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Probabilistic seismic hazard assessment of Kazakhstan and Almaty city in peak ground accelerations

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A B S T R A C T

As for many post-soviet countries, Kazakhstan's building code for seismic design was based on a deterministic approach. Recently, Kazakhstan seismologists are engaged to adapt the PSHA (probabilistic hazard assessment) procedure to the large amount of available geological, geophysical and tectonic Kazakh data and to meet standard requirements for the Eurocode 8. The new procedure has been used within National projects to develop the Probabilistic GSZ (General Seismic Zoning) maps of the Kazakhstan territory and the SMZ (Probabilistic Seismic Microzoning) maps of Almaty city. They agree with the seismic design principles of Eurocode 8 and are expressed in terms of not only seismic intensity, but also engineering parameters (peak ground acceleration PGA). The whole packet of maps has been developed by the Institute of Seismology, together with other Kazakhstan Institutions. Our group was responsible for making analysis in PGA. The GSZ maps and hazard assessment maps for SMZ in terms of PGA for return periods 475 and 2475 years are considered in the article.

1. Introduction

About 11% (300 thousand km^2) of the territory of Kazakhstan are the high seismic zone. More than 5 million people live, more than 40% of the country's industrial potential is concentrated and about 400 settlements are located in this area, including the largest industrial and cultural center of the country - the city of Almaty with a population of more than 1.7 million people. In the late X1X - early XX centuries Almaty was subjected to the strongest North Tian Shan earthquakes — the 1887 Verny *Ms*7.2 earthquake, the 1889 Chilik *Ms*8.3 earthquake, the 1911 *Ms*8.2 Kemin earthquake, and repeatedly experienced weaker events. An earthquake similar to the Verny earthquake in the vicinity of Almaty can cause catastrophic destruction and large loss of life. The reason of such potential damage is not only the strength of a possible earthquake, but also the underestimation of seismic hazard, the choice of sites for construction and other factors.

For the first time, the seismic hazard of the territory of Kazakhstan was analyzed from the probabilistic point of view and in the quantitative parameters of ground motions. The seismic potential and the character of the seismic process were considered on a new methodical basis both on a large scale for the country as a whole and in the small-scale for the most earthquake prone megalopolis of Kazakhstan - Almaty.

Seismological observations and studies in Kazakhstan for a long time focused only on high seismic southeastern and moderately seismic eastern territories, and platform areas were considered practically aseismic. The development of seismological observations in the central, western and eastern parts of Kazakhstan revealed weak natural seismic activity there, as well as technogenic activation in the rapidly developing oil and gas producing regions. Estimation of the level of potential seismic hazard for these areas is of great importance.

Seismic microzoning of Almaty was carried out more than 30 years ago. Since then, the city's territory has grown more than twice. Modern analysis of seismic hazard in engineering parameters performed for Almaty serves as a basis for performing seismic zoning on a city scale and methodological basis for carrying out similar studies in other cities of Kazakhstan.

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Probabilistic estimates in engineering parameters can best be used for seismic zoning, seismic risk assessment, rational planning of development of various regions, and implementation of anti-seismic measures. An essential part of preparedness for an earthquake - one of the most devastating natural disasters, is creation of reliable seismic zoning maps at different scales and their proper usage in national regulations for seismic design in seismic prone areas.

The approach to seismic hazard assessment and the development of seismic zoning maps is not uniform in all countries. The historically established practice is of great importance for this. The US and other western countries, where the seismic zoning from the beginning was carried out under the aegis of building engineers, have a more "engineering" approach, meeting the needs of earthquake engineering and seismic risk mitigation. For many years in these countries hazard maps are made in terms of ground motion parameters - mostly PGA (peak ground acceleration) and spectral acceleration. In the USSR (Union of Soviet Socialist Republics) seismic zoning, including hazard assessment, was initially developed by geologists, seismologists and geophysicists. As a result in many post-Soviet countries the macro-seismic intensity is the main output parameter describing seismic effect. Many other countries have their own peculiarities in methodology, mapping parameters and representation of results. In the Kazakhstan's operating building code the seismic intensity (MSK-64(K)) is also the final parameter of the general and detailed seismic zoning. It cannot be used directly to design behavior of building and structures during earthquakes. To obtain seismicity coefficients (that are acceleration in the ground level) used in Kazakhstan's BC, engineers have to transfer traditional MSK-64(K) intensity into ground motion parameters [1]. It would be more accurate and convenient to use directly PGA for a site.

As for many post-soviet countries, Kazakhstan's building code [1] for seismic design was based only on a deterministic approach. At the same time outputs of a PSHA (probabilistic hazard assessment) are best suited for design of buildings and facilities for performance because they provide ground shaking for a predetermined period of time. Probabilistic approach is preferred in engineering and reinsurance. Probabilistic maps are also helpful in seismic risk mitigation and management.

Kazakhstan seismologists have already adapted the procedure of PSHA [2–4] to meet the standard requirements of the Eurocode 8. The developed procedure includes both domestic experience in the allocation and parameterization of zones of probable earthquake sources and the advantage of the western engineering approach. Based on this procedure, the Institute of Seismology, together with specialists from other Kazakhstan Institutions (Kazakhstan National Data Center, Kazakhstan Geotechnical Institute for Survey, Kazakhstan Scientific-Research and Design Institute for Construction and Architecture), has developed probabilistic maps of GSZ (General Seismic Zoning) and SMZ (Seismic Microzoning) of the territory of Almaty city. Kazakhstan's regulations for seismic design, which will provide use of the new maps, are under development.

GSZ includes a set of 5 maps in the scale of 1: 2,500,000. They are the map of seismo-generative zones in Kazakhstan's territory, two PSHA maps with hazard expressed in macro-seismic intensity for two probabilities (10% and 2% exceedance in 50 years), and two maps with hazard expressed in mean values of the geometric mean PGA (in g) for rock and soils behaving similar to rock for two probabilities of exceeding 10% and 2% during 50 years. In the result of SMZ for Almaty city, apart from the probabilistic maps in intensity (MSK-64(K)) and PGA (10% and 2% probability of exceedance in 50 years), a package of maps and charts was also received.

The two return periods of 475 and 2475 years are recommended [5] as corresponding to the DBE (Design Basis Earthquake) and the MCE (Maximum Considered Earthquake) respectively. The DBE earthquake is considered to have a probability of exceedance of 10% in 50 years (475 year return period), while the MSE represents 2% in 50 years (2475 year return period). These specific values are also associated with limit states for the design seismic action [6]. For ordinary structures, 475 return period corresponds to the "significant damage" limit state, while 2475 return period corresponds to the "near collapse" limit state.

Various studies within the projects (preparing earthquake catalogs and waveforms for areas were the Institute of Seismology has no stations, modification of generalized seismo-generative zones in that areas, gathering available borehole data and caring out boring and seismic-sounding field work, making maps of soil categories and *V*s distribution, calculating intensity increments, making PSHA and SMZ in macro-seismic intensity, etc.) were made by several research teams, and the research results will be reflected in their reports and publications. This article focuses on the results of probabilistic analysis and hazard mapping in PGA which our team was responsible for.

2. Data and research methodology

The main characteristics differences of the new approach for Kazakhstan were the use of probabilistic analysis and expression of hazard estimates in terms of not only macro-seismic intensity but also engineering parameters. The database used to develop GSZ and SMZ included updated earthquake catalogs, revised map of seismic source model and modern ground motion prediction equations. For making PSHA calculations the modern software m3c developed by the BGS (British Geological Survey) [7] was used.

In the deterministic approach [8,9] (traditionally used in Kazakhstan [10]) the maximum seismic effect at a site is calculated from the largest controlling earthquakes for this site; uncertainties are not considered. In probabilistic assessment [8,9] seismic hazard is calculated from all earthquakes of all probable magnitudes at all significant distances from the site in accordance with their frequency of occurrence. The probabilistic analysis [8,9] can combine alternative models of seismic sources, return periods of earthquakes, ground motion prediction equations, as well as a number of uncertainties arising from both a vague knowledge of certain parameters and the random nature of the occurrence of seismic events themselves. Calculation of ground shaking at a site (or a grid of sites) is performed for a particular time period (e.g. service life of standard buildings). PSHA output is a hazard curve, demonstrating the probability of exceeding a certain amount of ground shaking at a site within a time window. In the case of a grid of points a spatial distribution i.e. map will be obtained.

The PSHA procedure may be described by four steps:

1) Identification and characterization of potential earthquake sources, which are areas close to the site where the probability of the occurrence of the earthquakes is equal in each source. A set of seismic sources is called seismic source model.
2) Computation of the annual number of earthquakes in each seismic source using the catalog of earthquakes that have occurred in the source model.
3) Computation of the ground shaking produced at the site by earthquakes of all possible sizes in the seismic sources.
4) Estimation of the probability that the ground motion will be exceeded during a particular time period.

The model of seismic sources (seismogenic zones) for Kazakhstan territory was developed [11] based on the map of active faults of Kazakhstan and adjacent territories together with a complex set of geophysical, geological-tectonic and seismological data. The general outlines of zones were determined on the base of