ESC2016-455, 2016
35th General Assembly of the European Seismological Commission

Bayesian estimation of paleo-earthquake magnitudes from multiple observations

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An important aspect of fault characterisation regarding seismic hazard assessment are paleoearthquake magnitudes. Especially in regions with low or moderate seismicity, paleomagnitudes are normally much larger than those of historical earthquakes and therefore provide essential information about seismic potential and expected maximum magnitudes of a certain region. In general, these paleo-earthquake magnitudes are based either on surface rupture length or on surface displacement observed at trenching sites. Several well-established correlations provide the possibility to link the observed surface displacement to a certain magnitude. However, the combination of more than one observation is still rare and not well established.

We present here a method based on a probabilistic approach proposed by Biasi and Weldon (2006) to combine several observations to better constrain the possible magnitude range of a paleo-earthquake. Extrapolating the approach of Biasi and Weldon (2006), the single-observation probability density functions (PDF) are assumed to be independent of each other. Following this line, the common PDF for all observed surface displacements generated by one earthquake is the product of all single-displacement PDFs.

In order to test our method, we use surface displacement data for modern earthquakes, where magnitudes have been determined by instrumental records. For randomly selected “observations”, we calculated the associated PDFs for each “observation point”. We then combined the PDFs into one common PDF for an increasing number of “observations”. Plotting the most probable magnitudes against the number of combined “observations”, the resultant range of most probable magnitudes is very close to the magnitude derived by instrumental methods.

Testing our method with real trenching observations, we used the results of a paleoseismological investigation within the Vienna Pull-Apart Basin (Austria), where three trenches were opened along the normal Markgrafneusiedl Fault (MF). Even if the Vienna Basin is characterized by low to medium seismicity (Mmax = 5.3/Imax = 8), there is no historical seismicity recorded along the MF. However, our studies provide evidence for at least 5 major earthquakes with M > 6.0 along the MGNSF during the last $\sim$ 100 ka. Using events that are observed within all three trench sites, we derived common magnitude PDFs for each set of observed displacements related to a single event. The resultant magnitude PDFs are dominated by the largest observed displacement, especially with respect to the lowest magnitude that could have generated all observed displacements.

In total, we can show that by combining several surface-displacement observations, the associated uncertainties for the magnitude of a paleoearthquake decrease rapidly, seemingly with an optimum of 4 to 6 observation points to obtain a significant reduction. In addition, testing our method with data from earthquakes with known magnitude and surface displacement, the reproduced magnitudes are promisingly close to the instrumentally determined magnitude. Therefore, this approach seems to be a suitable method to combine observations from different locations to one magnitude value accounting for the natural variances of observed along-strike surface displacement.

Reference: Biasi, G.P. & Weldon, R.J., (2006). Estimating surface rupture length and magnitude of paleoearthquakes from point measurements of rupture displacement. Bulletin of the Seismological Society of America 96, 1612-1623.