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Experimental research systems for vibroseismic monitoring of seismic–prone zones

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The present paper is dedicated to the construction of an allocated system designed to perform vibroseismic monitoring of earthquake prone zones.

The main problem is associated with the creation of a distributed computer system providing collection, accumulation and processing of the observational data at an area of several thousands of square kilometers.

The monitoring systems of seismic–prone zones must make routine observations of expected earthquake sources and, using the dynamics of the behavior of prediction features, decisions on the force, place and time of a possible earthquake can be made.

A generalized information model of a system for active vibroseismic monitoring of seismic prone zones is proposed. It consists of the following basic elements: vibrator; object being studied (seismic–prone zone); observation system for collection of primary information; solution – computer module for the processing of routine observations, comparison and estimation of data, control of the working regimes of the vibrator; prediction – the system's element responsible for the prediction of the source behavior.

A version of the system is proposed for the sounding of earthquake focus areas using seismic arrays and powerful vibroseismic sources. Data flows and information rates are assessed for real time and bufferied data gathering. The module principle of earthquake prone zone sounding system design is considered.

Introduction

Earthquakes are one of the most disastrous natural phenomena that are difficult to predict. More than 1000 destructive earthquakes, accompanied by losses of 1.5 million people, have occurred in 70 countries of the World in this century (1900–1992). A severe impact has been estimated as hundreds billion dollars. One of the key problems of the earthquake prediction is the creation of modern distributed systems of collection and processing of data of the active seismic monitoring for seismic–prone zones. The main objective of such systems is the prediction of possible destructive shocks based on investigation of processes of the earthquake focus evolution.

Powerful vibroseismic sources make it possible to realize an active method of seismological investigations of the Earth's structure, study the geodynamic processes and rheological characteristics of anomalous zones of earthquake preparation. Since nuclear explosions are prohibited, the vibroseismic method is the only active method for deep Earth's sounding [1, 2].

In comparison to passive methods based on studying waves from earthquakes, the main advantages of active methods are as follows: the coordinates of the source and the time of its action can be determined exactly; multiple identical actions on the medium being studied (replication of experiments) are possible; oscillations of desirable form and polarization can be excited; experiments can be controlled on a computer. The vibroseismic methods can be used in various regions, including densely populated areas. They are safe for the environment, because recorded signals are at the level of microseismic noise, and the required signal-to-noise ratio is provided by the method of accumulation of weak signals.

Active monitoring is not only control of artificial fields, but also regular processing of observations using mathematical models of phenomena being studied to obtain characteristics, that cannot be measured directly, such as anisotropy, permeability, plasticity, cracking and stresses in the zone under control.

The main problems, that can be solved by the method of active seismology using powerful sources, include investigation of inhomogeneities in the Earth's crust, mantle and core by methods of seismic tomography. Modern digital seismological networks and superpowerful vibroseismic sources can be used for the investigations. Geodynamic processes can be studied by long-term observations of the velocities and polarization of vibroseismic waves at fixed distances, systems of active monitoring of seismic prone zones for medium-range and short-range earthquake prediction. Vibroseismic methods can be used for active microseismic zoning of large areas, investigation of stability of deep substructures in regions of exploitation of ecologically dangerous engineering constructions, large chemical enterprises, atomic power stations, dams in mountainous regions, etc.; study of physical-mechanical and chemical properties of rocks and other materials under vibroseismic actions.

1. Experimental investigations with powerful vibrators

Creation of powerful controllable seismic radiators (vibrators), that can simulate (after accumulation) a wave effect of medium-power earthquakes, is an important problem of active seismology. Such vibrators can be used to solve classical problems in seismology. Several types of powerful vibrators have been developed in the Siberian Branch of the Russian Academy of Sciences. The most powerful stationary centrifugal vibrator CV-100 provides actions onto the ground of up to 100 tons in a frequency range of 5–9 Hz. A mobile vibrator CV-40 that is based on the same principle provides actions onto the ground of up to 40 tons in a frequency range of 6–10 Hz. New hydroresonant vibrators HRV-50 and HRV-200 with vibrational actions onto the ground of 50 and 200 tons, respectively, have also been created [1]. They are based on resonant oscillations of large volume of liquid.

In the creation of powerful vibrators, a "quasiresonant" method of radiation has been theoretically and experimentally substantiated. This method is more effective in the range of seismological frequencies than the method of "forced" oscillations used in seismic prospecting. Owing to this method, the distance of recording from a 100-ton vibrator exceeded 1000 km in the harmonic regime and 350 km in the regime of sweep signals.

The scheme and technical design of hydroresonant vibrators can be used for creation of sources of various power. They make it possible to develop a project of a superpowerful vibrator with an action of 10000 tons for global seismology, abandon the concept of mechanical engineering and use a technology of other type, namely, mine construction. The basis of the vibrator is a water-filled shaft 12 m in diameter and 100 m deep, in which a liquid column with a mass of 10000 tons oscillates resonantly. Such a source will provide a distance of recording of up to 10 thousand kilometers in a range of seismological frequencies of 0.5–5 Hz. Owing to the creation of superpowerful seismic vibrators global seismic tomography of the Earth using controllable artificial sources becomes quite real [3].

Some elements of the system of vibroseismic monitoring have been tested during the 1995 Russian–Japanese experiment, in which the vibroseismic field of powerful vibrators on a 100 km profile has been explored in detail. Time variations in the parameters of the vibroseismic field at distances of 400–500 km have been investigated by methods of vibroseismic interferometry in 1996 experiments. A correlation between the time variations in amplitudes and phases of harmonic signals from vibrators and lunar-solar tides has been detected for the first time.

2. Architecture of computer–telecommunication system for the monitoring of seismic–prone zones

A generalized model of the information system covers the following basic components: a vibroseismic source, which generates mechanical vibrations within the given frequency range and the given form, aerial seismic units (ASU) for recording vibroseismic signals, the field processing complex (FPC) for gathering data from (ASU), for computation of controlled characteristics, for statistical data handling, and, finally, for prediction of seismic danger by means of the controlled parameters.

The given model describes the system installed directly in the seismic–prone zone, which can be a part of the global system consisting of several hierarhical levels:

- the level of gathering and preprocessing of seismic data with sequential transmission via the radiotelemetering network of the lower level implemented with the help of ASU;
- the level of data express-processing and making decisions, implemented on FPC (the level also provides the output to the higher level processing centers using the sattelite communication channels);
- the level of the network of information processing centers of the Federal System of Seismological Observations (the level provides the access to databases, exchange of geophysical information with international organizations).

One of possible versions of constructing the system, consisting of 4 sources and 16 ASU is described in [4]. The area covered by such a system of observations is about 40000 km^2. The system of obsrvations is based on the principles of constructing the seismic aerials.

In the proposed configuration of the system the maximal distance from the source is about 150 km, the minimal is about 50 km. This is quite sufficient for recording any types of seismic waves. With 9-element configuration of aerials in ASM 108 three-component seismic centers are needed. The given configuration of the system allows sounding the object under study under different angles. This system provides observations of the long- and medium-term earthquake precursors. In the case of appearance of abnormal effects, it is necessary to apply more powerful seismic aerials.

It should be noted that the presented version of constructing the system assumes the building-block principle of construction. Based on this principle the minimal configuration should include one source and four receiving aerials. In this case the area of observations will cover about 8000 km^2. According to the available estimations the frequency range for vibromonitoring of seismic–prone zones can be about 1 to 10 Hz.

Let us estimate the stream of data recorded by ASU. Observations in deep boreholes and places where seismic noise is minimal show that the minimal level of signals is about 2–4 mm and the maximal level is determined by possibilities of seismic sensors but does not exceed 10 mm. Thus, the dynamic range of recorded signals is 130–140 db. Evidently, each ASU generates the information stream

$$S = n \times R \times F \times d,$$

where n is the number of channels in ASU, R is the number of bits per reading, F is the upper frequency of signal spectrum, d is the coefficient connecting F with frequency of readings.

The value R should be not less than 16, which provides the dynamic range of recorded signals of 138 db with the error about 0.1%, F is determined by the upper frequency of radiation of the source, which is about 10 Hz. According to Kotel'nikov's theorem, the minimal value $d = 2$, which may be increased up to 5 for decreasing the requirements to the input filters.

Thus, in the three-component observation system each stationary ASU generates the information stream $S = 21.6$ Kbit per second. In transmitting the data in the real time mode, the bit-transfer rate with complementory information taken into account should be not less than 32 Kbit per second. In regular observations the value of supplied data $V = ST$, where T is time of performance of the vibrator. When $T = 60$ min, the volume $V = 15$ Mb.

It is possible to use two versions of the system of the given configuration. The first version is connected with collection of data for seismological observations and carrying out the active vibroseismic monitoring. In this case we need the transmission of data in the real time mode from ASU to FPS. To this end it is possible to make use of the radio link with the radius of action of about 50 km. In this case the nearest four ASU will be served by one FPS. The given version makes it possible to minimize computer costs needed for all the ASU by increasing the costs for the data transmission channels and FPS.

The other version, that is more preferable, is in conducting a preliminary analysis of the data aimed at separation of seismic events using special algorithms. These algorithms make it possible to decrease by one order the information stream.

In this case we need the buffer memory either in ASU or in FPS if the data transmission rate is the same (32 Kbit per second). In this case the time for processing should be coordinated with the time of filling the buffer. In conducting the analysis the time interval is taken about 100 sec. With sampling rate of 50 Hz and two bytes per one reading we will have 10 Kb per one channel. Correspondingly, for the three-component nine-element aerial the buffer memory is 279 Kb, while for four aerials the buffer memory of about 2 Mb is sufficient. This can be easily realized either on the hardware level in ASU or on the software level in FPS.

The functions of FPS are in receiving the infromation from ASU via several digital channels, its processing, storage and transmission to the Regional Computer Center (RCC). Each FPS includes a personal computer with a kit of telecommunication tools. Using the telecommunication via sattelites we can solve practically all the questions connected with data transmission, however this will require considerable costs.

The proposed concept of constructing the telecommunication system makes it possible to create a new instrument of studying the seismic–prone zones that will sufficiently increase the reliability of earthquake prediction.

References

[1] A.S. Alekseev and V.V. Kovalevsky, *Powerful vibrator for deep Earth interior investigations*, LX Annu. Int. Meeting Soc. of Expl. Geoph., San-Francisco, California, 1990, 956–957.

[2] A.S. Alekseev, B.M. Glinsky, V.V. Kovalevsky, and B.G. Mikhailenko, *Multidisciplinary mathematical model for earthquake prediction studies and vibroseismic monitoring of seismic prone zones*, Proc. 2nd Int. Conf. on Seismology and Earthquake Engineering, Teheran, JJEES 1, 1995, 97–104.

[3] A.S. Alekseev, B.M. Glinsky, V.V. Kovalevsky, and B.G. Mikhailenko, *Problems of active seismology. Upper mantle heterogenetics from active and passive seismology*, Nato Advanced Research Workshop, 13–16 April, Moscow, Russia, NATO ASI SERIES, **17**, No. 336, 1997, 123–130.

[4] B.M. Glinsky, *Architecture of computer-telecommunication systems for active seismology*, Proc. 15-th IMACS World Congress, Berlin, **6**, 1997, 353–358.