INDUCED SEISMICITY

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Contents

Summary

The processes that can result in strong earthquakes, as well as weak and moderate seismicity, can be initiated by both natural and technogenic activity: the Earth's tide, near and distant earthquakes, changes in the velocity of the Earth's rotation, and meteorological processes, as well as the construction of large reservoirs, oil and gas extraction, underground nuclear explosions, and powerful electrical impacts on the Earth's crust. The interaction of these processes has direct and indirect influence over seismicity.

Induced seismicity may manifest itself in either increase or decrease of seismic activity, and shortening of the generation time of strong earthquakes. Artificial actions may initiate devastating earthquakes in places where there have never been any or where

earthquakes were very rare. The sensitivity of seismicity and the scale of the response changes in time and can depend on interaction between initiating natural and technogenic processes. This property may be used for artificial reduction of seismic hazard and risk by means of tectonic energy discharge stimulation, by causing weak or moderate earthquakes, or the triggering of a strong earthquake at a specific time. It is also possible to create a technogenic regime of weak induced seismicity and natural activity in the Earth’s crust.

1. Introduction

A possible connection between strong earthquakes and the phases of the moon, and weather, such as droughts, showers, and hurricanes, was noticed even in ancient times. The medieval Arab historian Djalal Ad Din considered earthquakes and other hazards as God’s penalty for the sins of people. He wrote that if people lead dissolute lives, drink wine and play music then Allah would order the Earth to punish them with an earthquake. However many observations connecting earthquakes with natural phenomena were contradictory and it was impossible to rationalise them.

The first evidence of strong earthquakes being triggered by artificial actions on the Earth’s crust was obtained in the 1930s during construction of high dams and large reservoirs. The most prominent events which attracted attention to such problems of induced seismicity were: a) the devastating earthquake near the Koina Dam in India in 1967, which had a magnitude (M) of 6.7, and b) activation of mean seismic activity, magnitude 4.5 and more, in Denver, USA, at the end of the 1960s, which resulted from the pumping of liquid waste into a tectonic fault.

The importance of and interest in the problem of induced seismicity becomes more prominent with increase in the technogenic load on the Earth’s crust, e.g. devastating earthquakes initiated by extraction of oil, gas and minerals. Recently, effects on seismicity have been demonstrated from the launching of rockets, underground nuclear explosions, and powerful electric pulses.

Technogenic influence on seismicity may come in a different guise. It can stimulate or “trigger” an earthquake which was waiting to happen, or it may induce a tectonic earthquake which would have never occurred naturally, or may have occurred much later, like hundreds or thousands of years later.

The influence of natural processes on seismicity has not been paid much attention, though their scale and impact are very important. The main processes influencing seismicity are the Earth’s tide, changes of the speed of the Earth’s rotation, strong earthquakes, and weather (changes of atmospheric pressure, wind and precipitation). Evidently natural processes trigger earthquakes which would have happened sooner or later without such influence.

In connection with technogenic stimulation of strong earthquakes, the issue of the “seismic weapon” is discussed, i.e. triggering a strong earthquake by nuclear explosion or in some other way. The article also discusses the possibility of reduction of seismic hazard by means of regular triggering of tectonic energy discharge by small magnitude earthquakes.

2. Seismicity induced by natural processes

Let us consider the influence on seismicity of the Earth’s tide, changes of the Earth’s rotation, strong earthquakes, and changes of atmospheric pressure.

2.1. Triggering of earthquakes by the Earth’s tide

The influence of the Earth’s tide as an initiating factor for earthquakes is revealed in the number of earthquakes taking place during the two principal phases of the Earth’s tide: compression and extension. If the epicentre of a future earthquake is in an area characterised by strong tidal compression, the probability of the earthquake occurring in the phase of tidal compression is higher than in the phase of tidal extension. The map of the Caucasus region in Figure 1 presents data on the number of earthquakes with magnitudes more than 4.0, within the period 1960 to 1998, in cells 1 degree longitude by 1 degree latitude. Each cell has two numbers. The upper number shows the number of earthquakes N- occurring during the phase of tidal compression, the lower number N+ shows that during the phase of tidal extension. It is possible to estimate tidal deformations for each point of the Earth at any moment with sufficient precision.

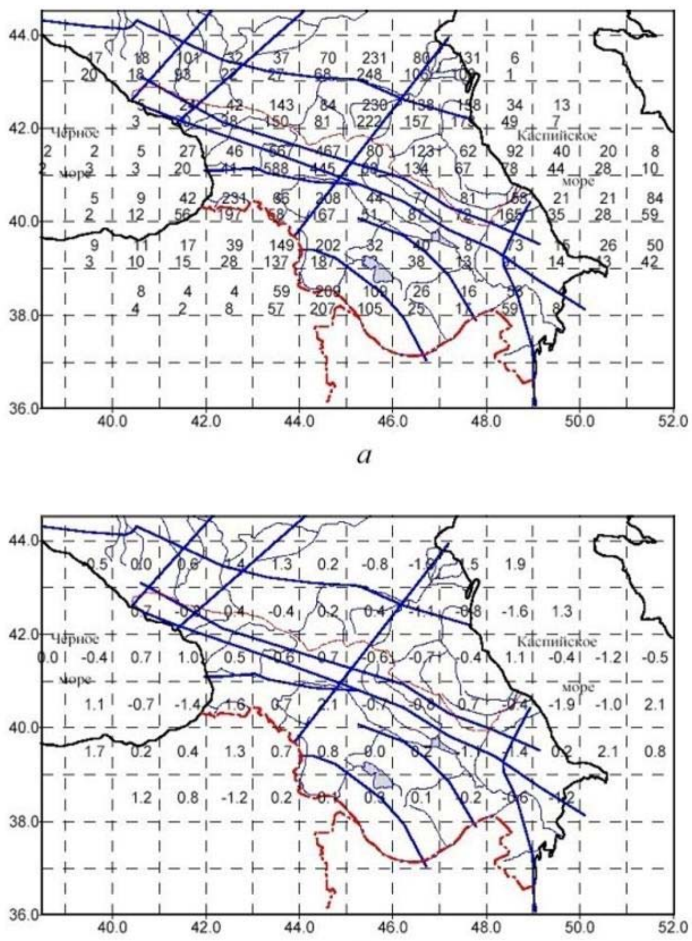

Figure 1. Map of the Caucasus earthquakes which happened in the phase of vertical

compression and extension (a) and map of normalised values of the earthquakes number t (b)

Fig.1b presents the map of parameter t defining difference of deviations of N- and N + parameters from mean value (N- + N+)/2, correlated with standard deviation 0.5 sq.rt. (N- + N+) characterising binomial distribution of N- and N+ in cells with equal possibilities 0.5.

As is evident from the map, in most cells the effect of earthquake triggering by the Earth's tide is weak. At the same time, in other areas the initiating influence of tidal deformations is seen very clearly. Detailed studies of the mechanism of triggering of earthquakes by the Earth's tide show that "sensitivity" of earthquakes towards tidal deformations changes with time. This peculiarity is due to permanent changes of background tectonic tensions.

Various harmonic components of the Earth's tide have different rate of impact; sensitivity of seismicity to separate components of the Earth's tide is spatially heterogeneous and also changes in time. The typical periodicity for such change is usually more than 10 to 15 years.

The Earth's tide not only influences weak and strong earthquakes but micro-earthquakes as well, including seismic and acoustic emission of rocks. Changes in the intensity of seismic emission reaction to tidal deformations are characteristic of tectonic discharge of the Earth's crust energy. This index is changeable in space and unstable in time. The complicated character of this phenomenon has been the theme of many long discussions which ended only recently.

2.2.Changes of the Earth's rotation speed

The influence of this factor is not well studied yet, but the available data show that mean annual values of the Earth's rotation changes correlate with the number of earthquakes in some regions. Figure 2 shows diagrams of changes of the absolute value of the rate of the Earth's angular acceleration and diagrams of values of the number of earthquakes by years, in the northern hemisphere, with magnitude more than 6.0, and depth of focus 50 to 250 km. This diagram shows a very significant relationship; other depths and magnitudes have less distinct correlations.

The correlation between changes in the Earth's rotation and seismicity may be attributable to a direct influence, or there may be some other common factor influencing both seismicity and the Earth's rotation rate. The direct influence may be manifested in changes in the balance of forces determining the equilibrium state of lithosphere. Since this effect is extremely small (it is expressed by relative changes of the angular rate of about 10-10), and respective variations of active tensions are very small too, the preference is given to conjecture that the correlation observed between the seismicity and the rate of the Earth's rotation is likely caused by some factor influencing both processes. The most probable one is change of global parameters of circulation of the atmosphere, as determined by measurements of atmospheric pressure. It is known that diurnal and seasonal changes of angular rate are determined by circulation of the air.

The correlation of long-term variations of atmospheric circulation with changes of angular rate is not very clear. Other theories suggest that the process influencing the rate of the Earth's revolution and the movement of its magnetic poles, is convection in the liquid core of the Earth.

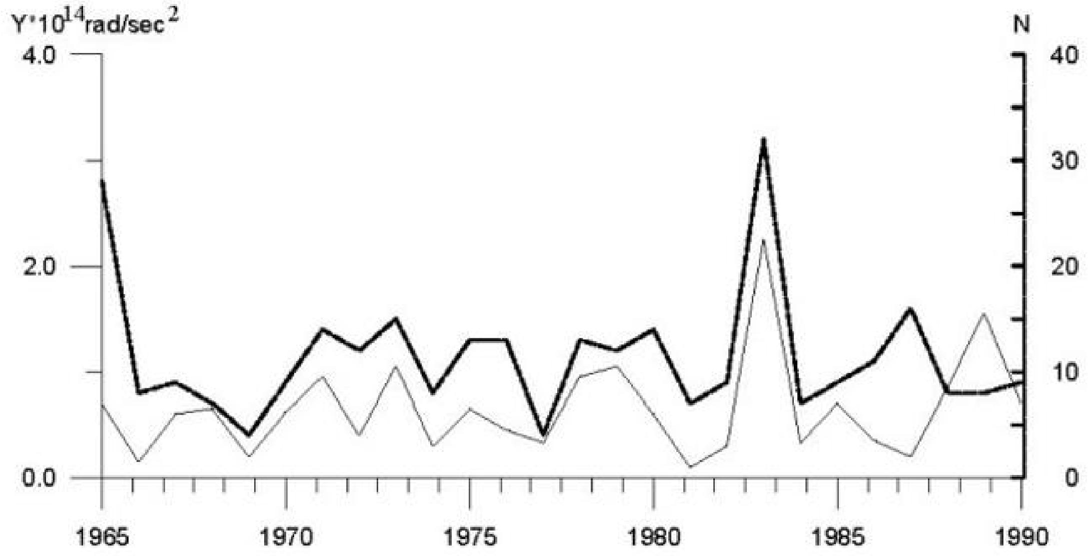

Figure 2. Annual values of angular acceleration modulus of the Earth Y (thin line) and number of earthquakes N, M>5.9, interval of depths 50-250 km (thick line) (Gor'kovaty et al., 1994).

So, changes in the rate of the Earth's rotation seems to have limited initiating action on seismicity and build-up of strong earthquakes, but they suggest powerful exogenous and endogenous processes influencing both, i.e. seismicity and angular velocity.

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Biographical Sketch

Alexei V. Nikolaev was born in 1934; Professor of Geophysics, Corresponding Member of Russian Academy of Sciences. He was graduated from Geologiocal Faculty of Moscow University in 1957 and began to work at the Institute of Physics of the Earth, USSR Academy of Sciences. Defended his Ph.D. thesis in 1994 and Doctor Degree in 1972. He conducts investigations in the field of experimental seismology and seismic prospecting. He published more 200 articles and four monographs, including "Seismic of inhomogeneous and turbid media" (1972). In the course of 30 years he fulfilled seismological field investigations in seismoactive regions of Central Asia, Northern Caucasus.