Fault Sources in the New Zealand Seismic Hazard Model

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Important Questions

• How complete is the NZ NSHM fault source model?

• What factors control the completeness?

• How sustainable is the one fault source one earthquake model?

• What is the likely slip rate of faults for future large magnitude earthquakes?

• How useful is the seismic cycle concept for forecasting future events?
New Zealand’s Onshore Active Faults

NSHM data
Stirling et al. 2012

New Zealand Historical Seismicity
1840-2014, Onshore, ≤25 km depth

Historical surface rupture 1840-2015
Kaikoura 2016 surface rupture

Magnitude (Mw)
- 5.0 - 5.4
- 5.5 - 5.9
- 6.0 - 6.4
- 6.5 - 6.9
- 7.0 - 7.4
- 7.5 - 7.9
- 8.0 - 8.5
- Kaikoura Eq

Datasets
Fault Incompleteness

Stirling et al. (2012)

NSHM Fault Sources

\[
y = 219.04x^{-1.306}, \quad R^2 = 0.9843
\]

~4200

\[
y = 612218x^{-2.188}, \quad R^2 = 0.9875
\]

~3500 (Mw6-7)

N=532

\[
y = 219.04x^{-1.306}, \quad R^2 = 0.9843
\]

\[
y = 612218x^{-2.188}, \quad R^2 = 0.9875
\]

N=532
Detailed mapping increased number of active faults. May be seeing ≤50% of active faults. Surface fault traces ≤50% subsurface length.
Larger magnitude events more likely to produce surface rupture.
No events ≤Mw 7 rupture ground surface (outside thin crust of the Taupo Rift).
Incompleteness increases with recurrence interval.
50% of historical >Mw 7 earthquakes on unknown faults.
• Multi-fault rupture.
• Ruptured faults with variable geometries, slip rates and recurrence intervals.
• Difficult to forecast based on surface geometries and locations.
• Will produce larger events than expected.
• May result in some double counting.
• Can be captured by raising max. magnitude for background seismicity model.
• Likely to occur no more frequently than every 5 kyr.
• How common multi-fault ruptures?

Kaikōura Earthquake and Surface-rupture

Kaikōura Earthquake
Mw 7.8 Nov 14 2016
Kaikōura Earthquake – incompleteness

Higher slip rate faults were known to be active and in the NSHM
How common are multi-fault ruptures?

- Subsurface rupture
- Surface rupture
- Possible surface rupture

1987 Edgecumbe Earthquake
Mw 6.5
≥5 faults
How common are multi-fault ruptures?

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Main Fault</th>
<th>Year</th>
<th>Magnitude (Mw)</th>
<th>Slip Type§</th>
<th>Maximum Slip† (m)</th>
<th>Surface Rupture Length‡ (km)</th>
<th>Number faults ruptured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marlborough</td>
<td>Awatere</td>
<td>1848</td>
<td>7.6</td>
<td>SS</td>
<td>9</td>
<td>110-120</td>
<td>≥1</td>
</tr>
<tr>
<td>Wairarapa</td>
<td>Wairarapa</td>
<td>1855</td>
<td>8.2</td>
<td>SS*</td>
<td>18</td>
<td>&gt;100</td>
<td>≥4</td>
</tr>
<tr>
<td>North Canterbury</td>
<td>Hope</td>
<td>1888</td>
<td>7.1</td>
<td>SS</td>
<td>2.6</td>
<td>15-77</td>
<td>≥1</td>
</tr>
<tr>
<td>Buller</td>
<td>White Creek</td>
<td>1929</td>
<td>7.7</td>
<td>R‡</td>
<td>4.9</td>
<td>&lt;64</td>
<td>≥1</td>
</tr>
<tr>
<td>Hawke's Bay</td>
<td>Napier</td>
<td>1931</td>
<td>7.8</td>
<td>R</td>
<td>3</td>
<td>80-130</td>
<td>≥3</td>
</tr>
<tr>
<td>Edgecumbe</td>
<td>Edgecumbe</td>
<td>1987</td>
<td>6.5</td>
<td>N</td>
<td>2.5</td>
<td>&gt;50</td>
<td>≥6</td>
</tr>
<tr>
<td>Darfield</td>
<td>Greendale</td>
<td>2010</td>
<td>7.1</td>
<td>SS</td>
<td>5.5</td>
<td>29.5</td>
<td>≥5</td>
</tr>
<tr>
<td>Kaikoura</td>
<td>Kekerengu</td>
<td>2016</td>
<td>7.8</td>
<td>R-SS</td>
<td>11.8</td>
<td>&gt;270</td>
<td>≥17</td>
</tr>
</tbody>
</table>

§Slip Type: SS, strike slip; R, reverse; N, normal. *Minor reverse. ‡Minor strike slip. †Maximum slip at the ground surface. *Total rupture length.

- Most historical surface-rupturing earthquakes post 1930 multi-fault events.
The next large magnitude earthquake (>M7) equally likely to occur on low, moderate and high slip rate faults?
Forecasting large magnitude earthquakes (>M7) using fault slip rates?

- ~33% of events in each recurrence interval category.
- 1 event/category every 30-40 years NZ wide.
- ~25% of historical events on high slip rate faults.
Elapsed time-recurrence intervals and future earthquakes

- Elapsed time ‘unlikely’ to exceed mean recurrence.
- Lack of elapsed times higher than mean recurrence partly sampling.
- Meaning for seismic hazard forecasting unclear.

<table>
<thead>
<tr>
<th>Ratio ET/MR</th>
<th>Observed</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>21-27</td>
<td>14.5</td>
</tr>
<tr>
<td>1-&lt;2</td>
<td>2-11</td>
<td>12</td>
</tr>
<tr>
<td>2-&lt;3</td>
<td>0-5</td>
<td>2</td>
</tr>
<tr>
<td>≥3</td>
<td>0-2</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Implications for Seismic Hazard Model

• Fault source model incomplete (emphasising importance of background seismicity model).

• Completeness is magnitude and slip rate dependent.

• Multi-fault ruptures are common in the NZ historical earthquake record and may need to be accounted for in the seismic hazard model.

• Future Mw ≥ 7.0 earthquakes are equally likely on slow, moderate and fast moving faults. Seismic hazard model improvements should focus on a range of slip rate faults.

• Few active faults appear to have elapsed time greater than mean recurrence intervals. This may be partly a sampling artefact.