'Locked, loaded and ready to roll'

San Andreas fault danger zones

Kate Ravilious, Cosmos Magazine, 12-5-16

A series of small earthquakes up to magnitude 4 started popping off right next to the San Andreas fault at the end of September, giving Californian seismologists the jitters.

This swarm of more than 200 mini-quakes radiated from faults under the Salton Sea, right down at the southern end of the San Andreas fault.

And although the small quakes only released tiny amounts of energy, the fear was that this fidgeting could be enough to trigger an earthquake on the big fault. “Any time there is significant seismic activity in the vicinity of the San Andreas fault, we seismologists get nervous,” said Thomas Jordan, director of the Southern California Earthquake Centre in Los Angeles.

Because despite a plethora of sensitive instruments, satellite measurements and powerful computer models, no-one can predict when the next big one will rattle the Golden State.

***

Slicing through 1,300 kilometres of Californian landscape from Cape Mendocino in the north-west all the way to the Mexican border in the south-east, the San Andreas fault makes itself known.

Rivers and mountain ranges – and even fences and roads – are offset by the horizontal movement of this “transform” fault, where the Pacific Ocean plate to the west meets the North American plate to the east. The fault moves an average of around 3.5 centimetres each year, but the movement comes in fits and starts. Large earthquakes doing most of the work, punctuating long periods of building pressure.

The fault divides roughly into three segments, each of which tends to produce a big quake every 150 to 200 years.

The last time the northern segment (from Cape Mendocino to Juan Bautista, south of San Francisco) released stress was during the devastating magnitude-7.8 San Francisco Bay quake in 1906, which killed thousands and destroyed around 80% of San Francisco.

Meanwhile, the central section, from Parkfield to San Bernardino, has been quiet for longer still, with its last significant quake in 1857, when a magnitude-7.9 erupted underneath Fort Tejon.

But most worrying of all is the southern portion (from San Bernardino southwards through the Coachella Valley), which last ruptured in the late 1600s. With more than 300 years of accumulated strain, it is this segment that seismologists view as the most hazardous.

“It looks like it is locked, loaded and ready to roll,” Jordan announced at the National Earthquake Conference in Long Beach in May 2016.

This explains why the recent earthquake swarm was considered serious enough for the United States Geological Survey to issue a statement: that the risk of a magnitude-7 quake in Southern California was temporarily elevated from a one in 10,000 chance to as much as a one in one in 100.

“We think that such swarms of small earthquakes indicate either that fluids are moving through the crust or that faults have started to slip slowly,” says Roland Bürgmann, a seismologist at University of California, Berkeley. “There is a precedent for such events having the potential to trigger earthquakes.”

And last year he showed it’s not just the San Andreas fault we need to worry about. Working near the northernmost segment of the fault, Bürgmann and his colleagues used satellite measurements and data from instruments buried deep underground to map out the underground shape of two smaller faults – the Hayward and Calaveras – which veer off to the east of San Francisco. These two smaller faults, which are known to be capable of producing their own sizeable earthquakes (up to magnitude 7), turned out to be connected. Until now, sediments smothered the link.

And in October, another study published in *Science Advances* showed that the Hayward fault is connected by a similarly direct link to a third fault to the north – the Rodgers Creek fault.

“This opens up the possibility of an earthquake that could rupture through this connection, covering a distance of up to 160 kilometres and producing an earthquake with magnitude much greater than 7,” Bürgmann says.

“It doesn't mean that this will happen, but it is a scenario we shouldn't rule out.”

***

Down the other end of the San Andreas fault, Julian Lozos from the California State University in Los Angeles has been testing various earthquake scenarios using a detailed computer model of the fault system.

He too has shown that a seemingly minor side-fault – known as the San Jacinto – is more of a worry than previously thought. In this case, the San Jacinto falls short of intersecting the San Andreas by around 1.5 kilometres, but Lozos' model suggests large earthquakes can leap this gap.

“We already know that the San Andreas is capable of producing a magnitude-7.5 on its own, but the new possibility of a joint rupture with the San Jacinto means there are now more ways of making a magnitude-7.5,” says Lozos, whose findings were published in *Science Advances* in March this year.

By feeding historic earthquake data into his model, he showed that the magnitude-7.5 earthquake that shook the region on 8 December 1812 is best explained by a quake that started on the San Jacinto but hopped across onto the San Andreas and proceeded to rupture around 50 kilometres north and southwards.

If such a quake were to strike again today, the consequences could be devastating, depending on the rupture direction.

“The shaking is stronger in the direction of unzipping,” explains Lozos. And in this case, the big worry is a northward unzipping, which would funnel energy into the Los Angeles basin.

In 2008, the United States Geological Survey produced the ShakeOut Scenario: a model of a magnitude-7.8 earthquake, with between two and seven metres of slippage, on the southern portion of the San Andreas fault.

Modern buildings could generally withstand the quake, thanks to strict modern building codes, but older buildings and any buildings straddling the fault would likely be severely damaged.

But the greatest concern was the effect the movement would have on infrastructure – slicing through 966 roads, 90 fibre optic cables, 39 gas pipes and 141 power lines. Smashed gas and water mains would enable fires to rage, causing more damage than the initial shaking of the quake.

The overall death toll was estimated at 1,800, and the long-term consequences expected to be severe, with people living with a sequence of powerful aftershocks, and a long slow road to recovery. Simply repairing water mains, for instance, could take up to six months.

In this simulation, the city of Los Angeles doesn't take a direct hit, since it lies some way from the San Andreas fault. But there is another scenario which keeps Jordan awake at night.

Back in 1994, a magnitude-6.7 “Northridge” earthquake struck the San Fernando valley, about 30 kilometres north-west of downtown Los Angeles, killing 57 people and causing between US$13 and $40 billion of damage – the costliest natural disaster in the US at that time.

“This was a complete eye-opener for us all, as it occurred on a blind thrust fault that no-one knew existed,” says Jordan. Geologists have since worked overtime to discover these hidden faults, and in 1999 they found that Los Angeles itself sits atop the Puente Hills fault – a steeply angled “thrust” fault that is thought to produce earthquakes of greater than magnitude 7 every few thousand years.

“We are more likely to see a large earthquake on the San Andreas fault in the short to medium term, but we still have to accept that this thrust fault could move at any time, and because of its location underneath Los Angeles, the consequences would be very severe,” says Jordan.

Much of Los Angeles is underlain by soft sediments, which wobble furiously when rattled by a quake, and it is these areas that would likely sustain the most damage.

Thankfully, the Los Angeles city council is taking the risk seriously. Models such as ShakeOut Scenario motivated the city to produce emergency plans and retrofit dangerous buildings. Seismologists such as Jordan and Lozos live in Los Angeles, but confess that the risk does affect their everyday life.

“It crosses my mind when I drive over the freeway that collapsed in 1994, or when I'm deciding what kind of house to live in,” says Lozos. “Others mock me for worrying, but as a seismologist, I know that the longer you go without a quake the greater the chances of a quake are.”

Meanwhile, Jordan, who lives in a house underlain by solid granite bedrock, justifies his decision to live in this precarious part of the world: “If you want to hunt elephants, you have to go to elephant country.”