

Short Note

The Length to Which an Earthquake Will Go to Rupture

by Steven G. Wesnousky and Glenn P. Biasi

Abstract Using a database of 22 historical strike-slip surface rupture earthquakes, an apparent upper limit is observed in the number of steps through which an earthquake is likely to rupture. The number of ruptures is also observed to decrease as a function of the number of steps through which the respective earthquakes propagated. The observations may be important for assessing the expected length of earthquake ruptures where fault sections interact on mapped fault systems.

Introduction

Estimating the size of an earthquake that will rupture in a system of mapped active faults is a fundamental step in probabilistic seismic hazard analysis and thus maps showing the distribution of active faults are now commonly the foundation on which seismic hazard maps are built (e.g., Wesnousky *et al.*, 1984; Field *et al.*, 2009). Generally, the size of an earthquake on a fault is considered proportional to the length of the fault and estimated from empirical regression of historical earthquake rupture length versus earthquake magnitude (or seismic moment) (e.g., Wells and Coppersmith, 1994). Though simple in concept, significant uncertainty arises in estimating the length to which a rupture will propagate because historical earthquake ruptures have been observed to jump across discontinuities along fault strike and break more than one fault or fault segment in a single event (e.g., Sieh *et al.*, 1993). Prior work has suggested that there exists a correlation between the endpoints of historical ruptures and step discontinuities along fault strike (Fig. 1) and that there appears to be a physical limit of step width (about 3–4 km) wider than which an earthquake is unlikely to rupture (Wesnousky, 2006, 2008). Taken together, these observations help provide a physical and statistical basis to quantify the uncertainties associated with estimating the extent of future earthquake ruptures on mapped fault systems. Here we put forth an additional observation that may help further reduce the uncertainties in estimating the length of expected earthquake ruptures where steps or fault-to-fault linkages are being considered.

The Observations

We plot in Figure 2 the number of steps through which historical strike-slip earthquakes have ruptured versus the length of the respective rupture. The data are taken from the compilation of maps and measurements along surface rupture earthquakes put forth recently by Wesnousky (2008).

Steps are counted if rupture spanned a step of at least ~1 km. Restraining and releasing steps are not distinguished. Gaps in ruptures are not counted as steps if the fault trace is judged to be continuous based on available geologic mapping. The plot shows that among these earthquakes the maximum number of steps through which ruptures have propagated is three, and that there is no apparent correlation between the maximum number of steps observed along fault strike and the fault rupture length. Using the same data, Figure 3 shows the number of earthquake ruptures as a function of the number of step-overs spanned by the rupture. The histogram shows that the number of occurrences of earthquake ruptures is a decreasing function of the number of steps through which the respective earthquakes have propagated.

Discussion

A strictly empirical examination of the data set (22 events, 23 steps) indicates that the likelihood of an earthquake rupturing through zero, one, two, or three steps is 41% (9/22), 32% (7/22), 9% (2/22), and 18% (4/22), respectively. Fitting these data with a simple probability model can summarize the observations and provide the accompanying likelihood that ruptures with more than 3 steps may occur in the future. We explore this by using a maximum likelihood method to fit the observations to Poisson and Geometric distributions (e.g., Larson, 1982). Fitting parameters and the relative probability of earthquakes rupturing through a particular number of segments are shown in Figure 3 and summarized in Table 1. The Poisson model assumes that steps are distributed within a rupture with a frequency per rupture described by the Poisson parameter. This model considers step-overs to be randomly related to ruptures and implies nothing about the physics of step-overs in the rupture process. The Geometric distribution model assumes that each step-over has a random probability of stopping the rupture and that rupture extension reflects the compounding improb-

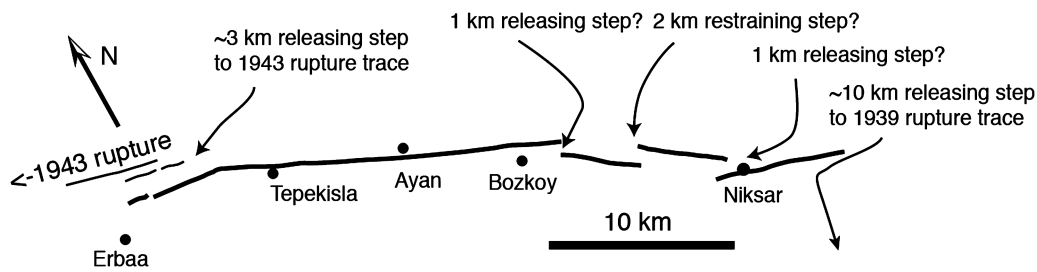


Figure 1. The rupture traces of earthquakes on strike-slip faults are often not continuous but rather broken by steps in the fault trace. The rupture trace (thick bold lines) of the Erbaa-Niksar earthquake of Dec 20, 1942 on the Anatolian fault zone of Turkey serves as example (event 9 in Fig. 2). Three steps greater or equal to 1 km in dimension are observed within the length of the fault that ruptured. The step dimension is measured perpendicular to fault strike. The rupture traces of the 1939 and 1943 earthquakes occurred along the same fault zone and are separated from this rupture by steps of 3 km and ~10 km, respectively. Figure adapted from [Wesnousky \(2008\)](#).

ability of passage. For this data, the mean estimate of the geometric parameter is 0.49 (Table 1). This is very close to the expectation from tossing a fair coin, in which the likelihood of a rupture continuing through one step is 50%, two steps is 25%, three steps 12.5%, and so on. The Geometric model is more in concert with the idea that step-overs have a causal role in impeding rupture propagation. Prior observations and models (e.g., [Harris and Day, 1999](#); [Wesnousky, 2006](#); [Oglesby, 2008](#)) suggest a likely causal relationship between fault step-overs and the endpoints of rupture, so the Geometric model might be favored in that respect, but the present data do not provide a compelling basis to prefer one

above the other (Table 1 and Fig. 3). The goodnesses of fit using the chi-square test are virtually equal for the two models and allowed 95% confidence levels, though neither model predicts the observed excess of three step-over cases. The discrepancy at three steps may be an accident of the small sample size or that the Poisson and Geometric descriptions do not capture some aspect of the physics of the process. Nonetheless, the observations and approach embodied in Figures 2 and 3 may be useful in reducing the uncertainty attendant with estimating the endpoints of ruptures and rupture lengths on mapped multi-segment faults and fault systems.

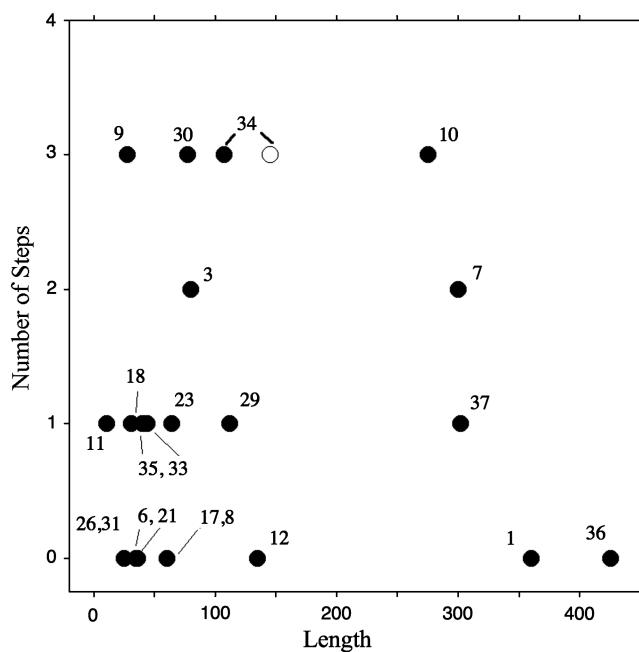


Figure 2. Number of steps greater than or equal to 1 km dimension versus rupture length for historical strike-slip earthquakes. Data taken from the compilation of [Wesnousky \(2008\)](#) and numbers next to data points correspond to table 1 of that same paper. Total length of Event 34 including offshore extent shown by open symbol.

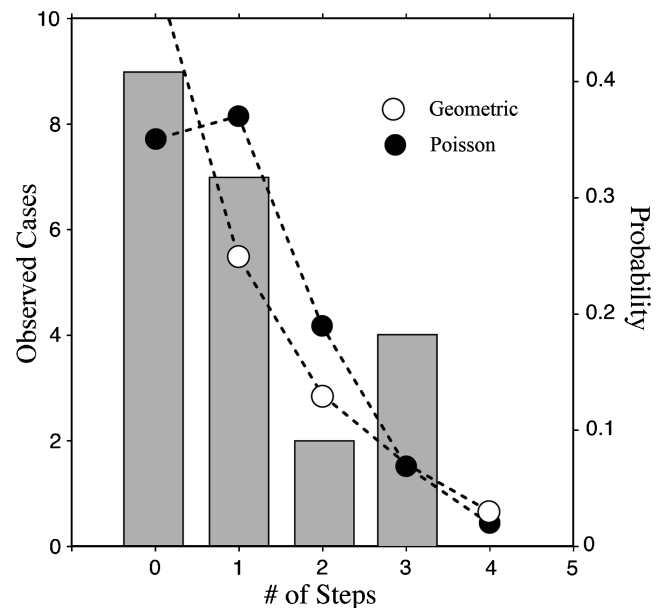


Figure 3. Histogram shows the number and percentage of times of historical strike-slip surface rupture earthquakes that ruptured through 0, 1, 2, or 3 steps along fault strike, respectively. Poisson and Geometric probabilities (right scale) are shown as open and closed circles, respectively. The goodnesses of fit as measured by the chi-square test are virtually identical between the two models.

Table 1
Probability Calculations

	Number of Steps					Mean est.	95% range
	0	1	2	3	4		
Observed fraction and probabilities of occurrence							
Observed Fraction	41%	32%	9%	18%	0%		
Geometric Probability	0.49	0.25	0.13	0.07	0.03	0.49	0.34–0.63
Poisson Probability	0.35	0.37	0.19	0.07	0.02	1.05	0.66–1.57
Observed cases and predicted number of cases							
Observed Cases	9	7	2	4	0		
Geometric	10.8	5.5	2.8	1.4	0.7		
Poisson	7.7	8.1	4.2	1.5	0.4		

Data and Resources

All data used in this paper came from published sources listed in the references.

Acknowledgments

We thank David Oglesby and an anonymous reviewer for constructive comments. This research was supported by the Southern California Earthquake Center that is funded by the National Science Foundation and the USGS Cooperative Agreements EAR-0106924 and 02HQAG0008, respectively. We also received support from the Southern California Earthquake Center (Contribution No. 1465) and the Center for Neotectonic Studies (Contribution No. 59).

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Manuscript received 11 January 2011

Queries

1. I have inferred that S.G. Wesnousky is associated only with the Center of Neotectonic Studies, and that G.P. Biasi is associated only with the Nevada Seismological Laboratory, is that correct?
2. I changed NSF to the National Science Foundation and SCEC to the Southern California Earthquake Center, is this correct?
3. Please rewrite to clarify the idea meant by “Histogram shows the number and percentage of times of historical strike-slip surface rupture earthquakes that ruptured . . .”