UP-TO-DATE DETAILED SEISMIC ZONING OF REGIONS IN KAZAKHSTAN (PGA CASE)

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Abstract

The results of the first project in Kazakhstan on the Detailed Seismic Zoning of regions on a new methodological basis are presented. The Probabilistic Seismic Hazard Assessment is carried out for the territories of East Kazakhstan (since 2022 EKO and Abay), Almaty (since 2022 Almaty and Zhetysu) and Zhambyl regions using a methodology consistent with the main provisions of Eurocode 8 and updated compared to that used in maps of the recent General Seismic Zoning of Kazakhstan territory. Modern methods and tools of analysis were used, as well as the most complete and up-to-date information available for the territories under consideration. The seismic source model included areal sources and active faults. The developed maps are discussed and hazard curves and uniform hazard spectra for the main cities in the considered regions are presented. The obtained results are generally consistent with the General Seismic Zoning but display some differences in PGA distribution due to including active faults and a comprehensively revised catalogue. Zoning maps will be the basis for the development of new state building regulations of the Republic of Kazakhstan.

Keywords: probabilistic seismic hazard assessment, seismic zoning, peak ground acceleration

I. Introduction

Until recently, Kazakhstan's regulatory documents regulating construction in seismic areas were based on a deterministic assessment of seismic hazards, and the main parameter describing the seismic effect was the macroseismic intensity [1]. With the transition of the construction state standards of the Republic of Kazakhstan to the basic principles of Eurocode 8 [2], seismic zoning maps corresponding to these principles were developed. The last General Seismic Zoning (GSZ) of the territory of Kazakhstan [3, 4] and Seismic Microzoning (SMZ) of Almaty City [5, 6] (the highest seismic city in the country) were carried out on a fundamentally new country-wide methodical basis. The new zoning maps became probabilistic and expressed in both macroseismic intensities and quantitative parameters – peak ground accelerations (PGA).

In the research project carried out by the Institute of Seismology of Kazakhstan in 2021–2023, "Seismic Hazard Assessment of Regions and Cities of Kazakhstan on a Modern Scientific and Methodological Basis," all elements of the used Probabilistic Seismic Hazard Assessment (PSHA) have been updated. We use the comprehensively revised and updated catalogue. A seismic source model includes not only area sources as before but also active faults. Sets of ground motion models (GMMs) have been updated. The Open Quake software is used both for calculations in PGA and macroseismic intensities. The project is the first stage of ongoing work and includes Detailed Seismic Zoning (DSZ) of three administrative regions (oblasts): East-Kazakhstan (East-Kazakhstan and Abay since 2022), Almaty (Almaty and Zhetysu since 2022), and Zambyl oblasts, and SMZ of Ust-Kamenogorsk city. In this paper, we will focus on the issues of DSZ in PGA.

II. Methods

The whole scope of study on the project covered such areas as geological-geophysical criteria of SHA, structural-tectonic criteria of SHA, seismicity and seismic regime, macroseismic data, GMMs selection and testing, source mechanisms and parameters of seismotectonic deformations, regional map of seismogenerative zones, map of active faults, catalogue of earthquakes and seismic regime, seismic source model (active fault, area and hybrid), PSHA and mapping in PGA and macroseismic intensities, etc.

PSHA procedure included identification and characterization of faults and area zones and creation of seismic source model; magnitude-frequency distribution for the seismic sources; evaluation of the generated ground motion and estimation of the probability that the ground motion will be exceeded during a particular period. We applied Cornell's methodology [7], but using the methodological formalism of Field et al. [8], implemented in the Open Quake Engine software [9]. Mathematically PSH is described by the following expression of the total probability theorem:

$$\lambda(a) = \sum_i v_i \iint P[A > a|m,r]\, f_{M_i}(m)\, f_{\frac{Ri}{Mi}}(r;m)\, dr\, dm,$$

where a is the specified ground motion amplitude, $\lambda(a)$ – annual frequency of earthquakes that produce a ground motion amplitude A higher than a (*PGA, PGV, SA*, MSK intensity, etc). The summation extends over all source zones, v_i is the annual rate of earthquakes with magnitudes higher than a threshold m_o in source i. $f_{Mi}(m)$ and $f_{Ri|Mi}(r;m)$ are probability density functions on m and r respectively. $P\,[A>a \mid m, r]$ is the probability that an earthquake of magnitude m at distance r produces a ground motion magnitude A at the site that is greater than a. Calculations were made for two probabilities of exceedance - 10% and 2% in 50 years.

We used the comprehensively improved earthquake catalogue for Central Asia, developed in the international ISTC Project "Central Asia Seismic Hazard Assessment and Bulletin Unification" (CASHA-BU). In that project completed last year, a huge volume of data, collected by several generations of seismologists, was digitized, systematized, reprocessed, and converted to a format suitable for different tasks of seismology. The full catalogue includes about 442.500 earthquakes. The work on the full catalogue is not finished yet, but for the needs of PSHA in Central Asia and Kazakhstan, a complete catalogue has been created on its basis [10].

The source model includes active faults and area sources. Area polygons were outlined taking into account the seismicity pattern, important topographic and tectonic characteristics and theoretically estimated seismic potential.

Modelling of active faults in the territory of Kazakhstan is complicated due to insufficient knowledge of the characteristics of most faults and, as a consequence, the lack of the required parameters for hazard analysis input (like, kinematic parameters or slip rates). To decrease errors, we used two models of active faults, one based on the Active Fault Data Base created in this project with the use of materials accumulated in our Institute for a long period of previous geological-geophysical studies and another based on the Data Base of Active Faults of Eurasia (AFEAD) created by the Geological Institute of Russian Academy of Sciences [11].

Available analogue records of the regional strong motion network operated in 1980-1996 were digitized in addition to later digital records for testing selected GMMs. We performed a comprehensive study on GMMs selection for seismically active regions of Kazakhstan and tested their applicability with the use of regional data. The territory of the considered oblasts is characterized by active and partially stable seismotectonic regimes. The upgraded GMM logic tree for active regions included weighted models of Akkar and Bommer, 2010 [12], Zhao et al, 2016 [13], Abrahamson et al, 2014, Boore et al, 2014, Chiou and Youngs, 2014 (NGA-WEST2 models [14], for stable areas – Boore, 2015, Darragh et al, 2015, Spahjouei and Pezeschk, 2015 and Yenier and

Atkinson, 2015 (NGA East models [15]).

Probabilistic analysis was carried out with the use of the Open Quake Engine software [9]. The seismic source logic tree included two models - a combination of area sources with two active fault models. The GMM logic tree included sets of five models for crustal earthquakes in active regions and four for earthquakes in stable regions.

The analysis was carried out for two probabilities of exceedance - 10% and 2% in 50 years (return period 475 and 2475 years, respectively). The calculations were performed in the average values of the geometric mean peak ground accelerations (PGA in fractions of g) for the territory of the considered oblast on a grid with an interval of 5 km in both directions. For each calculated point, the impact from seismic sources located within a radius of 300 km was taken into account, concerning their seismotectonic regime. Soil conditions correspond to rocky and rock-like geological formations, for the surface 30-meter strata of which are typical shear wave propagation velocities Vs30≥800 m/s.

III. Results

The obtained DSZ maps of East Kazakhstan (since 2022 EKO and Abay) oblast are shown in Figure 1, and hazard curves and uniform hazard spectra for the main cities in the region - Ust-Kamenogorsk and Semey - are shown in Figure 2. DSZ maps of the Almaty oblast are shown in Figure 3, and hazard curves and uniform hazard spectra for the main cities in the oblast - Almaty and Taldykorgan – are in Figure 4. Results for the Zhambyl oblast are shown in Figures 5-7.

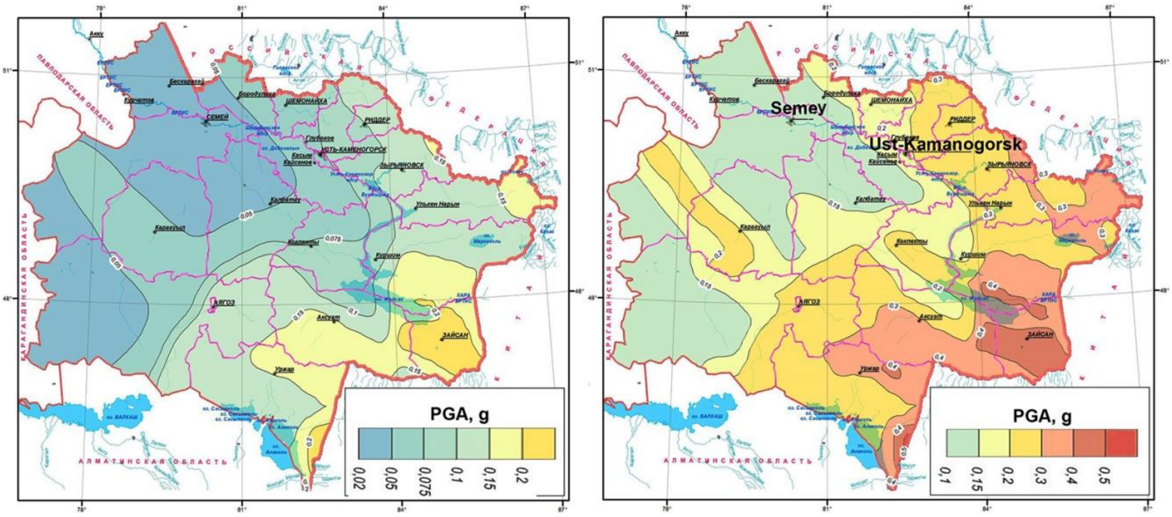

Fig. 1: *DSZ map of East Kazakhstan Oblast in PGA for 10% (left) and 2% (right) probability of exceedance in 50 years*

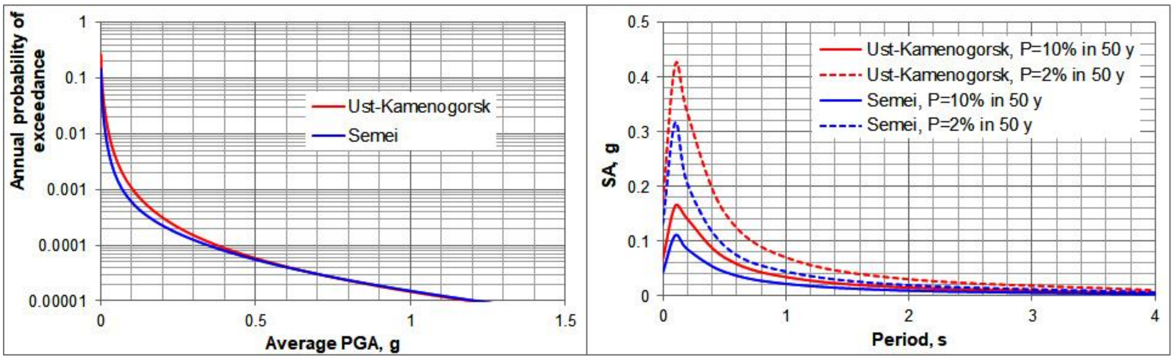

Fig. 2: *Hazard curves (left) and uniform hazard spectra (right) for the main cities in the East Kazakhstan oblast (rock conditions)*

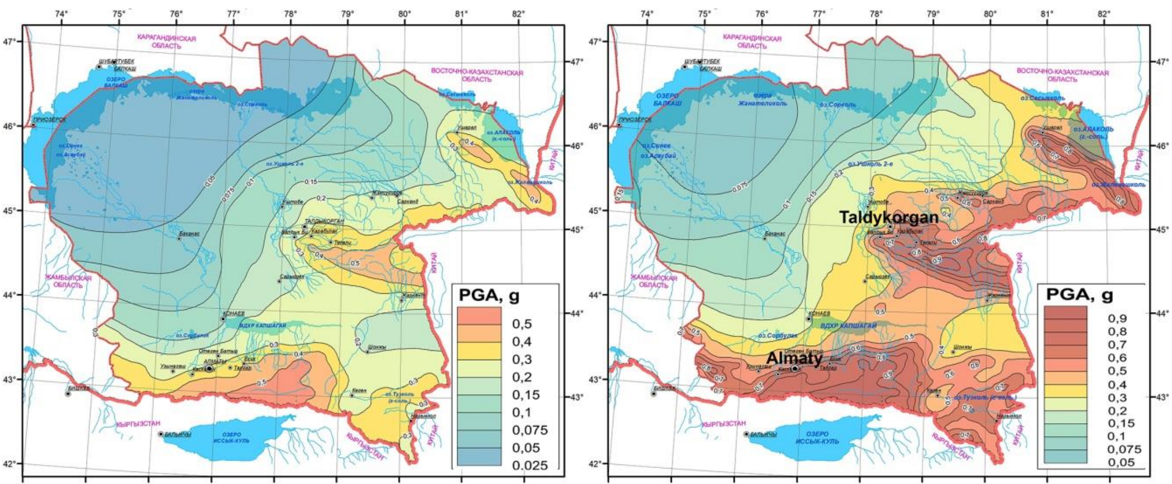

Fig. 3: *DSZ map of the Almaty Oblast in PGA for 10% (left) and 2% (right) probability of exceedance in 50 years*

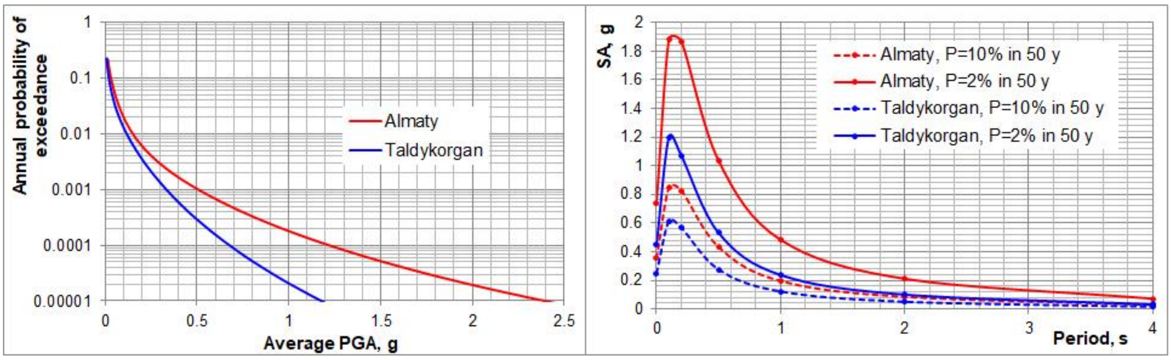

Fig. 4: *Hazard curves (left) and uniform hazard spectra (right) for the main cities in the Almaty oblast (rock conditions)*

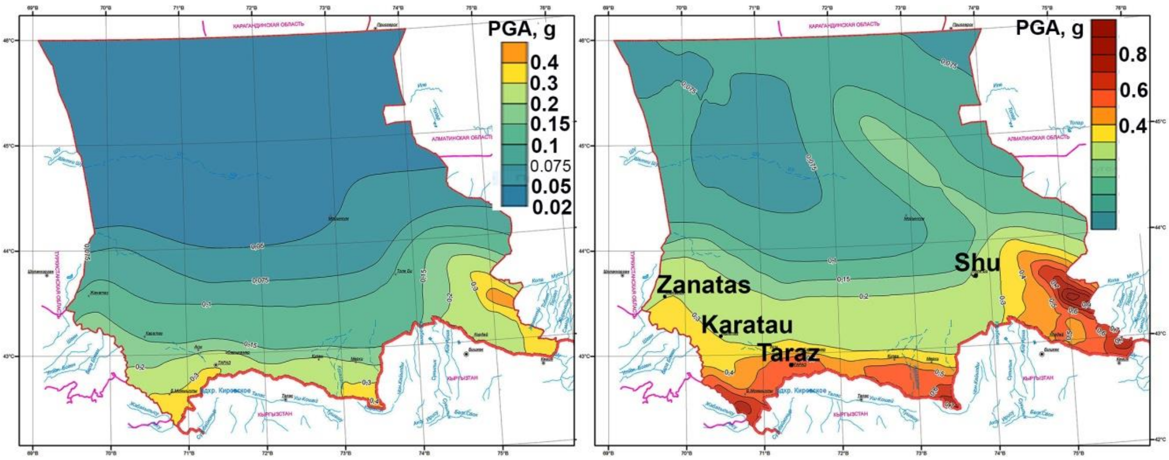

Fig. 5: *Preliminary DSZ maps of the Zhambyl oblast in PGA for 10% (left) and 2% (right) probability of exceedance in 50 years*

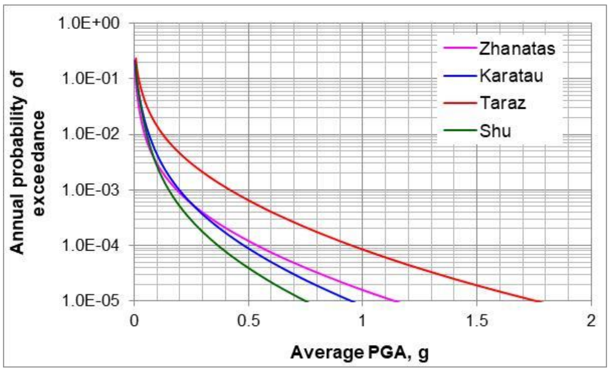

Fig. 6: *Hazard curves for the main cities in the Zhambyl oblast (rock conditions)*

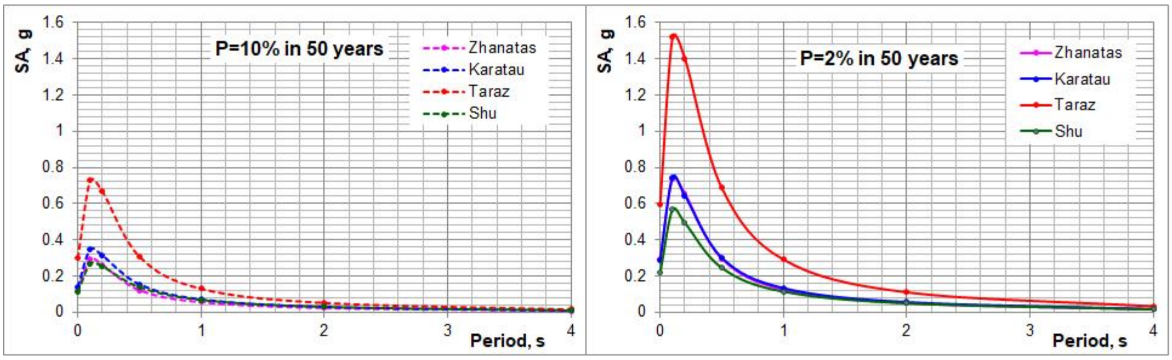

Fig. 7: *Uniform hazard spectra for the main cities in the Zhambyl oblast (rock conditions)*

IV. Discussion

On the resulting map of the DSZ of the East-Kazakhstan region (Figure 1), PGA increases from the northwest to the southeast, from the territories with a stable tectonic regime to the active regions. On the map with a probability of exceedance 10% in 50 years (return period 475 years), the PGA values increase from 0.040 g at the northwestern boundary of the region to 0.268 g in the south and 0.224 g in the southeast (Figure 1, left). On the map with a probability of exceedance 2% in 50 years (return period 2475 years), PGA increases from 0.132 g in the northwest to 0.514 g in the south and 0.482 g in the southeast (Figure 1, right). The maximum acceleration level in the southern part of the region is caused by an area source in the buffer zone with a higher density of earthquakes with an Mw magnitude of 5–6. In the southeast, the highly seismic areal zone with magnitudes Mw>6 as well as the North Zaisan (Mw up to 7.2) and Saur (Mw up to 7.2) faults (Figure 8 a) also have a great influence. The highly seismic Narym (Mw up to 7.5) and Rakhmanov (Mw up to 7.5) faults (Figure 8 a) increase the level of the expected PGA in the eastern part. Due to the use of not only areal sources but also active faults, thorough cleaning of the catalogue from explosions and refinement of the fault map, more pronounced areas of higher danger along the Chingiz-Tarbagatai fault (Figure 8) was obtained in the western part of the region (Figure 1) than during the General Seismic Zoning [4]. In the west of the territory, the values of expected PGA also increased due to more accurate consideration of seismotectonic conditions and the seismic potential of territories with a stable regime.

The map of DSZ of the territory of the Almaty region with a probability of exceedance 10% in 50 years shows that PGA values exceed 0.15g in half of the territory of the region, increasing in the southeastward from 0.025 to 0.55 g (Figure 3, left). The maximum values of 0.4-0.5 g were expectedly obtained for areas located southeast of Almaty, which corresponds to the location of the most seismically dangerous Zailiy (Mw up to 8), Kemin and North Kungei (Mw > 8) active fault zones (Figure 9), as well as in the area of the South Dzhungar (Mw up to 7.0) active fault zone. On the DSZ Map, with a probability of exceedance of 2% in 50 years accelerations similarly increase from 0.062 to 1 g (Figure 3, right). In half of the territory, the accelerations exceed 0.3 g, reaching more than 0.9 g in the area where the most highly seismogenerative zones are located.

On the DSZ maps of the Zhambyl region (Figure 5) PGA level increases from north to south towards the highly seismic regions at the southern border of Kazakhstan. At a probability of exceedance of 10% in 50 years, the values are in the range of 0.025–0.468 g; at a probability of 2% in 50 years, they are in the range of 0.074–0.960 g. The maximum values are predicted in the southeast in the area at the Zhetyzhol (Mw up to 7.0) and Kendyktas (Mw up to 7.0) active faults (Figure 10).

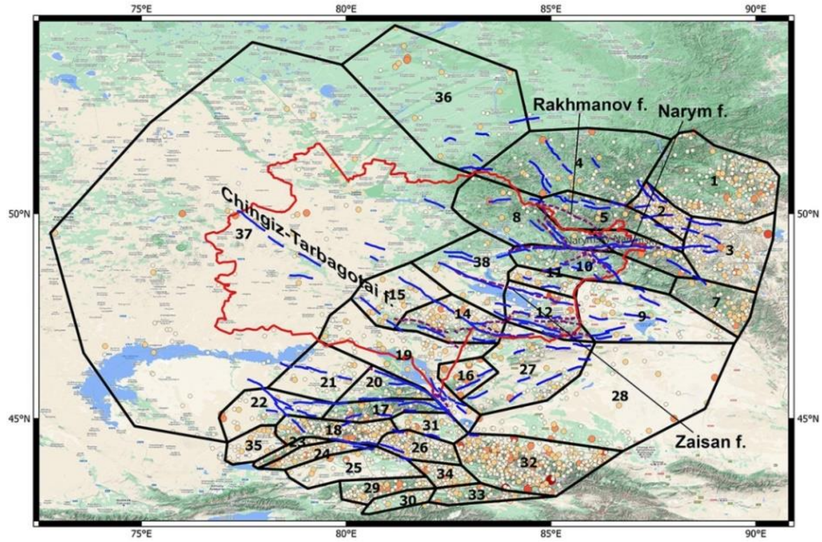

Fig. 8: *Fault and areal seismic sources for the East Kazakhstan region. Faults are shown as blue lines, and zones as black polygons. The region boundary is shown with a red line*

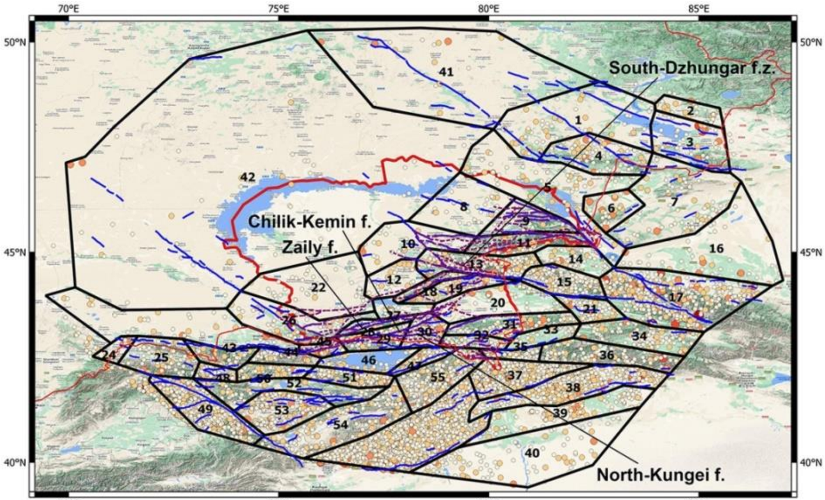

Fig. 9: *Fault and areal seismic sources for the Almaty region. Faults are shown as blue lines, and zones as black polygons. The region boundary is shown with a red line*

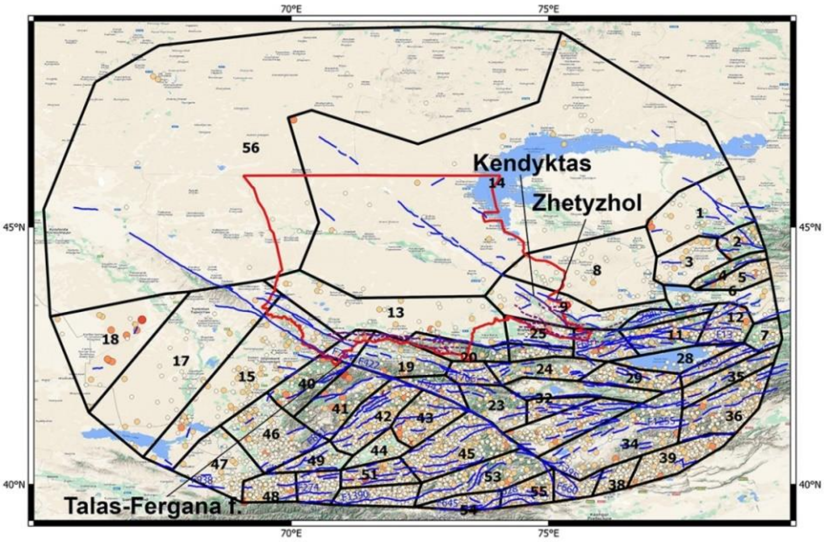

Fig. 10: *Fault and areal seismic sources for the Zhambyl region. Faults are shown as blue lines, and zones as black polygons. The region boundary is shown with a red line*

The obtained distribution of seismic hazard in the considered regions is consistent in general with the previous results of the General Seismic Zoning of Kazakhstan [4], but due to the inclusion of active faults and increased map detail, the distribution of seismicity has become more structured with more pronounced zones of increased danger along the faults. The use of a comprehensively revised catalogue also caused some changes in the PGA distribution pattern. In areas with stable regimes, more accurate accounting for seismotectonic conditions and less attenuation of seismic waves caused some increase in PGA compared to [4].

The developed Detailed Seismic Zoning maps will be the basis for the development of new state building regulations in the Republic of Kazakhstan and will serve as an important tool for improving the seismic safety and preparedness of the country.

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