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Displacement efficiency of faults and fractures: Discussion

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Abstract—Higgs and Williams present a kinematic classification of one-event faults. It is our contention that the new terms which they propose are misleading and that the conclusions drawn cannot be reconciled with the findings of earthquake seismologists.

DISCUSSION

INTEGRATION of structural analysis of ancient faults with earthquake seismology can be of great benefit (Jackson & McKenzie 1983, Sibson 1983). However, in a recent article in the *Journal of Structural Geology*, Higgs & Williams (1987) present a 'kinematic' classification of single-event faults which contains a number of assertions that cannot be reconciled with the findings of earthquake seismologists. Higgs & Williams (1987) argue that single-event faults may be characterized kinematically by two parameters: (i) *normalized displacement magnitude* (M_n)—the ratio of maximum displacement to movement-parallel fault length; and (ii) *displacement efficiency*—the area under a normalized displacement vs fault length curve. Our contention is that neither term should find common usage.

Earthquake magnitude is a standard parameter by which earthquakes are quantified (Kasahara 1981). Modifications of Richter's original definition (M or Ml) have been introduced: Ms—seismic wave magnitude; Mw—moment magnitude; Md—duration magnitude; and mb—body wave magnitude. Normalized displacement magnitude, as defined by Higgs and Williams, is not a measure of the size of an earthquake, but is proportional to stress drop, a source parameter which is approximately constant for seismic events of a given type (interplate or intraplate) over a wide range of magnitude (Kanamori & Anderson 1975, Kasahara 1981, Scholz 1982).

Three principal types of faults are recognized by earthquake seismologists: Type I—interplate faults, which occur along plate boundaries; Type II—intraplate faults which are plate boundary-related; and Type III—intraplate faults which are not plate boundary-related (Scholz *et al.* 1986). Higgs & Williams (1987) describe the slip characteristics of one Type I creep event and two Type III faults. Seismologists have established a difference between the mean slip/length ratios (and stress drops) of earthquakes on large Type I and Type II faults (1×10^{-5} and 6×10^{-5}, respectively; Scholz *et al.* 1986); insufficient data are available to make a comparable study of Type III faults. Differences in displacement characteristics between Type I and Type II faults reflect differing frictional properties and boundary conditions. We consider the analysis of displacement characteristics of different fault types which does not acknowledge the distinction between interplate and intraplate faults, to be unacceptable.

Higgs & Williams (1987) further complicate the usage of their term *normalized displacement magnitude* by quoting two M_n values for the same fault (as calculated from measurements along both the principal axes of an elliptical fault surface, their fig. 4). Normalized displacement magnitude should be referred to simply as the maximum slip/length (or width) ratio: this is not a normalized quantity.

A basic assumption of Higgs and Williams' paper is that the three slip (or displacement) distributions described are products of single-slip events. Whilst this is clearly true of the Hayward–Calaveras interplate creep event,the faults in Quaternary lacustrine sediments and Westphalian Coal Measures have displacement/length ratios which are several orders of magnitude higher than a single event fault (Kanamori & Anderson 1975, Scholz *et al.* 1986). This indicates that these faults are multiple event structures (Watterson 1986).

Displacement efficiency is defined as the ability of a fault to maximize displacement over its surface (Higgs & Williams 1987). It has been shown that in an isotropic elastic medium the distribution of slip on a Somigliana dislocation is represented by a semi-circular profile on a normalized slip-distance plot (Eshelby 1957, Keilis-Borok 1959, Archuleta & Brune 1975). The Hayward–Calaveras creep event approximates this ideal slip profile (King *et al.* 1973), but has, according to Higgs & Williams (1987), a displacement efficiency of only 67%. Clearly, the displacement efficiency of a single-event fault has no simple mechanical or kinematic significance. The introduction of this term is all the more unfortunate, in that it is not related to seismic efficiency (the ratio of radiated seismic wave energy to the change in strain energy at the source) which, for a given tectonic stress, has been taken to be directly proportional to the stress drop (Kanamori & Anderson 1975, Kasahara 1981).

Higgs & Williams (1987) argue that for a given propagation rate a displacement efficient slip event initiates with low slip rates at the centre of the fault and propagates with increasing slip rate towards the fault tips. King *et al.* (1973) have demonstrated that the Hayward–Calaveras creep event initiated at one tip and developed towards the other tip with decreasing propagation speed and slip velocity. During the event the slip velocity at each point on the fault plane was not constant. Therefore, the slip geometry cannot be explained in terms of *ad hoc* kinematics, such as varying slip and propagation rates, but is rather a product of the propagation dynamics of a rupture within an elastic medium. In addition, actual propagation and slip rates in a single dynamic elastic event are different concepts from the time-averaged propagation and displacement rates inferred from the geometry of the static structure (Williams & Chapman 1983). In the latter case, characterization by the two rates is meaningful only if they are independent variables: this is not the case with single slip events where each event produces a very similar geometry.

Higgs and Williams state that all of the four faults and fractures studied, which include a tension gash with curved calcite fibres, approximate to 50% displacement efficiency. They argue that "if this observation is repeated, this may have important consequences in fault modelling and in the interpretation of faults in seismic sections, cross-sections and geological maps". We question this conclusion because their model is for single-event faults, which rarely have a maximum slip of as much as 5 m. Faults of this size are not usually shown on cross-sections and geological maps and are unlikely to be imaged on seismic sections. More significantly, a single-event slip of 5 m would be associated with a slip surface of maximum dimension 80–500 km, while the slip on a slip surface of maximum dimension 5 km would be approximately 5–30 cm (Scholz *et al.* 1986).

Displacement/length ratios and displacement distribution on fault surfaces are important concepts, but understanding their significance will not be assisted by coining of unnecessary, and in our view, seriously misleading terms. Structural geologists should acknowledge that they have much to learn from earthquake seismologists about single slip events and, so far, little to contribute.

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