Earthquake Physics as a basis of Prediction

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A direct way to prevent or reduce seismic risk is, of course, the reliable deterministic prediction of epicenter, occurrence time, and magnitude of an impending earthquake. The criteria for predicting an earthquake must be: 1. r±30 km for the earthquake epicenter; 2. time: t±3 days for the occurrence time; and 3. M±0.5 for the magnitude. Up to date, except for very few earthquakes, deterministic earthquake predictions totally failed. Challenges of deterministic earthquake prediction are: (1) Unlike weather, to date predictions are made in the absence of or only few directly visible signals; (2) There is difficult to debunk unfounded and non-testable predictions, especially for short-term ones; (3) Decisions are usually made under high uncertainties, because it must take years to validate probability models, and, thus, it is difficult to assess cost-benefit; and (4) There is lack of a comprehensive physical model.

The observations of so-called precursor were usually not strictly tested. In order to increase reliability of precursor, the observations of all kinds of precursor must be strictly testable. The methodologies for testing can be: 1. the statistical model; 2. the statistical plus physical model; and 3. the physical model. The first two methods are somewhat available, while the third one is incomplete. Of course, the third method is the best. However, in past time the reductive approach was prevailing for earthquake prediction, while the deductive approach was very weak. In principle, the reductive approach cannot predict anything, but the deductive approach can. The deductive approach demands the construction of a comprehensive physical model.

To construct a comprehensive physical model, the minimal set of ingredients includes: 1. plate tectonic (to restore energy dissipated in faulting and creeping); 2. ductile-brittle fracture rheology of the seismogenic zone; 3. the stress re-distribution after fractures in the source area; 4. non-uniform geometry of the fault plane; 5. heating and cooling on a fault; 6. the fluid effect in and around the source area; and 7. the healing process of a fault zone. Current capability is modest for modeling, incomplete for the constitution law of friction, and totally unknown for initial conditions.

Keilis-Borok (1990) assumed that the lithosphere of the Earth can be viewed as a hierarchy of volumes, from tectonic plates to grains of rock. Their relative movement against the forces of friction and cohesion is realized to a large extent through earthquakes. The movement is controlled by a wide variety of independent processes, concentrated in the thin boundary zones between the volumes. A boundary zone has a similar hierarchical structure, consisting of volumes, separated by boundary zones, etc. Altogether, these processes transform the lithosphere into a large nonlinear system, featuring instability and deterministic chaos. Characteristics of nonlinearity are: 1. sensitive to initial condition (SIC); 2. capability of generating chaos; and 3. fractal behavior. The second property results in unpredictability, thus leading a question: Can we predicate an earthquake, if a fault system is nonlinear? The answer is disputable. But, in order to predict an earthquake, it is necessary to monitor all related phenomena continuously and completely in the space-time domain of a fault system. As mentioned by Keilis-Borok (1990), some integral grossly averaged empirical regularities emerge, indicating a wide range of similarity, collective behavior. On the basis of a comprehensive physical model of earthquake, geoscientists can examine the physical state of the fault system step by step, and then adjust evaluation. This makes earthquake prediction possible.

References

Keilis-Borok, V.I. (1990). The lithosphere of the Earth as a nonlinear system with implications for earthquake prediction, Rev. Geophys., 28(1), 19-34.