

DIFFERENCES IN PHYSICAL PROCESSES IN THE FOCI OF WEAK AND STRONG EARTHQUAKES

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Abstract

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GEOPHYSICS

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**DIFFERENCES IN PHYSICAL PROCESSES
IN THE FOCI OF WEAK AND STRONG
EARTHQUAKES**

(Presented by Academician M. A. Sadovskii, 23 XII 1968)

As the energy of an earthquake increases, the size of its focus also increases. The length of the zone of ruptures formed in the strongest earthquakes ($M \approx 8^{1/2}$) reaches 1000 km. The linear dimensions of the foci of weak earthquakes ($k = 3-4$) are measured in tens of meters (⁵). It should be noted that the lower limit of earthquake energy has not yet been found. Therefore it may be said without exaggeration that the linear dimensions of the foci of the weakest and strongest earthquakes differ by no less than 5 orders of magnitude. Naturally, the processes occurring in volumes that differ so greatly in size may be substantially different.

In the course of deformation of the Earth's crust, its individual elements are displaced. The acting forces and the stresses arising thereby, for each element of a continuous ideally elastic medium in a gravitational field, are related by the equations:

$$\rho \dot{j}_i = \rho g_i + \partial P_{ik} / \partial x_k \quad (i, k = 1, 2, 3), \quad (1)$$

where ρ is the density of the medium, j is acceleration, g is the acceleration of gravity, P is stress, and x is a coordinate. If physically similar processes occur in two volumes of the Earth's crust, then they will be described by equation (1) provided the following similarity criterion is satisfied (¹⁻³):

$$C_\rho C_j C_l = C_P; \quad (2)$$

here $C_\rho = \rho' / \rho''$; $C_j = j' / j'' = g' / g''$; $C_l = x' / x''$; $C_P = P' / P''$. Quantities with one prime refer to the first volume, and those with two primes to the second.

The preparation of an earthquake is a long process of growth of stresses in a certain volume of the Earth's crust. The accelerations of the displaced elements

of the volumes under consideration may be taken as equal to zero, since the tectonic process proceeds at a rate of a few centimeters per year. In this case equation (1) will be an equation of equilibrium. Since the density of the material within the Earth's crust varies extremely little, one should set $C_\rho = 1$. Likewise, within the Earth's crust the acceleration of gravity is everywhere the same, and therefore $C_j = 1$. Thus, the similarity criterion (2) takes the form

$$C_l = C_p. \quad (3)$$

Suppose that, at some instant of time, at some point of the focus of a future earthquake, the stresses have reached the local strength of the material of the Earth's crust. This instant corresponds to the beginning of the earthquake. Before this instant, equation (1) is applicable. Passing to a future focus of considerably larger dimensions, it must be acknowledged that, according to the similarity criterion (3), at the corresponding points of it the stresses will be greater by the same factor by which its linear dimensions are greater, if the foci are physically similar. At some value of the size of the focus, the maximal-

...stresses at some point of its volume will reach the limiting strength of the material of the Earth's crust, and further growth of the dimensions of the focus cannot be accompanied by an increase in stresses.

This conclusion compels us to divide earthquake foci into, at least, two types.

In foci of the first type, the magnitude of the stresses increases with an increase in their geometrical dimensions. This is possible if the displacements occur along an already existing fracture and the maximum stresses are determined by the strength of the contact or by the magnitude of friction on the surface of the future displacement. Relatively weak earthquakes belong here ($M < M_x$). For these earthquakes the seismic energy is determined both by the dimensions of the focus and by the magnitude of the maximum stress.

The second type includes earthquakes in whose foci the maximum stresses reach the strength of the material of the Earth's crust. In this case, further increase in the dimensions of the focus cannot be associated with stresses. Consequently, the foci of strong earthquakes ($M > M_x$), strictly speaking, are not physically similar either to one another or to the foci of weak earthquakes. The seismic energy of such earthquakes is possibly directly proportional to the volume of the foci.

Since, at the moment of an earthquake, a disruption of continuity occurs in its focus, or at least a rupture of the displacement field, equation (1) is not applicable within its limits. However, one may consider a point outside the focus but near its surface. The displacements and accelerations here will be considerable; therefore the accelerations in equation (1) can no longer be neglected. If we restrict ourselves to the particular case of horizontal motions in the focus, then the term containing the acceleration of gravity vanishes. The similarity criterion (2) takes the form

$$C_j C_l = C_p. \quad (4)$$

Consequently, in passing from a focus of smaller dimensions to a similar focus of larger dimensions, at corresponding points of their neighborhoods one should expect an increase in stresses and (or) a decrease in the accelerations of the moving masses.

In a strong earthquake, all the accumulated elastic energy cannot be released at the moment of the main shock, and some part of it, the residual elastic energy, continues to be released after the strong earthquake in the form of aftershocks. In a first approximation, the process of release of residual stresses in the course of a sequence of aftershocks can be described with the aid of Maxwell's equation for a viscoelastic medium ⁽⁴⁾

$$\frac{\partial e_{ik}}{\partial t} = \frac{1}{2\mu} \frac{\partial P_{ik}}{\partial t} + \frac{P_{ik}}{2\eta} \quad (i, k = 1, 2, 3; i \neq k), \quad (5)$$

where e is strain, μ is the shear modulus, P is stress, t is time, and η is viscosity.

For this equation the similarity criterion will be ⁽¹⁻³⁾

$$C_\eta = C_p C_t. \quad (6)$$

Considering relations (1), (3), (5), and (6) together, one may rewrite

$$C_\eta = C_l C_t. \quad (7)$$

Applying relation (7) to observations of aftershocks, we make the following estimate. The largest linear dimension of the focus of a very strong earthquake ($M \geq 8$), assuming that it is nonspherical, may be estimated as 10^3 km. The corresponding dimension of the focus of an earthquake of moderate strength ($M \approx 5$) we take to be 10 km; consequently, $C_l = 10^2$. As the corresponding time intervals we take t' and t'' , i.e., such intervals of time during which half of all aftershocks occur. In this case

we shall have in mind aftershocks of n higher orders of energy and shall regard n as the same for both strong and weak earthquakes. After a very strong earthquake ($M \geq 8$), half of the aftershocks occur in the first 5-6 days ($t' \approx 10$ days). If we put $C_\eta = 1$, then $C_t = 10^{-2}$, and for an earthquake with $M \approx 5$ we obtain $t'' = 10^3$ days. It is obvious that the aftershocks of such an earthquake, being very weak shocks and being distributed over so large a time interval (2-3 years), will for the most part be lost against the general seismic background. The paucity of aftershocks after weak earthquakes is well known. Nor should the other assumption, $C_\eta \neq 1$, be rejected. In this case the viscosity of the medium will be different in the foci of earthquakes of different strength.

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Note: Figure translations are in progress. See original paper for figures.

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