Seismometric Monitoring of Toktogul Hydroelectric Power Station

Vladimir Dovgan
Kyrgyz-Russian Slavonic University, Bishkek, Kyrgyzstan
dovgan@mail.ru

***Abstract*— The short description of seismometric observations system on Toktogul hydroelectric power station (Kyrgyzstan) is given. Some results of these observations are presented.**

***Keywords*— dam; earthquakes; hydro-start-ups; noises**

The highland Kyrgyzstan, located in Tien-Shan, possesses the unique hydropower complex. The basis of this complex is made with cascade of Toktogul Hydroelectric power station on the Naryn river. Most powerful of working - Toktogulskaya - has the concrete gravitational dam in height of 215 meters and the water basin in volume 19.5 billion cubic meters. The dam is at height of 900 m in a deep canyon with a high level of natural tectonic stresses. The construction age is more than 30 years. The Toktogul district is attributed to the zone of the possible sources of earthquakes with magnitude 7.5 on modern and historical seismicity [1].

The prototype system of seismometric monitoring installed at the Toktogul hydroelectric power station in 2005 remains operational nowadays [2]. Location of observations points is chosen taking into account the hydrounit structure: seven points are at different levels and in different blocks of the dam, two - in boards and one (basic) - on distance of 736 m from the construction - in the rocks (fig. 1). Each observations point is equipped by three seismometers SM-3, the digital controller and the communication line with the computer (fig. 2).

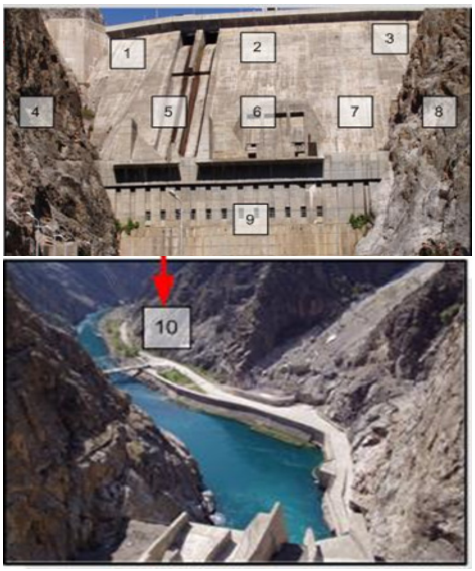

Figure 1. Location of observation points : on dam and boards (above), in rock (below).

Figure 2. Equipped observation point (above) and the digital controller (below).

The controller convert analogue signals from seismometers to the digital form and transfers data in the computer of preliminary processing of the information. Calibration of seismometers and temperature measurement in supervision points is carried out by means of the controller.

The seismic data acquisition subsystem operates round-the- clock and records earthquakes, microseisms and hydro-unit start-ups. Microseisms are recorded as spectrum averaged on one hour interval basis.

The control of the condition of the dam equipment, the analysis of data and the decision of methodical problems is carried out in the research centre of monitoring of high-rise dams at the Kirgiz-Russian Slavonic University (Bishkek city). Communication of the centre with the dam is carried out through the Internet.

The monitoring system is capable to control the dam and monitor background seismicity. So far it has recorded some 200 earthquakes which had caused fluctuations of the dam.

Records of earthquakes are exposed to the filtration for clearing from noises. The spectral-time field allows to allocate a range of the frequencies connected with noise of the dam and earthquakes (fig. 3).

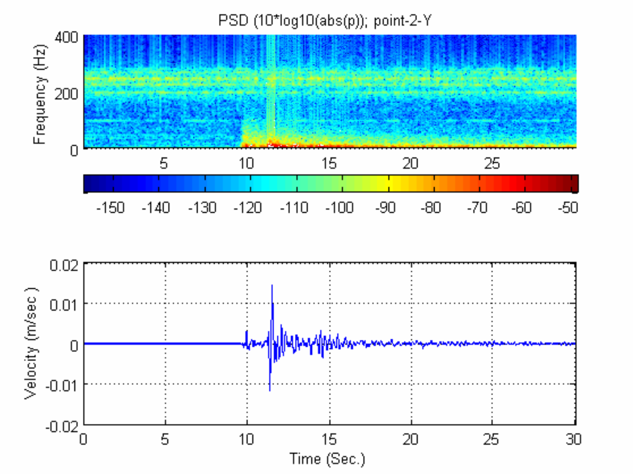

Figure 3. Spectral -time field on record in the second point of observations.

On the spectrogram on record in the second point on the crest in the dam centre separate frequencies and ranges of intrinsic frequencies of the dam are visible: 44.6 Hz, 90-100 Hz, 155-160 Hz, 170-180 Hz, 190-195 Hz, 210-220 Hz, 260-270 Hz. Lower intrinsic frequencies of hydro system, such as 2.7 Hz - frequency of rotation of turbines, are crossed with a spectral band of earthquakes. Noises are considerably weakened in the basic tenth point located in the rock.

The software developed allows to observe the dynamics of seismic waves passing through the dam body, to determine delays of seismic wave propagation between points of observations, to define the transfer functions, to estimate opening of joints in the dam structure and deformation of the central block as well as relative motion of the canyon sides during earthquake, to define peak deformations, to carry out spectral and correlation analyses.

Based on analysis of the earthquake records there were defined critical areas in dam structure where dam is most subject to dynamic influences, and therefore specific parameters were preset to control dam in those places of potential failure. The long-term analysis of these data, in addition to having the information on processes occurring in construction, will make it possible to undertake timely measures to prevent catastrophic consequences that might occur at earthquake.

The example of distribution of fluctuations velocity amplitudes on the dam body at influence of the local earthquake which have occurred on August, 13th, 2006 (K=11.6), is given on fig. 4.

The maximum oscillations on records of the earthquakes majority on the component «the north the-south» (on a current) are observed in the central (second) point of the dam located at height of 880 m.

Spectra of earthquakes records lay in frequencies band from 0 to 20-30 Hz (fig 5).

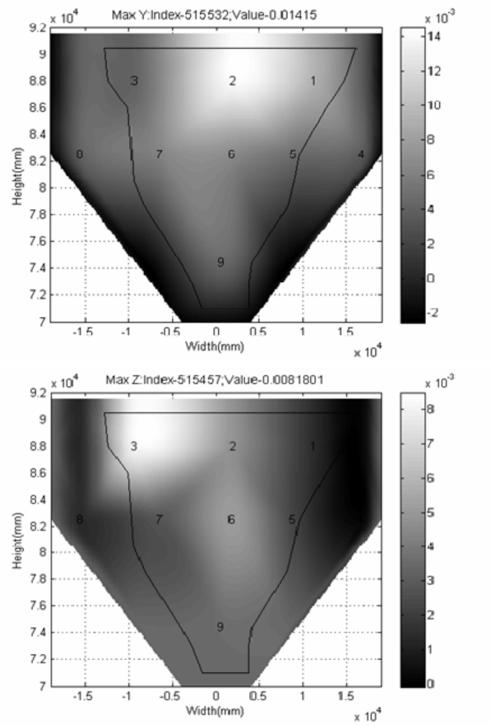

Figure 4. Distribution of oscillation velocity on the dam body on components Y "north-south" (on the current) and Z (vertical). Contour of the dam is shown by the line, location of observation points is noted by numbers.

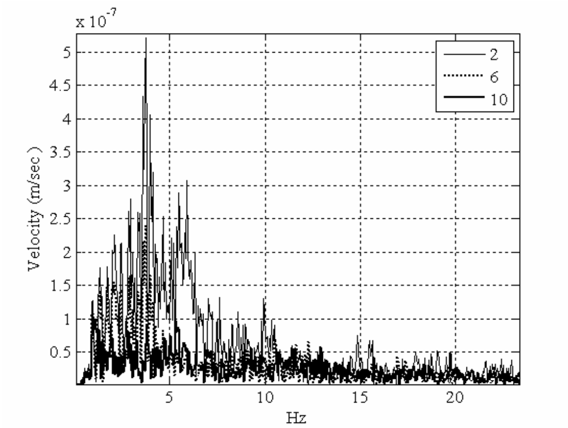

Figure 5. Spectra on records of local earthquake in the second, the sixth and the tenth-basic points of supervisions.

Spectra of distant events are limited by frequencies to 3-6 Hz. The dam almost does not strengthen fluctuation from distant earthquakes. Short earthquakes have wider spectral structure to which separate frequencies of dam fluctuations get: amplitudes of spectra sharply increase in the dam centre on frequencies from 3 to 5-8 Hz (fig. 5).

The analysis of all earthquakes, which have been written down by system of supervision, has shown, that they have not done serious harm to the hydro construction for the present. For this period the dam was exposed to the maximum influences during two strongest local pushes on July, 30th and on August, 13th, 2006 with energy classes K=11.5-11.7, and also during Nura-Alajsky distant earthquake on October, 5th, 2008 (K=16, R=250 km).

The greatest displacements at these earthquakes were observed between the top blocks of the dam and have made 0.3-0.4 millimeters. Distribution of intensity of fluctuations on the dam body, opening of joint between blocks, in which the first and second points of observations are located, and a projection of movement of the joint to three planes at local earthquake are shown on fig. 6.

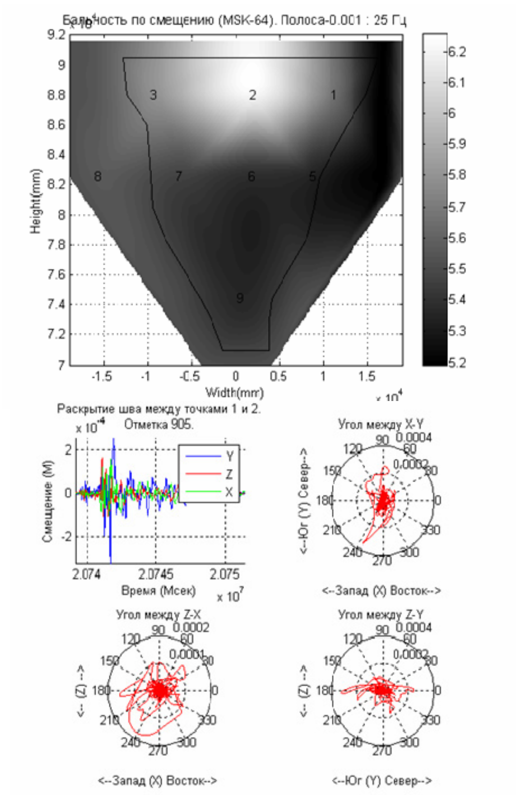

Figure 6. Distribution of intensity of fluctuations on the dam body on record of local earthquake on July, 30th, 2006 and opening of joint between blocks.

Start-up of hydro-units on influence level is close to weak local earthquakes [3]. The source of fluctuations at start-up is in the body of the dam unlike earthquake. These fluctuations appear through all construction. The example of records of typical start-up of the hydro-unit and its spectra are resulted on fig. 7. Hydro-unit start-ups have the wide spectrum of fluctuations from 0.2 to 60 Hz with lifting on frequencies of 10-25 Hz. Frequency of 95 Hz is not connected with start-up and concerns of the equipment process. The energy maximum at start-up is allocated in the ninth point, which is located in immediate proximity from hydro-units, and in the second point (fig. 8).

The analysis of records of hydro-start-ups allows to carry out diagnostics not only the dam, but also hydro-units. We have made the analysis of record of failure of the second hydro -unit of Toktogul hydroelectric power and have established, that its start-up passed at the braked condition, the unit did not rotate. Our conclusions were confirmed with the commission on incident investigation.

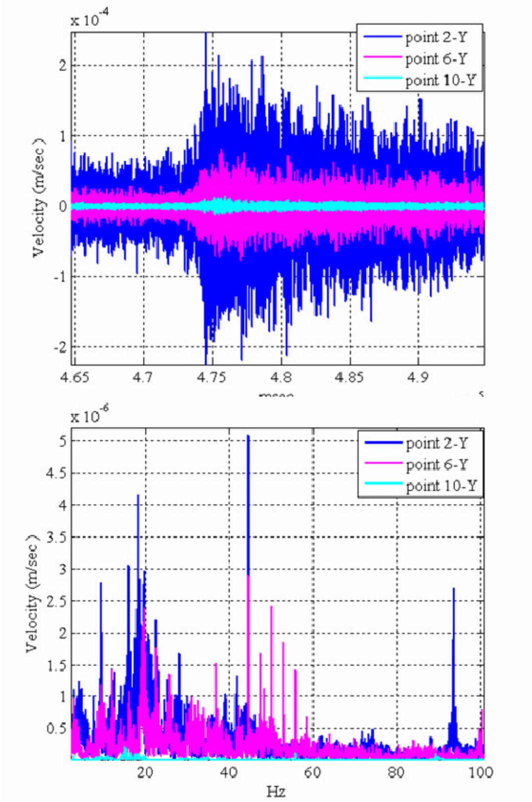

Figure 7. Records of start-up of the second hydro-unit and its spectra.

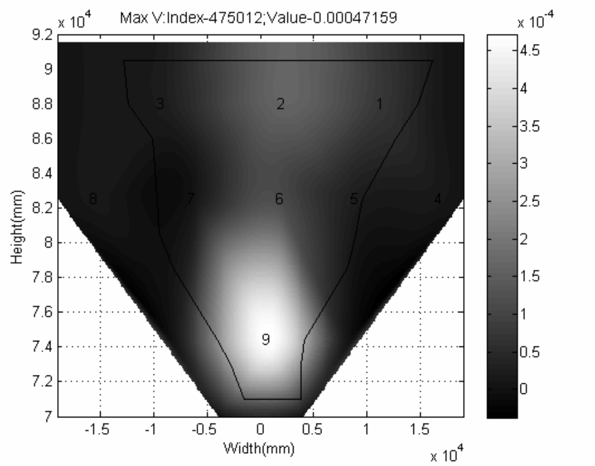

Figure 8. Energy distribution at hydro- braked unit start-up.

In a time interval between earthquakes and start-up the monitoring system registers microseisms and noise of the dam which are averaged and collect in the form of hourly spectra (fig. 9).

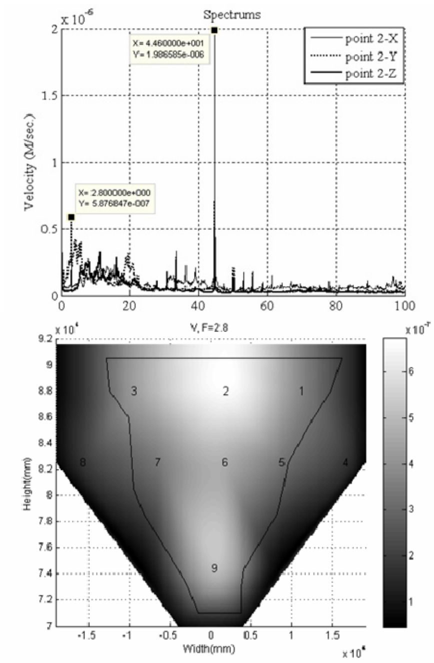

Figure 9. Spectrum averaged on one hour interval basis on noise record in the second point on three components and distribution of fluctuations on the dam body on frequency of 2.8 Hz (frequency of rotation of hydro-units).

These data are used for definition of resonant frequencies of the dam and the equipment, frequencies of fluctuations of sources of an artificial origin, and also changes in spectra after earthquakes. In the noise spectrum frequencies of hydro-units are especially allocated: 2.8 Hz - frequency of rotation of the turbine and 44.6 Hz - frequency rotation of blades of hydro-units, and also their harmonics (fig.9). Fluctuations of amplitudes on these frequencies coincide with fluctuations of the capacity developed by hydroelectric power station. The maximum of fluctuations on frequency of 2.8 Hz is observed on the second point located on the crest in the centre of the dam, with smooth fall to other points (fig. 9). Such behaviour is caused by the dam design. In the centre water passages are located. Vibrations are transferred to the crest on water passages and amplify by the dam itself. Frequency of 2.8 Hz always is present at the spectrum of earthquakes and is dangerous both to the dam, and for hydro-units. The amplitude of fluctuations increases in 5 times on this frequency during local earthquakes.

By analyzing the vibration frequency of hydro-units running under real load conditions one may identify the developing failure in the early stage of deterioration and intervent with the measures not allowing the machinery to fail. Thus, monitoring resulted into analyses of hydro-units at emergency, before repair and after. Information gathered has ensured improvement in machinery reliability and trouble-free operation.

Hourly spectra allow to estimate the residual phenomena in the body of the dam after earthquakes. The graph of change of noise spectra before earthquake on August, 13th 2006 (K=11.7, R=7 km) and after it is presented on fig. 10.

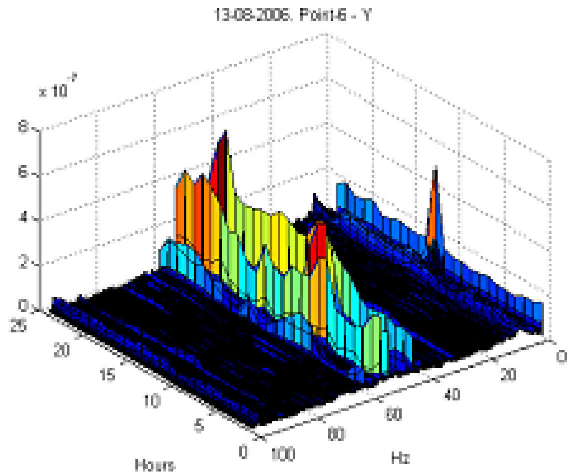

Figure 10. Hourly average spectra for day on August, 13th 2006.

The increase in amplitudes at low frequencies was observed within an hour after earthquake, further all has settled into shape. The system of supervision fixes also the events which have been not connected with earthquakes and start-up of hydrounits. They are comparable on influence level to weak local pushes. The analysis of these events has shown that in most cases they are caused by sharp increase in the pressure of water in water waters.

Mentioned technique can be used to monitor large constructions, bridges and buildings. The structure of the monitoring system and location of observation points are to be defined by construction design.

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