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Quantitative Estimating of the Duration of the Lithospheric Failure Cycle from Earthquake Catalogues Data

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During the last few decades, the seismic regime has become an increasingly important subject of the quantitative physical research. This approach involves the general problem of the quantitative comparison of inferences from physical theories of failure with statistical estimates of seismic parameters derived from in situ observations. The difficulty lies in the incommensurability of their spatial domains. A typical spatial size in the physics of failure is the size of the fractured region or, with regard to seismology, the size of the earthquake source. Seismic statistical estimates relate to regions that include many earthquake sources and thereby greatly exceed the latter in size (the only exception being, to an extent, studies of aftershock sequences). Therefore, the transfer of experimentally derived statistical estimates into the theoretical domain is their extrapolation in terms of spatial scales. This extrapolation can be correct only with due regard for the possible dependence of the estimated quantities on the size of the region (spatial scale). This fact is well known in both the experimental and theoretical physics of fracture of heterogeneous materials, but it is only in recent decades that adequate ideas of the spatial pattern of seismicity have been developed, making it possible to reduce seismic statistical estimates to scales that are relevant to the physics of failure. Correct quantitative estimation of physical parameters of the seismic regime is of critical importance for understanding which of the possible physical mechanisms of failure control the seismic process at its various stages. By elucidating how the parameters of the physical model depend on the failure scale, it is possible, in particular, to determine the quantitative measure of the physical self-similarity of the failure process.

Statistical estimates of seismic parameters obtained on various scales have traditionally been compared solely on the basis of the Gutenberg-Richter law, i.e., the power-law size distribution of seismic sources. The earthquake distribution in space and time is considered uniform within the spatiotemporal “elementary” cells used for the estimates. The roughness of this approach is quite obvious, because at least the spatial inhomogeneity of seismicity is obvious. This fact often leads to the so-called scale effect and actually makes it possible to compare results on markedly different scales (e.g., derived from in situ and laboratory experiments) only qualitatively. The research of the last few decades indicates yet another statistical property of the seismic regime: statistical self-similarity in space, i.e., fractality of its geometric structure. Fractal objects are characterized by the dependence of their average density on the scale of averaging, and it is this dependence that explains many scale effects arising in various natural sciences when estimates are transferred from one scale to another.

Modern ideas of the physics of failure rest on fracture mechanics and the kinetics of the system of defects developing on various scales in a stress field. These ideas involve several key parameters controlling the development of the failure process. One such parameter is the average time between two successive acts of fracture in the same region of the medium, or the duration of the failure cycle. In fracture mechanics, it is determined by the time during which one or more adjacent cracks attain an unstable state. This time is commonly assumed to depend on the rate of stress increase, the ultimate strength of the medium, and the degree of crack interaction. In the kinetic theory of strength, this parameter is referred to as the durability, or long-term strength. Its value is a function of the applied stresses and the structural parameter, which depends in particular on the defectiveness of the medium. Irrespective of the physical interpretation (mechanical or kinetic), the failure cycle duration can be regarded as a characteristic of the intensity of the failure process. In seismology, the failure cycle duration is associated with the earthquake recurrence. However, the recurrence in its classical interpretation characterizes the average earthquake recurrence interval in a certain region that is usually much larger than the volume of the medium fractured during an earthquake. The failure cycle duration, as it is understood here, is defined by the average recurrence interval of fracture of the same portion of the medium.

The generalised frequency-magnitude relation, combining the energy- and space-domain scaling laws of seismicity and known as unified scaling law too, allows to estimate the duration of the lithospheric failure cycle from data of earthquake catalogues for a limited time interval.

The estimates of the duration of the lithosphere failure cycle are obtained and mapped from the instrumental data of the seismological catalogues for the last 40 years. A dependence of the duration on the size of failure area (on the earthquake source size) is estimated and mapped too. The estimates are obtained on two levels of detail: on global - for main seismic belts of the Earth and on regional - for selected regions. The values of failure cycle durations are within the interval from hundreds years to hundreds thousands years, average dispersion of this value from region to region is one and half - two orders generally. Less values are corresponding to the regions with more active tectonics on the whole, but not always are matched in details to the known active faults. Found range of cycle duration is in agreement with known estimates of the earthquake recurrence interval derived from paleoseismological and geological data. The range of spatial variations in the failure cycle duration complies with current ideas on the possible regional variability in properties of the lithosphere and velocities of tectonic movements.

In average for all regions in background mode the duration of the failure cycle depends weakly on the scale of failure (on the earthquake source size). On the contrary this relation is very bright for transient mode of seismicity, particularly for aftershock sequences. Considered physical parameters demonstrate the difference of seismic regime for two global tectonic structures - island arcs and oceanic rifts. The difference is manifested both in the value of the duration of the failure cycle (in the intensity of the seismic process) and in the character of its dependence on the failure scale (in distribution of the intensity of the seismic process on its spatial scale). On the whole, the failure cycle duration in the Pacific island-arc ring is nearly an order of magnitude shorter than for the rift ring surrounding Africa; the seismic process is more intense at its larger-scale levels in the island-arc ring and at its smaller-scale levels in the rift ring.

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