Does strong-motion data have a nationality?
Investigating regional dependency of earthquake ground motions

19th March 2014, Nicholas Ambraseys Memorial Symposium, London
Ground-motion prediction equations (example)

\[
\log_{10}(\text{PGA}) = a_1 + a_2 M_w + (a_3 + a_4 M_w) \log_{10} \sqrt{r_{jb}^2 + a_5^2} + a_6 S_S + a_7 S_A \\
+ a_8 F_N + a_9 F_T + a_{10} F_O
\]

Where:
- PGA: peak ground acceleration
- \(a_1 \ldots a_{10}\): regression coefficients
- \(M_w\): moment magnitude
- \(r_{jb}\): Joyner-Boore distance in km
- \(S_S\) and \(S_A\): site conditions: \(S_S = 1\) for soft soil sites and 0 otherwise, \(S_A = 1\) for stiff soil sites and 0 otherwise
- \(F_N, F_T\) and \(F_O\): faulting parameters: \(F_N = 1\) for normal faulting, \(F_T = 1\) for thrust faulting, \(F_O = 1\) for odd faulting and 0 otherwise

\[
\begin{align*}
    a_1 &= 2.632 \quad a_6 = 0.124 \text{ (soft soil)} \\
    a_2 &= -0.109 \quad a_7 = 0.070 \text{ (stiff soil)} \\
    a_3 &= -2.990 \quad a_8 = -0.033 \text{ (normal)} \\
    a_4 &= 0.289 \quad a_9 = 0.090 \text{ (thrust/reverse)} \\
    a_5 &= 8.1 \quad a_{10} = -0.039 \text{ (odd/oblique)}
\end{align*}
\]

Ambraseys et al. (2005)

Key component of seismic hazard assessments
Increasing European data and GMPEs

Ambraseys (1975)

Ambraseys (1978)

Faccioli (1979) - Friuli

Sabetta & Pugliese (1987) - Italy

Ambraseys & Bommer (1991)

Ambraseys (1995)

Ambraseys et al. (1996)

Ambraseys et al. (2005)

Bindi et al. (2011) - Italy

Pan-European (examples)

Region/country-specific (examples)
**Born of necessity**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Station coverage (1 × 1°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data</td>
<td>M_w ≥ 5 &amp; R_epi ≤ 200 km</td>
</tr>
<tr>
<td>All Europe</td>
<td>17%</td>
</tr>
<tr>
<td>‘High’ hazard</td>
<td>44%</td>
</tr>
<tr>
<td>‘Low’ hazard</td>
<td>1%</td>
</tr>
</tbody>
</table>

**Map:**
- Pan-European
- National
- Local
- Map shows seismic activity across Europe with data distribution.
At present, there is **no doubt that these relations are different for different seismic regions**, and “region and site-specific” models should be developed on the basis of available strong ground motion records.

From Sokolov (2000)

We have found for peak accelerations remarkable agreement between Europe and western North America and we are as yet **unconvinced by apparent regional differences** such as are found in Central America and Japan.

From Ambraseys et al. (1997)
Seismotectonic arguments

Delavaud et al. (2008)
Comparing GMPEs

- Japan
- California
- Europe/Middle East
- Local (Turkey, Italy, Greece, Iran & NZ)

$M_w 7$

- $r_{rup} = 5$km
- $r_{jb} = 5$km
- $r_{epi} = 16.3$km
- $r_{hypo} = 22.1$km

strike-slip

Graph showing period vs. PSA (g) for different regions.
The problem with local models (intra-regional dependence)

Douglas (2007)

$M_w$ 6, focal depth 10km

Douglas (2007)
Turkey (Ulusay et al., 2004) v Italy (Sabetta & Pugliese, 1987)

95% confidence limits (Sabetta & Pugliese, 1987)

95% confidence limits (Ulusay et al., 2004)

\[ \hat{y} \pm t_{\alpha/2,\nu} \sigma \sqrt{\frac{1}{n_0} + X_0'C'X_0} \]

Douglas (2007)
### Comparing standard deviations of GMPEs

<table>
<thead>
<tr>
<th>Reference</th>
<th>Region</th>
<th>M range</th>
<th>d range (km)</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bindi et al. (2006)</td>
<td>Umbria-Marche</td>
<td>239</td>
<td>1 ≤ d_e ≤ 100</td>
<td>0.27</td>
</tr>
<tr>
<td>Bragato and Slejko (2005)</td>
<td>Eastern Alps</td>
<td>1402</td>
<td>0 ≤ d_f ≤ 130</td>
<td>0.36</td>
</tr>
<tr>
<td>Costa et al. (2006)</td>
<td>Friuli</td>
<td>900</td>
<td>1 ≤ d_e ≤ 100</td>
<td>0.34</td>
</tr>
<tr>
<td>Frisenda et al. (2005)</td>
<td>NW Italy</td>
<td>6899</td>
<td>0 ≤ d_h ≤ 300</td>
<td>0.32</td>
</tr>
<tr>
<td>Kalkan and Gülkan (2004)</td>
<td>Mainly NW Turkey</td>
<td>112</td>
<td>1 ≤ d_f ≤ 250</td>
<td>0.27</td>
</tr>
<tr>
<td>Luzi et al. (2006)</td>
<td>Molise</td>
<td>886</td>
<td>5 ≤ d_h ≤ 55</td>
<td>0.35</td>
</tr>
<tr>
<td>Marin et al. (2004)</td>
<td>France</td>
<td>63</td>
<td>5 ≤ d_h ≤ 700</td>
<td>0.55</td>
</tr>
<tr>
<td>Özbey et al. (2004)</td>
<td>NW Turkey</td>
<td>195</td>
<td>5 ≤ d_f ≤ 300</td>
<td>0.26</td>
</tr>
<tr>
<td>Sabetta and Pugliese (1987)</td>
<td>Italy</td>
<td>95</td>
<td>1 ≤ d_f ≤ 179</td>
<td>0.17</td>
</tr>
<tr>
<td>Zonno and Montaldo (2002)</td>
<td>Umbria-Marche</td>
<td>95</td>
<td>2 ≤ d_e ≤ 100</td>
<td>0.28</td>
</tr>
<tr>
<td>Abrahamson and Silva (1997)</td>
<td>Mainly California</td>
<td>999</td>
<td>0 ≤ d_r ≤ 220</td>
<td>0.19–0.31</td>
</tr>
<tr>
<td>Ambraseys et al. (1996)</td>
<td>Europe &amp; Middle East</td>
<td>422</td>
<td>0 ≤ d_f ≤ 260</td>
<td>0.25</td>
</tr>
<tr>
<td>Ambraseys et al. (2005)</td>
<td>Europe &amp; Middle East</td>
<td>595</td>
<td>0 ≤ d_f ≤ 99</td>
<td>0.19–0.36</td>
</tr>
<tr>
<td>Berge-Thierry et al. (2003)</td>
<td>Europe &amp; Middle East</td>
<td>802</td>
<td>4 ≤ d_h ≤ 330</td>
<td>0.29</td>
</tr>
<tr>
<td>Boore et al. (1997)</td>
<td>Mainly California</td>
<td>271</td>
<td>0 ≤ d_f ≤ 118</td>
<td>0.23</td>
</tr>
<tr>
<td>Campbell and Bozorgnia (2003)</td>
<td>Mainly California</td>
<td>443</td>
<td>2 ≤ d_s ≤ 60</td>
<td>0.17–0.25</td>
</tr>
<tr>
<td>Joyner and Boore (1981)</td>
<td>Mainly California</td>
<td>182</td>
<td>0 ≤ d_f ≤ 370</td>
<td>0.26</td>
</tr>
<tr>
<td>Lussou et al. (2001)</td>
<td>Japan</td>
<td>3011</td>
<td>4 ≤ d_h ≤ 600</td>
<td>0.32</td>
</tr>
<tr>
<td>Sadigh et al. (1997)</td>
<td>Mainly California</td>
<td>960</td>
<td>0 ≤ d_r ≤ 305</td>
<td>0.17–0.30</td>
</tr>
<tr>
<td>Spudich et al. (1999)</td>
<td>Worldwide extensional regimes</td>
<td>142</td>
<td>0 ≤ d_f ≤ 99</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Douglas (2007)
Residuals with respect to model for broad region

Bommer et al. (2007)
True for weak motions → for strong motions too?

natural logs

Southern California

Central California

Chiou et al. (2010)
Some ways forward

> GEM Working Group on Tectonic Regionalization:
  - Seek to develop global map of tectonic regimes
  - Objectively combine evidence from various global resources:
    - Global plate boundary map
    - Global strain rate map
    - Global Q map
    - ...

> Better GMPEs
  - Remove pseudo-regional dependency
  - Models with regional (e.g. Q) terms (e.g. NGA West 2)

> Rapidly developing networks:
  - Broadband networks
  - Accelerometric networks
  - Citizen observatories, e.g.:
    - Quake-Catcher (cheap MEMS accelerometers)
    - Did you feel it (macroseismic intensity)?

With G. Weatherill, M. Pagani, F. Cotton and others
The verdict

Not proven (the Scottish Verdict):

‘… the "not proven" verdict is an acquittal used when the judge or jury does not have enough evidence to convict but is not sufficiently convinced of the accused person's innocence to bring in a "not guilty" verdict.’ (Wikipedia)

‘Doubt is an uncomfortable condition, but certainty is a ridiculous one.’

‘Le doute n'est pas un état bien agréable, mais l'assurance est un état ridicule.’

– Voltaire
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