ON RELATIONS BETWEEN ASPERITY POPULATION AND EARTHQUAKE POPULATION ON A FAULT

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The first study of properties of asperity population on a seismogenic fault [1] was based on near field data. Now additional evidence is presented obtained by interpretation of short-period (SP) teleseismic data, including magnitude (or peak amplitude A_{SP}) and spectral level S_{SP} vs M_0 trends. Reinterpretation of published m_{PV}^{SKM}, m_b^*, and $\hat{m}_b$ data enabled us to rather reliably estimate the b value in the relation $A_{SP} \propto M_0^b$ to be 0.35 for $\log M_0 = 26\text{-}30$. As for ß value in $S_{SP} \propto M_0^{\beta}$, the data (compiled) are scarce and indicate to $\beta \approx 0.39$ as a reasonable but preliminary value. Note that such a combination (ß, b) definitely contradicts to Gaussian noise model of SP record.

The empirical (ß, b) values were compared with the theoretical ones expected from the initial version of multiasperity fault model [1], namely, $\beta = 0.333$, $b = 0.667/\alpha = 0.33$, where $\alpha = 2$ is the exponent of the assumed[1] power law distribution of asperity strength. This law and the particular value of α were proposed based on near field data. Evident disagreement between theory and observations suggests to generalize the model and, instead of M_0-independent asperity radius R_a, to assume its growth with increasing M_0. Such a tendency can be deduced from several published observations of f_{max} vs M_0 relation when the simple relationship $f_{max} \propto R_a^{-1}$ that implies from multiasperity model is taken into account. Hence we assume $R_a \propto M_0^{\gamma}$ and obtain modified theoretical estimates $\beta = 0.333 + \gamma$, $b = 2\gamma + (0.6667 - \gamma)/\alpha$. Comparison with empirical values gives estimates: $= 0.06$ which reasonably agree with empirical values $\gamma = 0.07\text{-}0.11$; $\alpha = 2.38$ which is somewhat below the near field estimate of 2. One can believe that the interval estimate of $\alpha = 2\text{-}2.5$ is rather reliable.

Of great interest is the comparison between empirical α estimates and the theoretical ones. These can be based on the widely assumed power law distribution of earthquake source sizes on a fault. Fukao and Furumoto[2] have noted that this kind of distribution can indicate the specific near-critical mode of source growth. To explain such a mode they propose that there exists a hierarchical set of grids of linear barriers on a fault, organized in such a manner that the larger the cell size of a grid, the stronger its constituent barriers are. Gusev[1] replaced linear barriers of the model by chains of asperities. He modified the Barenblat-Dugdale crack model for a case of multiasperity fault and obtained the following critical condition (no friction assumed):

$$k_f \tau \approx (R_S \; / \; d)^{0.5} \sigma_\infty \qquad (1)$$

where τ is the critical asperity strength, k_f is the proportion of fault area covered by asperities ($k_f \ll 1$), R_S is the crack source radius ("source" here is a region where all asperities are already broken), d is the average distance between asperities ($d \approx (\pi / k_f)^{0.5} R_a$), and σ_∞ is the shear load at infinity. Applying this condition, Gusev [1] demonstrated that $\alpha = 2$ for the critical mode in the modified Fukao-Furumoto model.

The specific highly organized structure assumed in this model seems still unlikely, and the question arises wheather random asperity distribution over fault surface can produce the near-critical mode of growth. We studied this question based on modified Eq. 1 where σ_∞ was replaced by the average stress drop arising when most asperities over a source area are broken but several of them are so strong that can " resist being surrounded". If they suffice in number, τ can be reduced to the average/median strength; this results in the sought behaviour. Thus, the near-critical (neither Griffits-like explosive nor guaranteed stopping) mode of growth can in fact be realized in case of randomly dispersed asperities, but the exponent of the power law is much below the observed one. This can mean that some organized hierarchical structure does exist which improves resistance so that the lower number of strong asperities is needed. In particular the structure can consist of linear chains or of a hierarchy of clusters. The latter variant can help to bring into accord the two different estimates on asperity size: a few tens of km or about 1 km, both based on different empirical data.

Now, let us discuss the assumed R_a vs M_0 scaling. There is an explanation of f_{max} vs M_0 relation based on the crack source model [3] : f_{max} is related to the width of cohesion zone and the following chain of positive correlations acts: cohesion zone width -> fault zone width -> fault length -> typical source size and M_0. Based on multiasperity model, our explanation of f_{max} vs M_0 (i.e. R_a vs M_0) relation employs somewhat different chain: typical asperity size R_a -> typical interasperity distance d -> gouge zone thickness h -> cumulative fault offset -> fault length -> typical source size and M_0. Relative movement of fault walls causes wear of their surfaces and thickening of the gouge zone. During this movement, at first small and then larger details at wall relief are cut off and material is supplied to cover up other details. Gouge zone thickening with increasing fault offset is the observed geological fact. Relating the term "asperities" as it is used by seismologists with the real asperities of the differential relief of the fault walls we can assume that the typical interasperity distance will increase with accumulating fault offset because of smoothing of this relief.

However, a problem arises: is it correct to assume the existence of typical or characteristic asperity size whereas a fault trace line and fault wall surface are of fractal nature, so that a wide range of asperity sizes can be expected. To clear this situation, let us assume the fault trace to be a fractal of dimension D slightly above 1 ($D \approx 1$) and its lower fractal limit to be below 1 km [4]. To model asperities, assume that a plane is cut along a line which is a plot $y(x)$ of a random function with k^{-3} power spectrum, its $D = 1$. Let us move the upper halfplane upwards by h and then to the left by a. The observed gap is described by "gap profile" $g(x) = y(x) - y(x + a) + h \approx ay'(x) + h$, the power spectrum of which is of k^{-1} type. This reminds of the proposal of Main [5] that the fault strength is proportional to $y'(x)$; we believe that it is rather highly non-linear (still increasing) function of $g(x)$ because of contact phenomena.

To model real smoothed asperities, assume the gap profile to be band limited, and the lower k_1 and the upper k_2 cutoffs to be such that $2\pi/k_1$ is near to the fault length L, and $2\pi/k_2$ is near to certain l. One can show that at the given conditions, the average distance between peaks of $g(x)$ (identified with interasperity distance d) is near to l. (This is valid for sufficiently rough profiles only: for k^{-4} initial spectrum, $d \approx (lL)^{0.5}$). Now, assuming stability of k_f, we can find the typical R_a value. Therefore, some simple but realistic assumptions about the band-limited fractal nature of a profile imply the existence of typical or characteristic d and R_a values related to the value of a lower fractal limit.

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