Synthetic Seismicity Models of Multiple Interacting Faults

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Abstract

We have developed a computer programme to generate long catalogues of synthetic seismicity for fault networks and also detailed individual rupture histories. The programme is an extension of the quasi-static type, approximating some aspects of the mechanics of faulting so as to remain computationally efficient. Faults in the network can be of any orientation. When applied to the Wellington, New Zealand, region the catalogues are used to investigate the temporal clustering of large events, which we find to be quite pronounced. Detailed slip histories of individual "characteristic" events on the Wellington fault match compilations of observed real-world events. These histories can be used to generate strong ground motion records. Application of the model to a generic network of strike-slip faults has so far failed to reproduce the proposed precursory accelerating moment release pattern.

Introduction

Some important questions about seismic hazard cannot be answered given the short historical record. Physically realistic computer models of seismicity on a network of faults can be used to examine such questions. For example, the clustering in time of large events can be examined, or the opposite stress-shadow effect. The synthetic seismicity catalogues must be long enough to sample all modes of fault interaction so that statistically valid conclusions can be made; it is dangerous to make inferences about triggering probabilities by simply modelling a single hypothetical event and looking at the induced stresses on other faults. The catalogues can also be used to search for proposed precursory seismicity patterns (e.g., the accelerating moment release, or AMR, model). Finally, individual event rupture histories can be used to generate strong ground motion seismograms.

Here we briefly describe a synthetic seismicity model and its use in modelling seismicity in the Wellington region, New Zealand (Robinson & Benites, 1995[3], 1996[4], 2001[5]). The primary question we wish to answer was posed to us by the Earthquake Commission (EQC), the prime earthquake insurer in New Zealand. Large earthquakes in the Wellington region are their biggest risk, and potential clustering of events has important implications for re-insurance options and civil defence needs. The question was: How often do large events occur within a few years of one another? We also describe a generic network of many strike-slip faults that is being used to look for the AMR pattern. Discussion of ground motion calculations is deferred to a separate paper.

Wellington lies at the southern tip of the North Island, a region of oblique plate convergence and subduction. In addition to the possibility of large subduction thrust earthquakes (20 km under the city), there are several major, active, strike-slip faults in the overlying plate. One, the Wellington fault passes through the city centre, another 20 km to the east had a magnitude 8+ event in 1855.

The Model

The synthetic seismicity model is composed of:

1) A geometric description of the faults in the area and their distribution of mechanical properties such as the coefficients of static and dynamic friction, stress drop, healing time and initial pore pressure;
2) A driving mechanism that loads the faults as time progresses;
3) Specification of the failure law, here taken as the Coulomb Failure Criterion;
4) Routines (Okada, 1992[2]) for calculating induced stresses, which propagate at the shear wave velocity;
5) An algorithm to advance the model through time.

Each fault is divided into a large number of small cells. As time passes one cell eventually fails due to the loading. This failure induces stress and pore pressure changes on all other cells, on all faults, but only after a time given by the distance/Vs. Thus the initial failure may cascade into a larger event. Once a cell has failed, its strength is reduced to a dynamic level until healing after a few seconds. Some aspects of dynamic rupture, such as directivity and rupture-edge stress enhancement, can be approximated as well. The resulting catalogues are used to tune various parameters to reproduce the known long-term slip rates and directions, as well as the behaviour of the faults (e.g., to produce characteristic events and match observed scaling relations).

For efficiency, all interaction terms are calculated once at the start and kept in RAM (memory). The programme has been parallized to run on a "Beowulf" cluster of Linux PCs.

Clustering of Large Events in Wellington

Included in the model are the six largest faults in the overlying plate, and that portion of the plate interface that is inferred from GPS studies to be locked. The driving mechanism is taken as uniaxial compression in the direction of plate convergence. Many models were run, with varying mechanical properties. On average, we find that clustering of large earthquakes ($M > 7.2$) does indeed occur (Figure 1). Most clustering is caused by the interaction between the subduction thrust and one of the overlying strike-slip faults, and by along-strike triggering of segmented faults. It is clear that the elastic interactions are responsible since the clustering disappears without it. Another aspect of the results is the broadening of the distribution of inter-event times for large events on an individual fault (Figure 2).

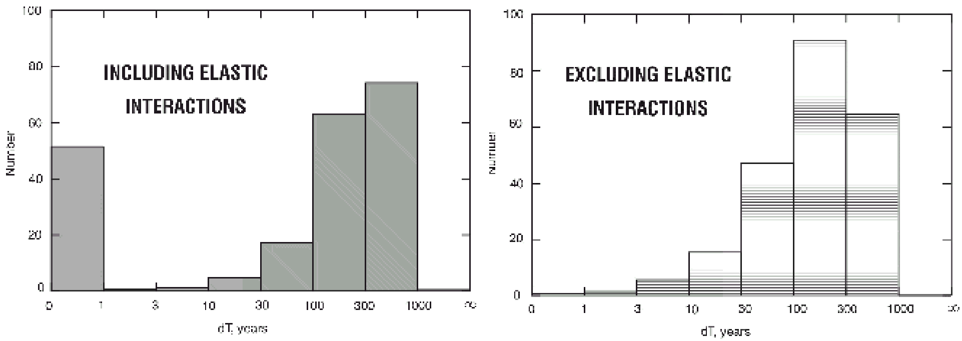

Figure 1: Histograms of time intervals between large (M > 7.2) earthquakes in the Wellington region, as modelled by synthetic seismicity. Left: faults interact elastically. Right: No fault interaction. Note the logarithmic time scale.

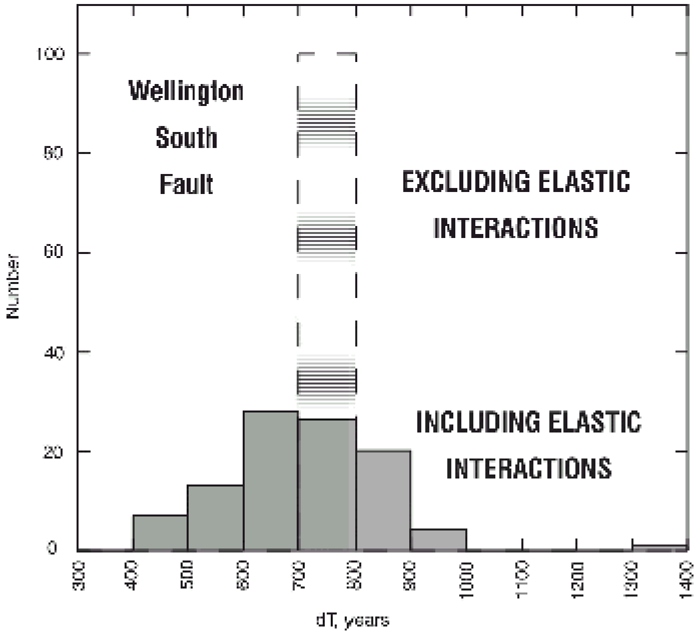

Figure 2: Histogram of the recurrence time of large earthquakes on the Wellington fault, as modelled by synthetic seismicity.

Characteristic Wellington Fault Events

EQC is also interested in the strong ground motion to be expected with a large “characteristic” Wellington fault earthquake. The synthetic seismicity model has been used to generate detailed rupture histories for such events. The mechanical properties used are listed below:

Fault Length: 75 km
Fault Width: 20 km
Fault Dip: 90°
Cell Size: 1 x 1 km
Coefficient of Friction:
  Asperity regions: Random between 0.65 and 0.95
  Non-Asperity: Random between 0.40 and 0.70
Stress Drop: 25%
Static/Dynamic Strength: 0.85
Healing Time: 3.0 s
Dynamic Enhancement Factor: 1.2
Pore Pressure: Initially ~ hydrostatic; varies with time
Stress Propagation Velocity: 3.0 km/s
Time Step During Rupture: 0.01 s

For this application it is important that the model earthquakes have properties consistent with real-world observations. Below we tabulate some such properties and compare them with the expected values (as a function of moment magnitude) as compiled by Somerville et al. (1999)[6]:

Moment: 1.41×10^{20} N-m; Mw 7.40

	Model	Somerville (1999) [6]
Rupture Area	1500 km^2	2810 km^2
Average Slip	2.35 m	1.96 m
Area of Asperities	345 km^2	630 km^2
Area of Largest Asperity	272 km^2	458 km^2
Radius of Largest Asperity	~9 km^2	13 km
Num. of Asperities	2 + 1 very small	2.6
Area Covered by Asperities	23%	22%
Average Asperity Slip Contrast	1.67	2.01
Corner Spatial Wavenumber,		
Along Strike	0.01 km^{-1}	0.01 km^{-1}
Along Dip	0.01 km^{-1}	0.02 km^{-1}
Slip Duration	3.0 s	2.55 s
Rupture Duration	~30 s	-

This model event has properties within the observed scatter for all the properties. As is usual for real New Zealand earthquakes, the rupture area is a bit small and the average displacement a bit large. The final slip distribution for one event is shown in Figure 3 (a colour movie of the rupture process is available at:

http://www.quakes.uq.edu.au/ACES/workshop2002/presentation2002.html

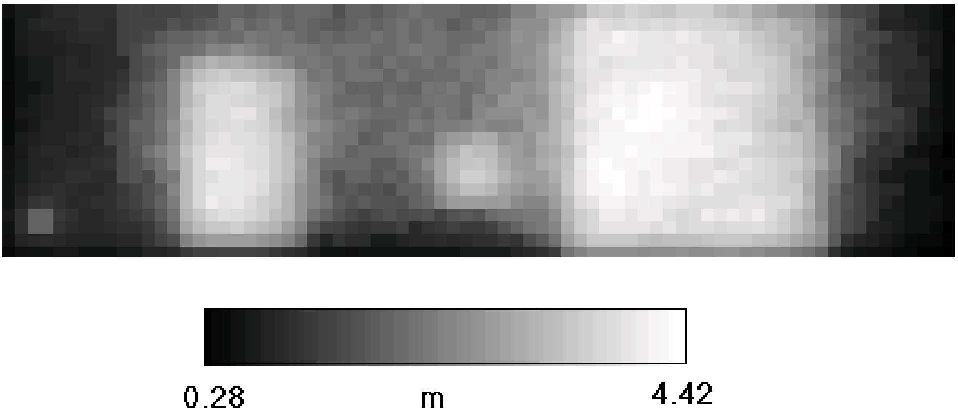

Figure 3: Final slip distribution for a characteristic earthquake on the Wellington fault, as modelled by synthetic seismicity.

Searching for precursory AMR

We are using the synthetic seismicity model to look for the AMR pattern in catalogues for a spatially extended, generic network of strike-slip faults. The network contains one major fault, 75 x 20 km in size, plus 2210 randomly placed smaller faults in an area 500 x 500 x 20 km. Each fault is subdivided into 1 x 1 km cells (over 22,000 in total), all of the same strike and vertical dip. The major fault generates characteristic events of Mw 7.2. Using the region as a whole, we observe no general pattern of accelerating moment release before these characteristic events, beyond what is expected by chance. Experiments are underway using precursory areas based on the pattern of the negative induced Coulomb failure stress for the characteristic events (Bowman & King, 2001[1]), and with a wider range of mechanical properties.

References

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