Strong motion record processing of the Baikal rift zone

Vasiliy A. Mironov[1,2], Sergey A. Peretokin[2,3] and Konstantin V. Simonov[1]

[1]*Institute of Computational Modeling SB RAS, Krasnoyarsk, Russia*
[2]*Krasnoyarsk Branch of the Federal Research Center for Information and Computational Technologies, Krasnoyarsk, Russia*
[3]*Schmidt Institute of Physics of the Earth RAS, Moscow, Russia*

Abstract
The work is devoted to the adaptation of the earthquake record processing algorithm of the Pacific Earthquake Engineering Research Center to the peculiarities of seismic monitoring of the Baikal region. A tool for forming a database for building a regional seismic attenuation model is presented.

Keywords
Peak ground acceleration, ground motion prediction equation, probabilistic seismic hazard analysis, earthquake.

1. Introduction

Seismic hazard assessment of a construction site is an integral part of the complex of engineering and geological surveys during design and building in active seismic regions. Most of the methods for seismic hazard assessment are based on two interrelated models: the earthquake source zone (ESZ) model and the attenuation model, also known as the ground motion prediction equation (GMPE). The task of the ESZ model is to adequately describe the distribution of earthquakes in space and time. The GMPE describes the dependence of the characteristics of ground vibration on the investigated site on the parameters of the earthquake rupture, distance to the source, local conditions of the site, etc.

The most modern can be considered the GMPEs published as a result of the NGA-West2 stage of the Global Earthquake Model (GEM) Global GMPEs project, namely Abrahamson et al. (2014), Boore et al. (2014), Campbell and Bozorgnia (2014), Chiou and Youngs (2014), Idriss (2014) [1].

The ESZ model and GMPE are input data for seismic hazard assessment using probabilistic seismic hazard analysis (PSHA) procedures. At the same time, the correctness of the PSHA results and the validity of the final assessments of seismic hazard depend on the quality, completeness and reliability of the initial data.

Modern GMPEs can be divided into global and regional. Global dependencies are built according to worldwide statistics without georeferencing to a specific region. In addition, they are distinguished by high epistemic and aleatory uncertainties. For well-studied regions,

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vasya-kun@mail.ru (V. A. Mironov); saperetokin@yandex.ru (S. A. Peretokin); simonovkv50@gmail.com (K. V. Simonov)

provided with reliable seismological statistics and detailed seismotectonic information, regional GMPEs are created. Such models are characterized by a lower level of uncertainty than global GMPEs. In the above foreign GMPEs, the coefficients for the regions of California, Turkey, Italy, Taiwan, China, and Japan are separately determined.

In accordance with the standard documents of the Russian Federation, the seismic hazard is mainly assessed in macroseismic scale point. At the same time, for calculating the seismic resistance of buildings, the intensity of shaking is recalculated to physical characteristics of vibrations using empirical formulas. The conventional character of this approach is considered as not complying with the current requirements by the majority of professional researchers and design engineers.

On January 22, 2016, the Scientific Council of the Russian Academy of Sciences (RAS) on Problems of Seismology discussed the issue of transition from macroseismic points to direct assessment of the physical parameters of seismic vibrations. As a result, the Scientific Council supported this direction of research to improve methods for assessing seismic hazard in Russia.

The improved PSHA algorithms, software tools and global GMPEs make it possible already now to obtain preliminary estimates of the seismic hazard of the territory of the Russian Federation in peak accelerations and generalized response spectra. However, in order to obtain more reliable seismic hazard assessment, there is a critical need to build new regional attenuation models for the territory of the Russian Federation.

The general scheme for building the GMPE consists of the following stages. Accumulation of strong motion records. Processing of earthquake records, calculation of their parameters. Evaluation of the applicability of the processing results — comparison with other GMPEs. Building of GMPE — development of a mathematical model. In this paper, the first three stages are considered. Algorithms and results of strong motion record processing for the Baikal rift zone are presented. The algorithms used are based on the Pacific Earthquake Engineering Research Center methodology [2]. These algorithms were adapted to the peculiarities of seismic monitoring of the Baikal region and implemented in the MATLAB.

2. Source data and processing algorithms

The source data are records of earthquakes recorded by a network of regional seismic stations on the territory of the Baikal rift zone. The network of seismic stations is organized by the Baikal Branch of the Federal Research Center of the Geophysical Survey RAS [3]. The work used data from 25 registration points located around Lake Baikal. The Baikal Branch provided 199 initial records from 38 earthquakes (19 earthquakes in 2003, 18 earthquakes in 2004 and 1 earthquake in 2020). In the future, it is planned to continue selecting records to increase statistics. The criterion for selecting earthquakes for further processing was the maximum epicentral distance ($\mathrm{Repi} \leq 300$ km) and the energy class of the earthquake ($K \geq 11$). Figure 1 shows the location of seismic stations, the epicenters of the considered earthquakes, their energy class.

Initial records of earthquakes were obtained by seismic stations “Baikal-11” and “Baikal-11MS”. The stations “Baikal-11”, “Baikal-11MS” have three short-period seismometric channels of increased sensitivity, registering ground velocities, and three channels of lower sensitivity, registering ground acceleration. The sampling rate is 100 samples per second. Frequency

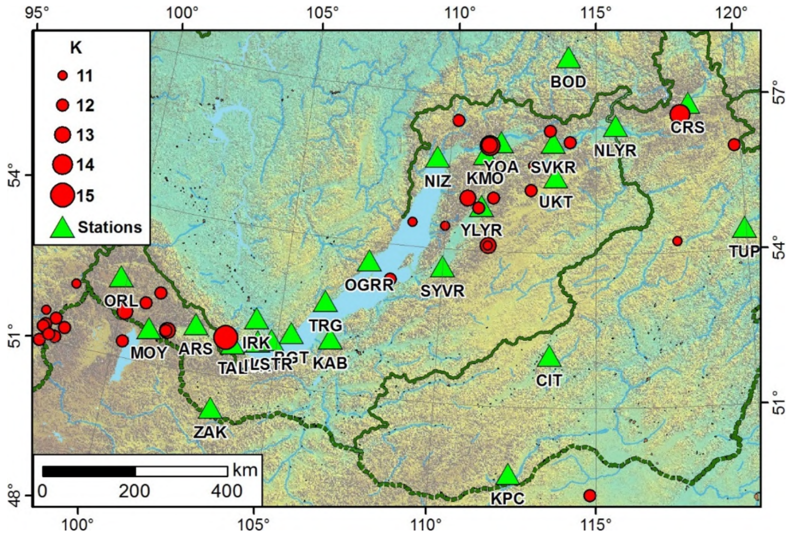

Figure 1: Location of seismic stations and epicenters of the considered earthquakes.

response were obtained for all stations. The source records are binary files. These files can be divided into two types. The first type corresponds to files containing records of 6 channels (3 channels of velocity time series and 3 channels of acceleration time series). The second type of files contains records of only 3 channels (velocity). To process the initial records, computational algorithms were implemented to achieve maximum automation of the data processing process. The general scheme of the procedure for earthquake record processing for each channel is shown in Figure 2.

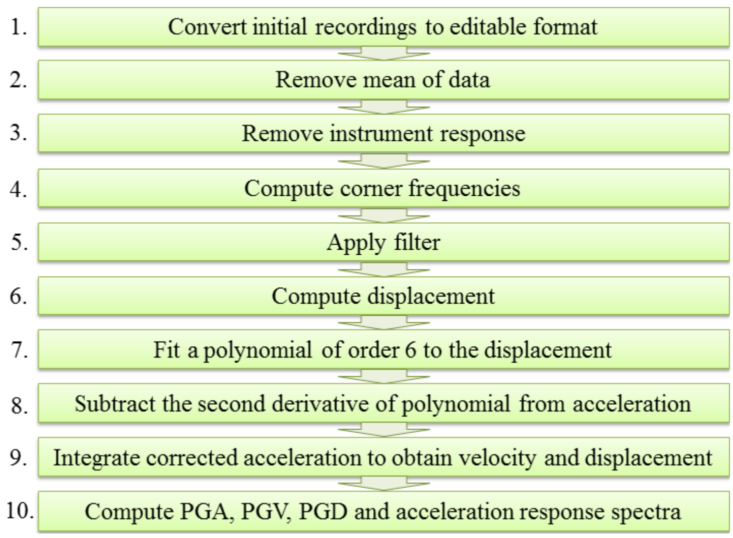

Figure 2: Record processing procedure.

Reading and converting the source binaries is performed first. After, for each channel, the average value of the entire record is subtracted from each element of the time series. A high-frequency 5-pole Butterworth acausal filter is used to remove the instrument response [4]. The corner frequency is determined from the frequency response of the instrument (the lowest frequency of the flat response boundary), which is reduced by a factor of 1.25 [5]. The need to reduce the corner frequency is due to the possible loss of data. Before filtering, zeros of the specified length are added to the ends of the record; after filtering, zeros are removed. This procedure is aimed at eliminating the appearance of edge effects after filtering time series. Further, the obtained time series is multiplied by the calibration coefficient of the instrument to convert the initial data into physical values of velocity or acceleration.

The next step is to define corner frequencies for basic time series filtering. For this, the window of the earthquake recording and the window of the noise before the earthquake are selected on waveforms. For each window, the Fourier amplitude spectrum and its smoothed function are calculated. The smoothed functions are used to calculate the signal-to-noise ratio. The frequency interval for calculating the signal-to-noise ratio is the corner frequency determined earlier and the frequency equal to 80% of the Nyquist frequency. The first frequencies where the signal-to-noise ratio is greater than 3 are taken as corner frequencies for band-pass filtering (5-pole Butterworth acausal filter). Zeros are added to the ends of the record before filtering.

Next, the displacement time series are calculated by integrating the filtered time series in the frequency domain using the fast Fourier transform. To remove a possible trend in the displacement series, a sixth order polynomial is fitted, with the zero and first order coefficients equal to 0. The resulting polynomial is twice differentiated and subtracted from the acceleration time series. From the corrected accelerations, we obtain a time series of velocity and displacement by integration. At the end, the previously added zeros are removed and the peak ground acceleration, velocity, displacement (PGA, PGV, PGD) and acceleration response spectrum are calculated. Also, the calculation of the geometric mean acceleration response spectrum from two horizontal components (RotD50) is performed, which does not depend on the azimuth of the earthquake epicenter relative to the recording station [6]. The obtained acceleration time series, velocity time series, displacement time series, PGA, PGV, PGD and acceleration response spectra will help to form a regional strong motion database.

3. Results of experimental studies

After processing the initial data, the resulting time series of accelerations, velocities, displacements were viewed. During the evaluation of the applicability, some data were excluded from further consideration. The reasons for exclusion are as follows. Noisy initial recordings or a failure of the recording instruments, as a result of which, after processing, incorrect time series of acceleration, velocity, displacement are obtained.

For each station-earthquake pair, the epicentral distance was calculated. Also, the hypocentral distance and the closest distance to the surface projection of the rupture plane (Rjb) were calculated. Figure 3 shows the distribution of energy class-Rjb distance. Since the majority of earthquake records are characterized by the presence of 6 channels, then data obtained from both accelerations and velocities were used. This was done to increase the statistics of the data.

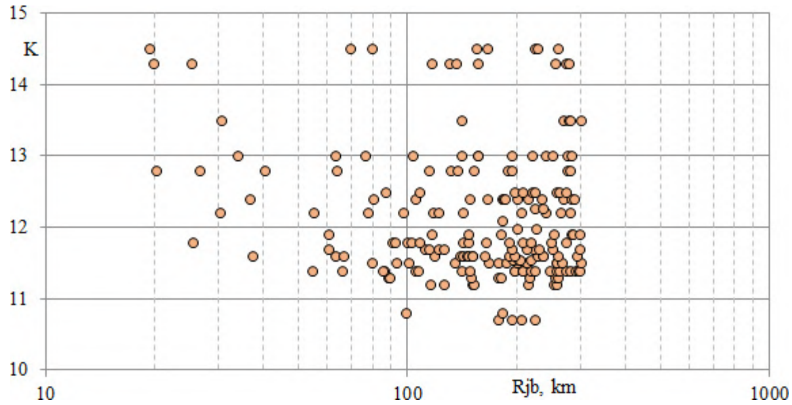

Figure 3: Distribution of energy class-Rjb distance.

Figure 4, a shows the acceleration time series for the E channel, obtained after processing the velocity recording ($\mathrm{PGA} = 0.0052\ \mathrm{m/s^2}$). Figure 4, b shows the acceleration time series for the E channel obtained after processing the acceleration record ($\mathrm{PGA} = 0.0051\ \mathrm{m/s^2}$). Figure 4 illustrates well the correctness of the data processing procedures.

For data validation, the PGA values of all processed records (two horizontal channels and RotD50 values) were compared with the GMPE Boore et al. (BSSA14) [7]. In Figure 5, different symbols indicate PGA for N, E channels and RotD50. In brackets, the symbol V denotes the values obtained from the velocities, a — the values obtained from the accelerations. Attenuation

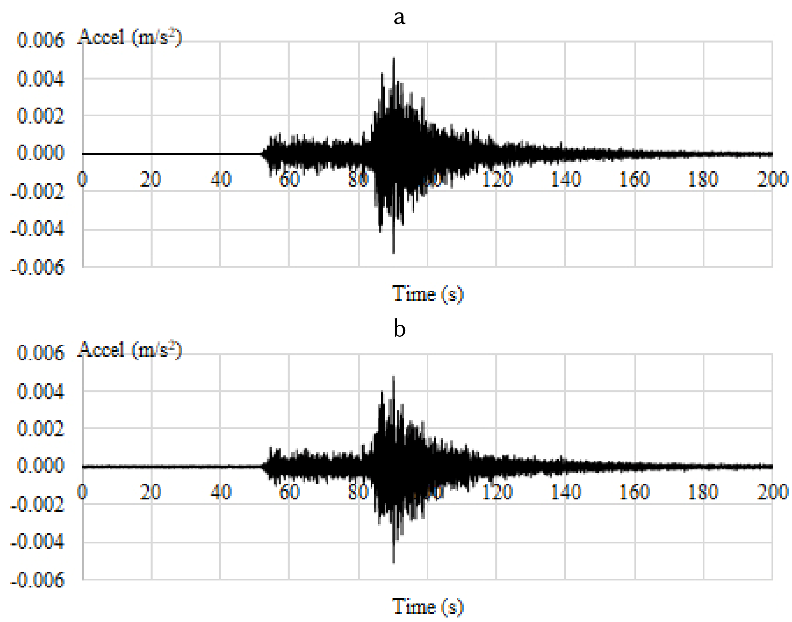

Figure 4: Acceleration time series obtained after processing the velocity record (a) and acceleration record (b).

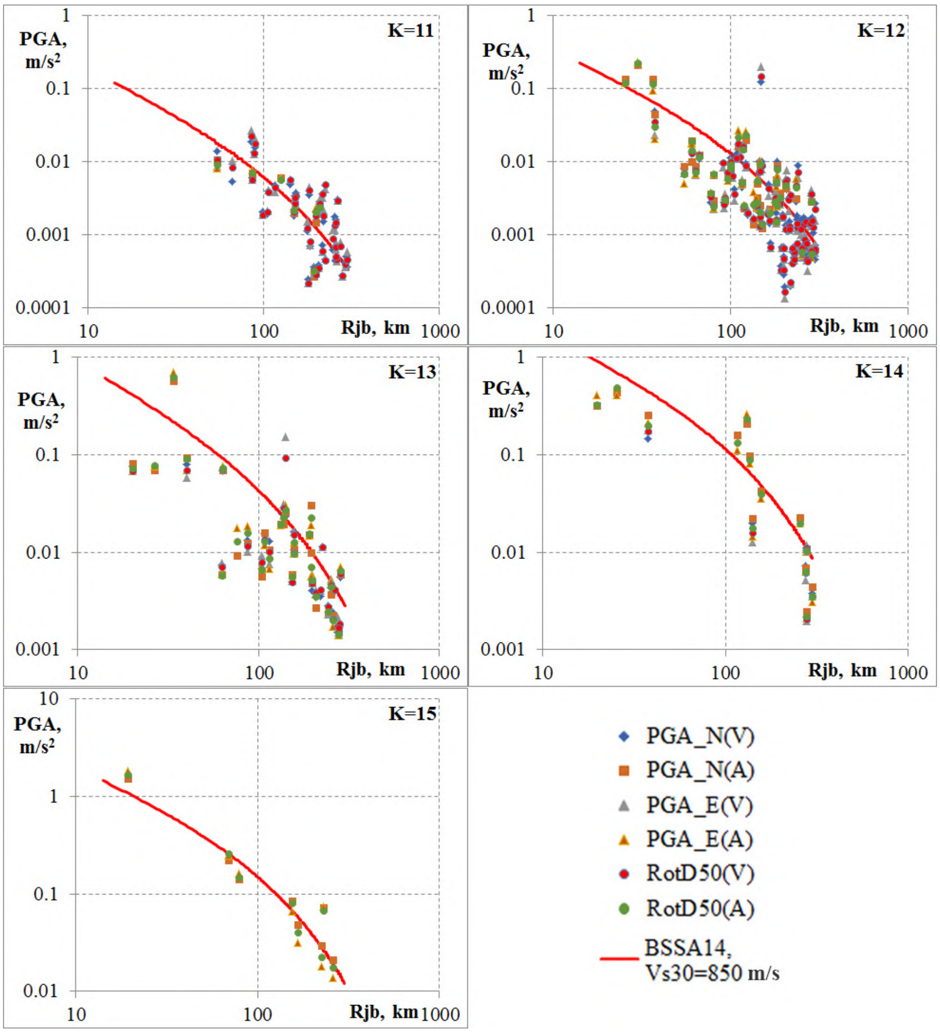

Figure 5: Comparison of PGA values with attenuation model BSSA14.

curves for BSSA14 are plotted for an averaged shear-wave velocity of the top 30 m of soil Vs30 = 850 m/s. Graphs are drawn for each energy class, the classes were combined to integer values.

Figure 5 shows that the PGA data obtained shows good agreement with the attenuation model BSSA14. A significant scatter of data relative to the average values of the model is associated with not taking into account averaged shear-wave velocity of the top 30 m of soil (Vs30) at the registration points, and the focal mechanism.

With the accumulation of sufficient statistics, determination of Vs30 at the points of registration and classification of earthquakes by focal mechanisms, the initial data will be divided according to these features. At the current stage of research, there is not enough data to statistically formulate a regional GMPE. First of all, it is necessary to increase the amount of data for the near zone of 10–50 km.

4. Conclusion

The work is devoted to the implementation of the earthquake record processing for the formation a strong motion database of the Baikal rift zone. The proposed algorithms based on the Pacific Earthquake Engineering Research Center methodology were adapted to the peculiarities of seismic monitoring of the Baikal region and implemented in the MATLAB.

The formation a database of strong movements for the Baikal region has begun. After processing 199 records from 38 earthquakes and excluding some of them, the PGA-distance distributions for different levels of energy classes were constructed. Comparison with GMPE Boore et al. (2014) showed good agreement, and the existing scatter of data relative to the average values of the attenuation model is associated with not taking into account Vs30 at the registration points and the focal mechanism.

In the future, it is planned to expand a strong motion database by continuing the selection of records of earthquakes in the Baikal rift zone. In addition, such data processing will consider not only the PGA values, but also the maximum accelerations in the engineering range of the response spectrum oscillation periods. As a result, the obtained data will be used to build a regional attenuation model of the Baikal region in order to obtain correct seismic hazard assessment.

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