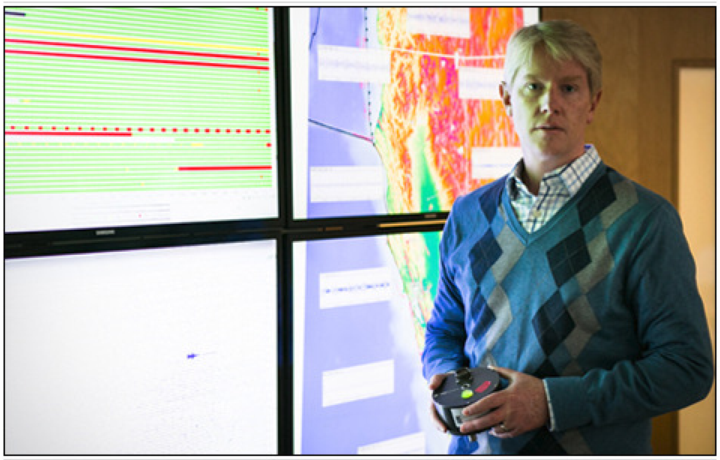
Sounding the Alarm

An early warning system would save thousands of lives when the next major earthquake hits. But will California find the money to implement it?

By Azeen Ghorayshi



At 2:46 p.m. on March 11, 2011, the Pacific Plate, just off Japan's northeast coast, suddenly thrust downward, unleashing a monstrous, 9.0-magnitude earthquake that rocked the country for the next six minutes. The massive Tohoku quake and resulting tsunami are believed to have killed at least 16,000 people and injured 6,000 more. Another 2,600 people are still missing and presumed dead. The quake was the most powerful to ever strike Japan, and was the fourth-largest ever recorded. It also was the first earthquake to be heard in outer space, and was the most expensive natural disaster in human history, generating $235 billion in total damage. But there was a silver lining, if you could call it that: Tohoku was also the first time that Japanese citizens were given the precious, if limited, gift of time.

That gift came in the form of Japan's earthquake early warning system, which detected the giant temblor just before it hit and immediately sent computer-generated alerts across the country to cellphones, TVs, schools, factories, and transit systems. Japan put its finishing touches on its $500 million early warning system in 2007, leaving four years — barely the blink of an eye in geological timescales — before the investment paid off.

And in 2011, by all accounts it did. Although it's impossible to quantify the number of lives that the system saved, there were reports in the quake's aftermath of schools having had time to get all their students under desks, of eleven 320-mile-per-hour bullet trains slowing to a stop; of more than 16,000 elevators automatically shutting down when the alarm system went off. In the sixty seconds before the giant temblor struck, roughly 52 million people received text-message warnings that the quake was fast approaching and that they needed to get out of harm's way.

In 2007, the same year that Japan finished building its early warning system, earthquake scientists roughly 5,000 miles away in California marked a related, albeit far humbler, benchmark. Richard Allen, director of the Seismological Laboratory at UC Berkeley, was in his office on October 30 when a 5.6-magnitude earthquake hit the Alum Rock section of San Jose. The quake caused only moderate shaking and very little damage, but Allen had reason to be excited: The event marked the first time his Berkeley group was able to test its own early warning system, set up just two weeks before. "It was our first proof-of-concept event," Allen recalled in a recent interview. Thirty minutes after the light shaking ended, Allen received an email showing that the system had successfully detected the right waves, done the right math, and made the right prediction about when and how strongly the quake would hit.

Yet this was only a researcher's victory. The tiny system his team had built produced no cascade of texts, no TV or radio transmissions, and no widespread notification that an earthquake was on its way. In the event of a disaster, the technology wasn't even in place for Allen himself to receive a real-time notification from his own system.

But this was not a case of Japan being light years ahead of the United States in terms of earthquake-science research. Instead, the wide technological gap between the two countries has more to do with each nation's sense of urgency about the dangers of earthquakes, and the need to prepare for them. In fact, back in 2003, Allen had co-written what essentially became *the* seminal scientific paper on quake predictions. His work showed that it's technically possible to predict the size and location of quakes right before they strike, and argued for the methods that became the basis for early warning systems, much like the one later built in Japan.

And yet a decade after Allen co-authored that paper, California, the second-most seismically active state in the nation (behind only Alaska), still has next to nothing in terms of a public seismic warning system. The technology exists and has for years, but the state legislature has failed to find or allocate the necessary funds to make it happen.

In the next few months, however, that might change. A new bill introduced in the state Senate proposes to construct a statewide early warning system, modeled after Japan's successful program, over the next five years. The system, which is projected to cost $80 million to develop and run, could give Californians up to sixty seconds advance warning before a major quake strikes. It could save thousands of lives — perhaps even more if the state is hit by a so-called super quake of Tohoku-like proportions. However, it remains to be seen whether Sacramento will find the money to build it in time.

"Seismologists don't like to make very many predictions," Allen said. "But I will make you one prediction, and that is that we will definitely build an early warning system in California. The only real question is whether it's immediately after the next big earthquake, or whether we actually manage to build it before."

Richard Allen grew up in the United Kingdom, where there are no earthquakes. He's soft-spoken and carefully eloquent, with skin that the California sun has tanned slightly darker than the white blond of his hair. Rocks of different shapes and colors line the windows of his second-story, fault-map-adorned office, which is on the north side of the Cal campus and has a view of the Bay Bridge. Allen hadn't yet arrived at UC Berkeley when the Loma Prieta Earthquake knocked down a section of that bridge nearly 24 years ago, nor has he witnessed the devastating human impacts of any earthquake firsthand. But he's made it his life's goal to help mitigate the devastation from quakes as much as possible.

While Allen spent most of his time in the UK studying the earth's structure (he described it as "sort of like taking a CAT scan of the Earth"), he slowly became more and more interested in the science of catastrophic shifts in the earth's crust after coming to the United States to get his Ph.D. But it wasn't until 2001, when he moved west to the California Institute of Technology to study with earthquake expert Hiroo Kanamori, that working on real-time forecasting became an actual possibility.

That's not to say that the idea of early alerts for earthquakes was unheard of before Allen and Kanamori came along. As early as the late 19th century, people have postulated that telecommunications could be used to warn people about impending earthquakes.

In 1868, a local physician described his vision for such a system in an op-ed for the *San Francisco Daily Evening Bulletin*: "A very simple mechanical contrivance can be arranged at various points from 10 to 100 miles from San Francisco," wrote Dr. J.D. Cooper, "by which a wave of the earth high enough to do damage will start an electric current over the wires now radiating from this city and almost instantaneously ring an alarm bell, which should be hung in a high tower near the center of the city."

And until recently, this is essentially the quaint model that was in place. In countries like Mexico and Taiwan, seismometers would detect shaking at its source, and then quickly relay the message to cities many miles away, relying on the fact that the signal — traveling at the speed of light — would outpace the shaking.

But the system that Allen and professor Kanamori would argue for in 2003 boiled down to one major difference: It could detect an earthquake before the shaking hit the Earth's surface, even predicting the magnitude of its shaking.

Their research focused on something called the p-wave. "Our whole planet's crust is moving," explained Jennifer Strauss, spokeswoman for the Berkeley Seismological Laboratory, circling her hands in tandem around an imaginary globe. "And so you have this plate moving this way and this plate moving this way, and because they're all in motion, they all exert pressure at different points." An earthquake occurs when this pressure builds and builds until there is some sort of jutting motion at a point in the plates. The energy released from this sudden collision comes in two waves: the p-wave, a benign but detectable warning, and the s-wave, the source of the potentially deadly shaking.

Though the waves release at the same time, the p-wave travels roughly twice as fast — allowing it to serve as an effective warning. "The p-wave, in effect, carries the information about what's happening, but the s-wave carries the destruction," explained Doug Given, earthquake early warning coordinator for the US Geological Survey.

And while the p-wave can't generally be felt, it's not totally imperceptible. "There's classic videos of earthquakes in Japan where people are at the store, they're buying stuff, and all of a sudden they pause, and they look," Strauss said with a hush, holding her hands up and glancing back and forth. "And then seconds later, the whole thing starts shaking."

But the most important factor is communication speed: Once seismometers stationed along a fault line detect a p-wave, computers then perform some quick calculations, and the system relays the message at the speed of light. Since the shaking wave is traveling at roughly one- to three-miles per second, the warning system is, at its crux, a race against the speed of the oncoming earthquake.

When Allen was on his way to Caltech a dozen years ago, having an early warning system based on p-wave technology didn't exist, nor did the technology required to process and communicate the wave data at such high speeds. Which is why Allen came to work with Kanamori.

"Hiroo Kanamori is considered to be the father of early warning in Japan," Given said. And within the seismology community, Kanamori is viewed as sort of the godfather of the field; among other things, he's credited with coming up with the magnitude scale used almost universally to describe earthquake size. But what really set Kanamori apart from most of the seismology community at the time was that he cared about real-time seismology at all. "Many people in seismology, they just take data from past earthquakes and then look at earthquake processes. So in that sense, it's a little disconnected," said Allen. "But Hiroo was always arguing and advocating for what we could do with real-time seismology. What can you even do in real time? What information can we provide to real people?"

Together, Kanamori and Allen envisioned taking seismology out of the lab and into its real-world applications. After their paper on predicting quakes was published in 2003, interest in the p-wave skyrocketed. "When I started working on it, the vast majority of the seismology community didn't think it was possible. And then as time progressed, it became impossible for them to deny that it was possible," said Allen. "And then the question became, 'Well, how useful is it?'"

Tohoku proved that it was. Culling data from more than 1,000 seismometers perched along the volatile Pacific Ring of Fire, the Japanese Meteorological Agency sent out TV and radio warnings, pop-ups on home computers, and texts to cellphones, giving people 15 to 65 seconds to take cover. Loudspeaker systems set up on building rooftops, in schools, on streets, and on public transit vehicles blared alarms. The system is so ubiquitous now that all new iPhones in Japan come with early-warning capabilities pre-installed; homes contain special earthquake receivers displaying the JMA's official earthquake warning logo, a yellow catfish, which in ancient Japanese lore was thought to predict earthquakes before they struck. In terms of infrastructure, not only did bullet trains and elevators stop, but heavy machinery in factories came to rest on the ground, and utilities at risk of having unpredictable and far-reaching effects powered down — including the Fukushima nuclear power plant, whose end was met at the hands not of the quake itself, but of the resulting tsunami waves that eventually engulfed it.

Today, Japan is the most earthquake-prepared country in the world. But Kanamori stresses that it really had no choice. "Seismic hazard is far more serious in Japan than in the US, and they feel strong shaking frequently," Kanamori wrote in an email. "So, obviously they would be more attracted to earthquake early warning in Japan than in the US. It would be difficult to promote this concept in the place where you do not feel earthquakes very often."

In other words, California, perched on the other side of the Pacific Ring of Fire — a volcanic, horseshoe-shaped area that includes both sides of the Pacific Ocean and is home to about 90 percent of the world's earthquakes — may have less impetus to install an early warning system purely because disaster prevention doesn't evoke the same emotions as disaster response. Though Allen, along with groups at Caltech and USGS in Southern California, has been working on a cohesive system since 2006, those developments have barely begun to make it out of the lab.

"Do you want to know why we don't have earthquake early warning yet in California?" asked Given. "The reason is simple: We just haven't had a big killer earthquake in the United States in recent memory. But I've been making the case that we shouldn't wait until after the earthquake — we should do it before."

The odds that the next big killer quake in the United States will take place right here in the Bay Area are high. From the massive San Andreas Fault that runs through the Peninsula, San Francisco, and Marin County to the smaller but perilous Hayward Fault in the East Bay, there is a spidery network of roughly eight fault zones in the region. "The Bay Area has the highest density of active faults per square mile of any urban area in the US," said David Schwartz, an earthquake geologist at USGS's Earthquake Science Center in Menlo Park. "So our hazard — that roughly 63 percent probability of a big quake happening in the next thirty years you hear about all the time — that's up there at the very top."

The Hayward Fault alone "crosses nearly every east-west connection that the Bay Area depends on for water, electric, gas, and transportation," noted a 2010 report commemorating the 140th anniversary of the last Hayward disaster. Though the 1989 Loma Prieta quake served as a wake-up call, leading to massive retrofitting projects by East Bay MUD, school districts, and hospitals across the East Bay in the last decade, many of these same entities would benefit from having the time to get ready for violent shaking when the next big quake strikes.

In the case of a repeat of Loma Prieta, said Allen, the Bay Area would receive a 24-second alert before the shaking starts — if California has a fully operational earthquake early warning system. That would be 24 seconds for teachers, hearing the blaring earthquake alarm, to make sure all students are safely under desks with their heads covered; 24 seconds for surgeons at Alta Bates Summit Medical Center or any of the roughly 46 other hospitals in the area to remove their scalpels from patients in the operating room; 24 seconds to turn planes around at Oakland and San Francisco international airports, both of which are on land that's at high risk for liquefaction; 24 seconds for Chevron or any of the other refineries scattered across the Bay Area to power down their operations, reducing the chance of the raging fires that almost always accompany catastrophic shaking; 24 seconds for millions of individuals receiving a notification on their smartphones, TV sets, radios, or specialized earthquake warning receivers, to get to safety.

But first, the system needs to be built. As it stands now, Berkeley, Caltech, and USGS combined operate roughly 400 seismometers equipped to supply data for earthquake early warning. Allen estimates that we'll need roughly 1,100 instruments lining the faults that spread like spilled milk across the state in order to have a dense-enough network to deliver reliable warnings everywhere. It's expected to cost $80 million to develop and run the system for five years.

Data from the seismometers would be fed to radio and TV stations and to factories and transit lines. But it wouldn't be a fully functioning system. That's because California's plan relies on telecommunications companies developing the products needed to get the early warning data to millions of people. "We're seismologists, not cellphone engineers," said Strauss. "And so it's all well and good if I send you a text message to tell you an earthquake is coming. But if we do a point-to-point text message to everybody who signs up, it could take hours for you to actually receive the message, because that's how texting works. And that does you no good."

To deal with this problem, the groups at Berkeley, Caltech, and USGS have already been in talks with telecommunications companies to discuss their potential roles in developing the apps and gadgets that would be most useful in relaying the message in the case of a quake. "People like Google, Verizon, and AT&T — they're the people who are obviously in a position to distribute it, and we see them as having a real business benefit in doing so," said Allen, stressing that if the consumer needs, the market will provide. "In the not-too-distant future, any device that you have that has communications will automatically provide earthquake early warning. And then we'll all be wondering why it was that it took us five years to go from demonstrating it was technically feasible to actually having a system in place."

For now, only one entity outside of the Berkeley, Caltech, and USGS research facilities is operating a full early warning system using their data: Bay Area Rapid Transit. Like Japan, where high-speed rail was the first early adopter of earthquake response technologies, last year BART announced an official partnership with Allen's group at Cal to have a fully operational system that will automatically slow trains from 70 to 26 miles per hour based on data fed to them from 200 Berkeley seismometers scattered along several Northern California faults. Now, if they receive warning that a quake is on its way, trains will be moving at a safe speed before the shaking even begins, helping prevent derailment.

But gadgets and apps will be of no use unless people know how to act within a twenty-second time window. One thing that almost every seismologist mentions as an additional hurdle in California is the lack of earthquake preparedness here compared to Japan, a country in which the threat of quakes is woven deep into the national psyche after so many natural disasters. It's certainly a hard-earned understanding; earthquake curriculum there begins in kindergarten and continues throughout a child's education, well into adulthood. And it goes further than just knowing how to prepare for a fast-approaching quake: "Tohoku DNA" was a phrase coined to describe the incredible resilience of a people able to band together for recovery after a catastrophe that destroyed so much.

"It's all well and good to say, 'We should do this today!'" said Strauss. "But it does no good to throw this information out to the mass public and not tell them what to do. You can't just say, 'Oh, an earthquake's coming,' and then watch people panic. So with the rollout of a public system, we also need a rollout of an education campaign so that people are confident, when they receive an earthquake alert, that they're going to get under a table, hold on, and stay safe."

Basically, once the system is in place, the hope is that California can create a culture and economy that, like Japan, is able to look the earthquake hazard straight in the eye. And when we do, we may find that the hazard we face is far more dangerous than scientists once imagined.

By all accounts, the 2011 Tohoku earthquake was not supposed to happen. "It was sort of an eye-opener, particularly for seismologists in Japan, because they simply did not think it was possible to have a magnitude nine there," said Allen. "I think that really shook the seismology community about being overly confident."

For decades, scientists thought that violent shaking from a major earthquake could not be felt strongly over great distances. At the same time, scientists also have long noted that the idea that a quake has a specific, fixed "epicenter" is just a myth. "If the earthquake is really small, you can basically think of it as emanating from a single point. But the rupture propagates, like pulling a zipper," explained Given of the USGS. "And that zipper can go on for a few meters, or it can go on for hundreds of kilometers."

Depending on the amount of energy released in the first lurching motion, the zipper can rip for a while. When that happens, there's an additive effect that leads to an even higher-magnitude quake that impacts a much larger area.

But scientists used to think that certain segments of a fault, dubbed "stable" zones, staved off huge earthquakes by preventing quake ruptures from propagating for too long. They were thought to act essentially like snags in the zipper, stopping quakes from getting too big.

But according to new research on Tohoku released earlier this year by Caltech and the Japan Agency for Marine-Earth Science and Technology, these "stable" zones, under certain circumstances, might actually make quakes larger than they would otherwise be and thus might actually be to blame for Tohoku's unprecedented size. The 2013 study argued that, at times, these zones can cause even more powerful slipping events — allowing the earthquake to propagate even further and leading to so-called "wall-to-wall" super quakes.

In California, a wall-to-wall super quake could rip from one end of the state to the other. The San Andreas Fault, which stretches from Mendocino County to the Salton Sea in Southern California, was long thought to be divided by a similar "stable" zone in the Central Valley. According to the new model, however, it is technically possible for a super quake to rip through the four hundred miles separating two of America's most populous areas. "They're arguing that it's not impossible," said Allen. "What it really means is that you can have the Big One in Southern California and the Big One in Northern California at the same time."

"I think the temperature in the room is that while it's a possibility, it's probably a fairly low possibility," stressed Given. "But, that said, we have seen other low-possibility events occur — like Tohoku itself. And we saw the impact of an event that some of the best earthquake scientists in the world thought was a very low-probability event."

State Senator Alex Padilla, a Democrat from the San Fernando Valley whose district includes Northridge, which was devastated by a 6.7-magnitude temblor in 1994, introduced Senate Bill 135 in January. The bill calls for the creation of a statewide early warning system. To date, SB 135 has passed through all its committee hearings without opposition. But in order to make it to the governor's desk in September, it's going to need to overcome a major hurdle: finding the $80 million to build it.

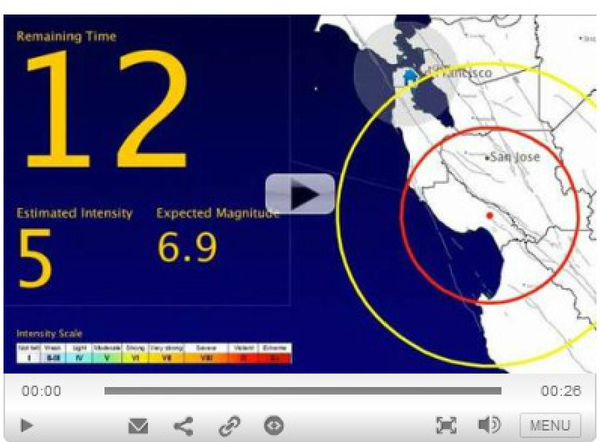
Padilla, who earned a degree in mechanical engineering from MIT and just announced his candidacy for California Secretary of State in 2014, said that he has no plans to dip into the state's general fund to pay for the system, despite the obvious benefits it will provide. Padilla has yet to fully explain his decision, but it's likely because of politics. Getting the legislature and the governor to sign off on spending scarce state funds on yet another new program would probably be a tough sell. Padilla has hinted instead that he will apply for federal grants, but his chances of success remain unclear.

Meanwhile, one private company in Southern California is already selling a similar technology to interested clients. Seismic Warning Systems, which includes a small team of six staffers operating more than eighty seismometers in Southern California, has implemented a sort of private-public model in Riverside and Imperial counties. The company sells its technology to other private companies in earthquake-prone regions, and then cycles some of the proceeds to pay for earthquake early warning in dozens of schools and fire stations in those counties.

Seismic Warning Systems is arguing that a similar model could work for the state. But it remains to be seen whether the company's technology, which is proprietary, is really as accurate as it claims, and whether it has the capability to expand in a way that could be useful on such a big scale. To date, the company has yet to share its technology with public agencies so it can be verified. And there have been reports of some tensions between Seismic Warning Systems and the public institutions vying to work with the state, although no one seems to be ruling out a public-private model at this point.

Still, there is no clear path forward right now for a statewide system. At a state Senate committee hearing last month in Sacramento, Republican Senator Jim Nielsen expressed concerns that reflect what many think when they hear about the potential of earthquake early warning system. "Seems like this is a no-brainer; they should've been working together for decades," Nielsen said, in his country-tinged drawl, addressing Padilla. "They should have been working on a plan. It's too bad that you have to thump them on the head to get them to do so."

Padilla responded quickly and firmly. "In their defense, sir, they've been thumping on us for attention and funding. They've been thumping on our Congressional delegation, and our federal agencies, for attention and funding. So, I know you don't want to be sitting with me after the next Big One if we haven't deployed an early warning system."



Here's what ShakeAlert — the warning system that Cal, Caltech, and USGS are working on — would look like.
Credit Richard Allen, University of California, Berkeley.