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Analysing earthquake signals

Statistical analysis of a well in China by a PhD student in Palmerston North has developed diagnostics for seismic activity that are being used in Taupo and Southern California. Jenny Rankine reports.

The Tangshan Well (above) is about 100km north-east of Beijing, in an area which has had many small earthquakes since 1976, when a magnitude 7.8 earthquake directly under the city killed about 240,000 people and flattened most of the city's buildings.

Chinese seismologists have known for years that the water level in this well is very sensitive to earthquakes. The level has been recorded daily since 1974, hourly since 1981 and digitally every minute since 2001.

Chinese student Ting Wang has studied in Beijing and is now doing her PhD at the Institute of Fundamental Sciences at Massey University, supervised by Associate Professor Mark Bebbington, Dr David Harte of Statistics Research Associates and Victoria University Emeritus Professor David Vere-Jones. She has analysed well level records since 2002, supplied by the Tangshan Earthquake Administration (TEA).

"Most fluctuations in water level register for about a half an hour to an hour, so hourly data is not useful for extracting well signals," she says. Her data set is two million measurement points, one minute apart, over four years, and a catalogue of global earthquakes from the USA Geological Survey's National Earthquake Information Center.

From this she extracted the arrival times of different earthquake waves - the primary and secondary waves, which travel through the earth, and the Rayleigh and Love waves, which travel along the earth's surface.

The amplitude of well level fluctuations increases after earthquakes. "We extract signals from the well data using a moving average filter method over a 10-minute window, and move that window along one minute at a time." She has used skill score and Poisson process tests to choose well signal filter parameters and magnitude thresholds for earthquake series.

"From the well point of view, there is a lot of movement and you don't know the cause. We've identified what is an earthquake response and what isn't," says Wang. About 40 percent - 237 of the 600 earthquakes above magnitude 6 - appeared to trigger identifiable fluctuations in the Tangshan Well. "We also found a threshold in the relationship between the magnitude of the earthquake and the well's distance from the epicentre, above which earthquake-related changes in well level are most likely."

The existing theory is that changes in water level are caused by Rayleigh waves, but in Tangshan arrivals from earlier waves, particularly primary waves, are often noticeable, although the Rayleigh waves do amplify movement in the well level.

Wang then turned her attention to analysing New Zealand earthquake data. "GNS Science has over 100 GPS receivers, which measure east-west, north-south and up-down position in each site each day, but only about 12 were in place around Taupo before 2004." The standard wisdom was that GPS signals measure only deformation after earthquakes. Using a lot of the same techniques, Wang was trying to find if any pattern of GPS movements from around Taupo preceded earthquakes.

Ting Wang at the Forbidden City in Beijing.

"We used a hidden Markov model to filter the data from the noise, then used mutual information to analyse which kind of movement is related to earthquakes. We found pre-seismic signals but they need more analysis; seismologists are very cautious."

While the Taupo analysis may provide some precursory information, there is not a risk to life or property. Wang moved her attention to GPS data and earthquakes in Southern California, which has more than 10 years of GPS data. "We needed a place with good GPS records and lots of earthquakes." There she found pre-seismic signals similar to what have been found at Taupo. With more testing and longer data sequences, Wang hopes that GPS measurements may be able to provide probability forecasts for large earthquakes.

$$V_t = \frac{1}{10}\sum_{s=t-9}^{t}\left(e^{-a(t-s)}d_s - \frac{1}{10}\sum_{s=t-9}^{t}e^{-a(t-s)}d_s\right)^2$$