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Fault plane heterogeneity determined by fractal geometry of fault zones

Kenshiro Otsuki[1*]

[1]Dept. Geol., Graduate School of Science, Tohoku Univ.

Investigation 1

Fault planes are inherently heterogeneous and this is a source of variety of earthquakes. Fault zones are composed of fault segments and jogs. Otsuki & Dilov (2005, JGR, 110, B03303) found for experimentally made fault zones of 1 mm order lengths that fault segments + jogs structures are hierarchically self-similar. With the additional data of small geological faults of a 10 m order length scale and strike-slip seismic faults longer than the thickness of seismogenic layer which emerged on the earth's surface, segment length L_S(i), jog length L_J(i) and jog width W_J(i) show the correlations below,

$L_S(i+1) = 0.348\ L_S(i)^{0.994}$ approx. $L_S(i+1) = 0.365\ L_S(i)$ —— (1)

$W_J(i) = 0.0278\ L_S(i)^{1.06}$ approx. $W_J(i) = 0.0402\ L_S(i)$ —— (2)

$W_J(i) = 0.191\ L_J(i)^{0.990}$ approx. $W_J(i) = 0.189\ L_J(i)$ ——— (3),

where i denotes the hierarchical rank. These relations indicate the fractal dimension D of fault zone geometry is close to 2.

For the individual three data set eqs. (2) and (3) are represented by $W_J(i) = b\ L_S(i)^H$, $W_J(i) = a\ L_J(i)^A$ with different proportional constants and power values.

For experimental faults......... b=0.00385, H=0.642, a=0.00694, A=0.516.
For geologic small faults....... b=0.333, H=0.763, a=0.141, A=0.558.
For strike-slip surface faults.. b=0.164, H=0.853, a=3.18, A=0.665.

Investigation 2

Seismologists have searched for appropriate distribution patterns of the heterogeneity which can explain the G-R law and the k^{-2} falloffs of earthquake displacement spectra (e.g. Madariaga, 1979, JGR, 84, 2243; Andrews, 1980, JGR, 85, 3867; Frankel, 1991, JGR, 96, 6291; Herrero & Bernard, 1994, BSSA, 84, 1216). They reached the conclusion that D is 2 if static stress drop is constant. This is very consistent with the analytical results for fault zone geometry mentioned above. The parameter H corresponds with the Hurst exponent, and it is related with D by D=E+1-H, where E denotes Euclidean dimension. Since H=0.853 for strike-slip seismic surface faults, D=2.15. Mai & Beroza (2002, JGR, 107, B11,2308) analyzed the slip distributions which were depicted by waveform inversions for many earthquakes, and found that D=2.29 and H=0.75 at an average, being consistent with my results.

Investigation 3

Mai & Beroza (2002, JGR, 107, B11,2308) estimated for correlation distances of slip distributions on fault planes to be about 1/3 of the effective fault lengths. Bersenev (2001, JGR, 28, 35) found that earthquakes are associated with sub-events with about 1/3 length scale of the main phases. These are consistent with eq. (1). It depicts that one overall fault zone is divided into three first-order segments, and that the fractal of fault plane geometry is not continuous but discrete (hierarchical). This discreteness is supported by the numerical simulations by Ben-Zion & Rice (1995, JGR, 100, 12959) in which real complex slip patterns were realized especially when strong and abrupt heterogeneities (of jogs) were assumed.

Investigation 4

Scholz (1982, BSSA, 72, 1) proposed that mean strike-slips are proportional to fault lengths even if the fault is much longer than the thickness of seismogenic layer (L-model). This curious problem has been open to discussion. My analytical results show that mean strike-slips U_m of surface large faults are related with fault lengths L_0 by the power function as,

$U_m = 0.246 {L_0}^{0.46}$ ——— (4).

Note that the power value is less than 1. This is caused by jogs which pin the fault slip to make faults stiffer. Only ${L_0}^{0.46}$ is interpreted to work as an fault length effective for slips. Recent numerical simulation results for seismic slips on heterogeneous fault planes (e.g. Hillers & Wesnousky, 2008, BSSA, 98, 1085; Dieterich & Smith, 2009, PAGEOPH, 166, 1799) realize such phenomena.

The relation with fracture surface energy and the evolution of fault zone geometry will be discuss elsewhere.

Keywords: fault plane, geometry, fractal, heterogeneity